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Growth, body composition, physical activity and motor performance of Peruvian children, youth and siblings. Probing the effects of the environment.

Carla Sofia Pinho dos Santos

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If you cry because the sun has gone out of your life, your tears will prevent you from seeing the stars.

(Rabindranath Tagore)

DEDICATION

To my parents and sister

Thanks for your unconditional love.

To my grandmother

Thanks for, despite no longer being with us, you asked a star there in heaven to light my way.

To my friends

Thanks for your patience and encouragement.

To my professors

Thanks for your lessons and constant support.

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Para cada um de vós…

"Aqueles que passam por nós não vão sós, não nos deixam sós.
Deixam um pouco de si, levam um pouco de nós"

(Antoine de Saint-Exupéry)

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RESUMO

Nesta tese são descritas e interpretadas diferentes facetas da variabilidade humana no crescimento físico, composição corporal, atividade física e desempenho motor enquanto expressões de processos adaptativos originados em diferentes contextos sócio-geográficos, educacionais e culturais no Perú - crianças, adolescentes e irmãos que vivem ao nível do mar, na região amazónica e em altitude. Os dados são de três projetos desenvolvidos em sincronia entre os anos 2009 e 2010: “*The Peruvian Health and Optimist Growth Study”*, “*The Peruvian Sibling Study on Growth and Health”* e “*The Peruvian Family Study on Growth and Health”*. Do primeiro projeto retirou-se uma amostra de 10795 crianças e adolescentes (6-17 anos). Do segundo retiraram-se 1618 irmãos biológicos (6-15 anos) de 758 famílias nucleares Do terceiro retiraram-se 247 irmãos biológicos (6-17 anos) de 234 famílias nucleares. A informação está hierarquicamente distribuída por dois domínios - individual e ambiental. As análises estatísticas foram efetuadas nos softwares R, SPSS, SuperMix e STATA. Os resultados mostraram que: (i) os parâmetros do salto pubertário estatural das crianças e adolescentes diferem em função do sexo e da área geográfica, revelando uma variabilidade generalizada quando comparados com outras populações; (ii) o atraso no crescimento linear (*stunting*) tem um impacto negativo nos níveis de aptidão física, sendo essa influência específica do sexo, idade e componente da aptidão; (iii) a variabilidade na composição corporal, aptidão física e coordenação motora é explicada por fatores individuais e do ambiente natural (área geográfica de residência) e construído (contexto escolar); (iv) a direção e magnitude dos resultados variam em função do fenótipo considerado e preditores utilizados; (v) diferenças na semelhança fraterna dependem do tipo de par e do fenótipo considerado; (vi) as caraterísticas individuais e o ambiente natural partilhado estão diferentemente associados com as componentes da aptidão física e com os fenótipos da atividade física. Esta tese desencadeou um conjunto de indicações que salientam a importância de se considerar as especificidades dos estratos culturais e sociais de cada região geográfica, bem como a teia relacional entre as caraterísticas individuais, familiares e ambientais aquando do delineamento de estratégias de intervenção que visem a promoção do crescimento saudável e o desenvolvimento sustentável de crianças e adolescentes.

ABSTRACT

In this thesis different facets of human variability in physical growth, body composition, physical activity and motor performance are described and interpreted as end-results of adaptive processes in Peru different socio-geographical, educational and cultural contexts - especially children, youth and siblings living at sea-level, Amazon region and high-altitude. The data comes from the three research projects, developed in synchrony, between 2009 and 2010: "*The Peruvian Health and Optimist Growth Study"*, "*The Peruvian Sibling Study on Growth and Health"* and "*The Peruvian Family Study on Growth and Health"*. From the first project, a sample of 10795 children and adolescents (aged 6-17 years) was used. From the second project, 1618 biological siblings (aged 6 to 15 years) from 758 nuclear families were considered. From the third project, 247 biological siblings (aged 6 to 17 years) from 234 nuclear families were investigated. All data is hierarchically distributed within two nested domains: individual and environmental. Statistical analyses were done in R, SPSS, SuperMix and STATA softwares. Results showed that: (i) Peruvian children and adolescents' physical growth spurt parameters vary according to sex and geographic area, revealing a widespread variation when compared to other populations; (ii) the early growth "retardation" (stunting) negatively influenced children's physical fitness, being specific for each sex, age and physical fitness component; (iii) the variability in body composition, physical fitness and motor coordination is explained by individual characteristics, as well as natural (geographic area of residence) and built (school context) environments; (iv) the direction and magnitude of the results varied in function of the phenotype and predictors used; (v) changes in sibling resemblance depend on sib-type and the phenotype considered; (vi) individual characteristics and shared natural environment were differently associated with Peruvian siblings' health-related physical fitness components and physical activity phenotypes. This thesis highlighted a set of issues that emphasize the importance of considering the specificities of cultural and social strata of each geographical region, as well as the complex and entwined relationships of the individual, familial and environmental characteristics when designing intervention strategies to promote children and adolescents' healthy growth and sustainable development.

LIST OF SYMBOLS AND ABBREVIATIONS

AAHPERD	American Alliance for Health, Physical Education, Recreation and Dance
ANOVA	Analysis of variance
APHV	Age-at-peak height velocity
BMI	Body mass index
BB	Brother-brother
BS	Brother-sister
CI	Confidence interval
CIFI^{2}D	Centre of Research, Education, Innovation and Intervention in Sport
cm	Centimetre
cm/y	Centimetre per year
e.g.	For example
EUROFIT	Eurofit Fitness Test Battery
FCT	Foundation for Science and Technology
g	Gram
GMC	Gross motor coordination
GMC$_T$	Total gross motor coordination score
GS	Grip Strength
GWAS	Genome-wide association study
HDI	Human development index
HH	Hopping for height on one foot
ICC	Intraclass correlation coefficients
i.e.	That is
IBM	International Business Machines Corporation
IOTF	International Obesity Task Force
JS	Jumping sideways
kg	Kilogram
kgf	Kilogram-force
km	Kilometer
KTK	KöperkoordinationsTest für Kinder test battery
M$_0$	Null model
M$_1$	Model 1

M_2	Model 2
M_3	Model 3
m	Metre
mm	Millimetre
min	Minute
MS	Moving sideways
n	Sample size
ns	Non-significant
OR	Odd ratio
PA	Physical activity
PBGM-1	Preece-Baines Growth Model 1
PE	Physical Education
PHV	Peak height velocity
PF	Physical fitness
PF_Z	Total physical fitiness Z score
s	Seconds
SD	Standard deviation
SE	Standard error of estimate
SLJ	Standing long jump
SPSS	Statistical Package for the Social Sciences
SR	Suttle-run
SS	Sister-sister
TEM	Technical error of measurement
WHO	World Health Organization
WB	Walking backward on balance beams
y	Year
z-score	Standard score
*****	Asterisk
º	Degree
β	Beta (regression coefficient)
Δ	Delta (change)
σ^2	Variance
χ^2	Chi-squared

η^2	Partial eta squared
F	*F*-test
p	*p*-value
%	Percentage
+	Plus or positive
–	Minus or negative
±	Plus-minus
<	Less than
≤	Less or equal than
>	Greater than
≥	Greater or equal than
=	Equal to
~	Approximately

CHAPTER I

General Introduction, Purposes and Formal Structure of the Thesis

GENERAL INTRODUCTION

1. Human variability and plasticity

The precise and wide-ranging interpretation of biological variability during human physical growth and development are still with us and crosses several scientific research domains (Molnar, 2016; Roche & Sun, 2003), especially Motor Development with its lifespan perspective (Heywood & Getchell, 2020). Further, human variability expresses itself in a relatively intense way between and within populations as outcomes from the complex network of interactions between the individual and the environment, i.e., between the subject and the surrounding context where he/she lives and evolves (Moran & Brondizio, 2013). Human variability manifests itself in a plethora of phenotypes (e.g., physical growth, body composition, physical activity, physical fitness and gross motor coordination) mainly due to the totality of environmental exposures throughout the lifespan, i.e., its Exposome (Wild, 2005). It also represents how human beings adapt to the diverse environmental constraints expressing their phenotypic plasticity (Roberts, Mascie-Taylor, & Bogin, 1995).

Plasticity is one of the utmost expressions of human adaptability, and is a precise indicator of morphological and functional changes by which organisms overcome life challenges (Lasker, 1969). In general, these adaptations result from exposure to physical and chemical environmental factors, as well as from intra- and inter-species interactions (Schell, 1995). The substantial flexibility of human phenotypes permits behavioral and morphological variations so that the organism may adjust itself to the interaction of the environment with the genotype (Moran, 2008). No wonder why human ecology emerges as a scientific field labouring with human-environment interactions, focusing on the investigation of how ecosystems interact with populations, the nature of these interactions and the consequences of these relationships for humans and the environment (Moran, 2008).

Available literature has shown the human ability to distinctively respond and adapt to different environmental conditions, mainly to hostile environments (Baker & Little, 1976; Beall, 1982; Frisancho, 1993). For example, native populations from warm climates generally have a body shape that is characterized by linearity to maximize heat loss, while native populations from cold climates tend to have shorter body shapes in order to minimize heat loss (Malina, Bouchard, & Bar-Or, 2004). In terms of body weight, similar adaptations are observed - populations from warm climates tend to have, on average, lower weight than those from cold climates (Malina, Bouchard, & Bar-Or, 2004). Also, there is a reasonable expectation of an inheritance of physical traits selected over hundreds of generations to provide protection against low oxygen levels *(hypoxia)* in populations living at high-altitudes (Hogan et al., 2010). Hence, taking advantage of its genetic plasticity, humans were able to adapt to all environmental conditions, such as high altitude, temperate climate, humid tropics and desert (Morán & Mastrangelo, 2000).

In a sense the present thesis is strongly embedded with the previous ideas, especially with children and adolescents' growth and development – their adaptability to different environmental exposures and resulting variability. During this stage of life, some entwined processes occur, as detailed below.

2. Children and adolescent growth, maturation and (motor) development: intertwined processes

Physical growth and development dominate the daily lives of children and adolescents for approximately the first two decades of life (Malina, Bouchard, & Bar-Or, 2004; Roche & Sun, 2003). These two processes occur simultaneously and interact in diverse ways (Ellison & Reiches, 2012). In very general terms, physical growth, characterized by its extraordinary plasticity (Ulijaszek, 2006), refers to measurable changes in body size and in various compartments of body composition (Malina, Bouchard, & Bar-Or, 2004). Further, height and weight are the two most important body dimensions extensively used in research to examine children and adolescents' physical growth.

Body changes occur at different rates and at different times, with considerably differences not only among individuals, but also between the sexes (Marshall & Tanner, 1970; Roche & Sun, 2003; Tanner, 1971), which can be explained by the two important facets of the biological maturation process – *timing and tempo*. Timing refers to a moment in which a given growth event occurs and tempo refers to the rhythm with which this growth event manifests itself (Malina, Bouchard, & Bar-Or, 2004). For example, girls generally have an earlier start of the pubertal growth spurt (9-10 years in girls and 11-12 years in boys, approximately) and also reach their final size earlier than boys of the same chronological age (Banik, Salehabadi, & Dickinson, 2017; Marceau, Ram, Houts, Grimm, & Susman, 2011; Roche & Sun, 2003). The variability in growth velocities can be investigated by constructing growth velocity curves and estimating relevant parameters using adequate mathematical models (Gasser, Gervini, & Molinari, 2004; Preece & Baines, 1978) allowing the collection of information about growth *timing* and *tempo*. Further, a widely used method to identify such an event is the maturity offset (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002), which estimates the distance, in decimal years, each subject is from age-at-PHV. A positive (+) maturity offset represents the number of years a given subject is beyond age-at-PHV, whereas a negative (−) maturity offset represents the number of years he/she is before age-at-PHV.

While biological growth processes occur, human development also proceeds simultaneously in several behavioural domains – cognitive, social, emotional, moral and motor (Berger, 2008). In the motor domain, children and adolescents have an extraordinary capacity to learn and develop a variety of fundamental motor skills, including locomotor, object control and balance skills, which increases and diversifies their motor repertoire in order to acquire more specific motor skills (Gabbard, 2014; Morgan et al., 2013). Taken together, the enhancement of motor skills facilitates the development of physical fitness levels, defined as an individual trait expressing the efficiency of a varied set of bodily systems and functions in a wide-ranging set of contexts (Bouchard & Shephard, 1994).

At this stage of life, children also learn how to synchronize the movement of their body's various parts, allowing the development of smoother, more coordinated whole-body movement routines that are needed for participating in organized sports (Manna, 2014), i.e., they develop their motor coordination, defined as the harmonious and economic interactions of the muscular, skeletal, nervous and sensorial systems aiming to produce precise and balanced motor actions, as well as adapted reactions to varied situations (Kiphard & Schilling, 1974).

Given the aforementioned, the unfolding of growth, maturation and motor development are continuous and intertwined processes. Due to their progress with regard to their physical growth and maturity of motor, cognitive, and social skills, many children become capable of acquiring and maintaining active and healthy lifestyles from childhood to adulthood.

3. Human–environment interactions: seeing the forest and the trees

The complexity and multidimensionality that characterize human physical growth and (motor) development requires the adoption of comprehensive and systemic approaches linking the network of biological and environmental characteristics, in a clear allusion to the need to look jointly at the forest and the trees. In fact, interactions among these two processes vary not only among individuals, but also within and between cultural groups, emphasizing the need to approach childhood and adolescence in a biocultural framework.

Such complexity was foreseen in the 1980s by Newell (1986), when he proposed a model highlighting the effects induced by the individual, task and environmental constraints in promoting changes in human movement across time, where patterns of these interactions lead to significant changes in motor development. This model reflects the dynamic, constantly changing interaction in motor development, briefly defined as a continuous process of changes in motor behaviour across the lifespan (Haywood, 1986).

Years later, Bronfenbrenner (1994) proposed the bioecological model of human development. This model views development as a lifelong process reflecting the individual understanding of the environment and his/her manifold relation to it (Bronfenbrenner, 1994). Hence, it conceptualizes the environment in terms of five ecological systems, namely: microsystem, mesosystem, exosystem, macrosystem and chronosystem (Bronfenbrenner & Ceci, 1994). Bronfenbrenner and Morris (1998) revised his theory and proposed an additional model that comprises four intertwined concepts in human development: the person, the process, the context and time.

This bioecological perspective is different from the historical approach of motor development. It is important to recognize that in the history of motor development, researchers focused primarily on individual factors to the exclusion of others (Heywood & Getchell, 2020). For example, in the 1940s it was assumed that an individual constraint – specifically, the structural constraint of the nervous system alone – shaped movement in children. Later, in the 1960s, developmentalists commonly believed that environment and task constraints, more than individual constraints, shaped movement. A new perspective on development – an ecological perspective – appeared during the 1980s and has become increasingly dominant and still used today by motor developmentalists (Heywood & Getchell, 2020).

Under this integrated heuristic rationale, a central tenet of research is to identify potential factors accounting for the intra- and inter-population variation in a wide range of phenotypes, like physical growth, body composition, physical activity, and motor performance. Biological and environmental constraints are the most expected factors to explain human variability (Jelenkovic et al., 2016), with an undeniable influence of the school, family and socio-geographic contexts during physical growth and development in childhood and adolescence (Pereira et al., 2021; Sigelman & Rider, 2021).

3.1 School context as an expression of variability in child-adolescent growth and (motor) development

During the first two decades of life, school is the key social context where children and adolescents spend a great part of their daily life, and where important behaviours can systematically be developed (Mollborn & Lawrence, 2018; Sylva, 1994). Hence, schools provide a rich opportunity to improve students' health by adopting adequate strategies (e.g., engagement in a wide variety of activities) respecting interindividual differences. Therefore, an interesting research avenue is to explore school environmental features that may be associated with children's physical growth and (motor) development.

It has been suggested that the school context has links with child-adolescent overweight and obesity (Procter et al., 2008). For example, O'Malley, Johnston, Delva, Bachman, and Schulenberg (2007) showed that USA schools with a high concentration of students from low socioeconomic status households have a greater chance of having higher proportions of obese students. On the other hand, Pallan, Adab, Sitch, and Aveyard (2014) reported that, in United Kingdom schools, the only school-level variable associated with BMI z-score was time spent in Physical Education classes (minutes/week).

In an effort to fight childhood overweight and obesity, school-based healthy eating and physical activity programs have been implemented across the globe, providing opportunities to enhance children's future health and well-being (Veugelers & Fitzgerald, 2005). Some systematic reviews have shown that school-based interventions can be effective in preventing obesity and promoting physical activity (Campbell, Waters, O'Meara, & Summerbell, 2001; Kriemler et al., 2011; Liu et al., 2019). On the other hand, there are also studies in which variables such as obesity, physical activity and sedentary behaviour are measured and no significant development can be observed (Harris, Kuramoto, Schulzer, & Retallack, 2009; Hung et al., 2015; Hynynen et al., 2016). Hence, the lack of evidence exploring how policies and practices within the school system are associated with an individual student's risk of being overweight and inactive continues to represent an important gap in the available literature.

Schools are highly organized and structured institutions offering children and adolescents a wide range of spaces, infrastructure, equipment, as well as other resources, and this exposure also has the potential to afford unique opportunities for them to engage in diversified opportunities for physical activity and motor performance. For example, Zhu, Boiarskaia, Welk, and Meredith (2010) reported that school physical education programs and policy factors were significantly associated with physical fitness levels. Similarly, Chaves et al. (2015) reported that the school context explained 10% of the total variation in gross motor coordination among Portuguese children, although Reyes et al. (2019) found no such linkage. Further, Nielsen, Taylor, Williams, and Mann (2010) showed that the number of recreational facilities positively influenced children's physical activity in New Zealand, whereas Gomes, dos Santos, Zhu, Eisenmann, and Maia (2014), with data from Portuguese children, reported that school size, location, type of recreation area, physical education class attendance, time for physical education, and qualifications of the teacher were also related to their physical activity levels.

Hence, probing into school context characteristics is an important issue given that children's physical growth and motor development trajectories will likely be of great relevance to their long-term health-related habits and behaviours.

3.2 Family context: siblings as part of a particular subsystem

The family orbit has also been highlighted as an important source to investigate intra- and inter-population variation in child-adolescent physical growth and development (Grotevant, 1998; Mackova et al., 2019; McMinn et al., 2011). Members of the same family share genes, family environment and built environment, school, friends, etc. Therefore, it is expected that individuals within the same family will be more similar to one another than individuals from different families in their physical growth and development (Plomin & Daniels, 2011). However, this does not always occur and the variation between related subjects is also remarkable (Pereira, Santos, Katzmarzyk, & Maia, 2019). Hence, an important research approach to unravel this question is the study of siblings, which allows for an examination of family processes.

It is well known that siblings are part of a very particular subsystem within the family orbit. They share a substantial part of their genes identical-by-descent, on average 50%, and develop under relatively similar circumstances. Moreover, they also share common family environments as well as neighbourhood histories and school contexts. However, they also differ in many such as in their personality, biological characteristics (e.g., age, sex, biological maturation), and their unique environments which enable distinct life experiences (Frisell, Öberg, Kuja-Halkola, & Sjölander, 2012; Keyes, Smith, & Susser, 2013). For example, Plomin and colleagues (Dunn & Plomin, 1991; Plomin, Manke, & Pike, 1996; Reiss et al., 1994) showed that the major source of variation between siblings, i.e., their differences, was not genetic differences but rather their non-shared environments.

Available data from siblings reveals the existence of significant familial resemblance expressed by the intraclass correlation (ρ) in a plethora of phenotypes. For example, Malina and Mueller (1981), using US sibling data, reported that brother-brother pairs were more similar (ρ=0.46) than brother-sister (ρ=0.24) and sister-sister pairs (ρ=0.19) in their muscular strength. Differently, Pereira et al. (2017), using Portuguese sibling data, showed greater resemblance for morphological, muscular and motor fitness components among sister-sister ($0.35 \leq \rho \leq 0.55$) and brother-brother ($0.25 \leq \rho \leq 0.60$) than brother-sister pairs ($0 \leq \rho \leq 0.15$), except for the cardiorespiratory component (1-mile run test: $\rho_{SS} > \rho_{BS} > \rho_{BB}$), after adjustments for biological, behavioural familial and environmental covariates. Further, they also showed that sister-sister pairs are more similar in their physical activity (ρ=0.53) than brother-sister (ρ=0.26) or brother-brother pairs (ρ=0.18). Differently, and using objective physical activity data collected by pedometers, Jacobi et al. (2011) found no differences in correlations among different sib-types (all ρ=0.28).

We are not aware of any study of variation in physical growth, body composition, physical activity and motor performance among siblings from developing countries such as Peru, where the native culture and a peculiar environment might influence intra- and inter-pair resemblance. Hence, research focusing on Peruvian sibling's data may provide suitable and valuable information to better understand aspects of their adaptive mechanisms expressed by their phenotypic plasticity in response to distinct environmental conditions.

3.3. Socio-geographic context: Peru as a kind of natural laboratory

There is no doubt that the socio-geographic context plays important roles in shaping children and adolescents' physical growth and (motor) development, and this is particularly evident in developing countries, like Peru (Cossio-Bolaños et al., 2015; Pereira et al., 2021). The Peruvian territory spreads across three main areas (sea-level, Amazon region, and high-altitude), and children and adolescents are exposed to distinct environmental stressors and their daily life conditions are marked by economic, educational, nutritional, and health resource disparities (Gallup, Gaviria, & Lora, 2003; INEI, 2018).

It has been reported that Peruvian children and adolescents are, on average, of shorter stature (Hoke & Leatherman, 2019). Further, there is evidence of linear growth retardation (*stunting*) (Pomeroy et al., 2014), which has also been related to maturation delay (Cossio-Bolaños et al., 2015) in children living at high-altitudes due to their permanent exposure to severe constraints (e.g., altitude, temperature regimes, and pollutants). On the other hand, children and adolescents living in the Amazon region have plenty of natural space to play freely and diversify their play activities, which may help to explain the higher motor performance levels reported in the literature (de Chaves et al., 2016). Conversely, children living at sea-level experience a high density population , increasing public insecurity and the lack of public recreational infrastructures available to schoolchildren, contributing to the adoption of sedentary lifestyles, which may help to explain the high percentage (78%) of children who do not meet the WHO recommendations for moderate-to-vigorous physical activity (Sharma, Chavez, & Nam, 2018). Moreover, the existence of several fast food restaurants, convenience stores, and marketing of unhealthy food choices increases the likelihood of children acquiring unhealthy eating habits, which may help to explain the higher rate of overweight/obesity reported in the literature (Tarqui-Mamani, Alvarez-Dongo, & Espinoza-Oriundo, 2018). Differences in siblings' gross motor coordination also seems to reflect distinct daily lifestyles and routine activities, as well as the dynamics of the traditional structure of Peruvian families in each geographical area (Valdívia et al., 2018). In sum, cultural variation and social contrast in Peru, along with an enormous biological diversity generate complex environments rich in factors that help to determine children and adolescents' sib-pairs physical growth and (motor) development processes.

Similarly, in other developing countries, the effects of sociogeographic or socioeconomic inequalities in children's growth and development have also been widely reported in the literature (Bradley & Corwyn, 2002; Fernald, Kariger, Hidrobo, & Gertler, 2012; Walker et al., 2007). For example, Artiningrum, Suryobroto, and Widiyani (2014) reported that children living at low altitude (sea-level) in Lombok Island, Indonesia, were taller than those living at medium (525 to 628 m) and high altitudes (1130 to 1213 m). In turn, Werneck et al. (2018) reported that the prevalence of physical activity was low among adolescents in the poorer regions of Brazil, whereas prevalence of sedentary behavior was high among those living in the wealthier regions, which reflects social inequalities and their implications for public health planning in developing nations.

In sum, due to its specific characteristics, Peru has been recognized as a kind of “natural laboratory”, a singular territory that has the potential to trigger the investigation of growth, body composition, physical activity and motor performance, because it allows the exploration of the adaptive mechanisms expressed by human phenotypic plasticity in response to diverse environmental conditions. Hence, when investigating the Peruvian context, with focus on physical growth, body composition, physical activity and motor performance it is important to integrate them into a multidisciplinary and multilevel approach that enhances the knowledge of the biological diversity of Peruvian populations from different geographical regions and distinct sociocultural environments. However, the majority of traditional methods commonly used to address these issues have struggled to cope with the nested structure that characterizes family and sibling data. Therefore, it is important to scrutinize which statistical methods are most suitable for analyzing clustered data.

4. Multilevel Modeling: the key for the analysis of clustered data

Bearing in mind Bronfenbrenner's theoretical framework (Bronfenbrenner, 1994), as a model that emphasizes the need to understand individuals' development within their environments, there is a need to use appropriate statistical procedures to analyze clustered data.

Hence, multilevel modelling emerged as a statistical procedure that comprises a set of methods and tools that allows us to adequately analyze non-independent or clustered data such as children nested within schools or nested within sib-ships (Hox, Moerbeek, & Van de Schoot, 2018). This framework has a wide range of advantages: (i) it allows for the simultaneous examination of the effects of school- and individual-level predictors; (ii) it accounts for the non-independence of observations within schools; (iii) it does not treat subjects and the school environment as unrelated, but they are seen as coming from a larger population, and (iv) it examines both inter-individual and inter-school variation as well as the contributions of school- and individual-level covariates (Snijders & Bosker, 2012). Further, when analyzing sibling pairs, we can estimate the between- and within-sibling variances. The within-sibling variance represents the extent to which siblings within the family differ from one another with higher values indicating more dissimilarity between them. The between-sibling variance indicates the extent to which sibling pairs differ from each other relative to the overall mean of the response variable. Moreover, this procedure is extremely flexible as it allows researchers to embed in the same equation (at the sibling level) putative covariates (i.e., confounders or predictors) as well as their interactions (Hedeker, Mermelstein, & Demirtas, 2012).

In sum, the multilevel modelling approach provides an important framework in which to consider the complex relationships between subjects and their contexts in a holistic manner (Courgeau, 2003).

OUTLINE OF THE THESIS

The present thesis was conceived and designed to investigate different facets of human variability in physical growth, body composition, physical activity and motor performance as end-results of adaptive processes in different socio-geographical, educational and cultural contexts in Peru - especially children, youth and siblings living at different altitudes (sea-level, Amazon region and high-altitude). This labour, framed within Bronfenbrenner’s ecological approach, required the systematic use of the multilevel modeling statistical framework with youth and sibling data arising from cross-sectional data to search for an in-depth understanding regarding these phenotypes within the natural (geographical areas of residence) and built environment (school context). Figure 1 shows a schematic design of the study.

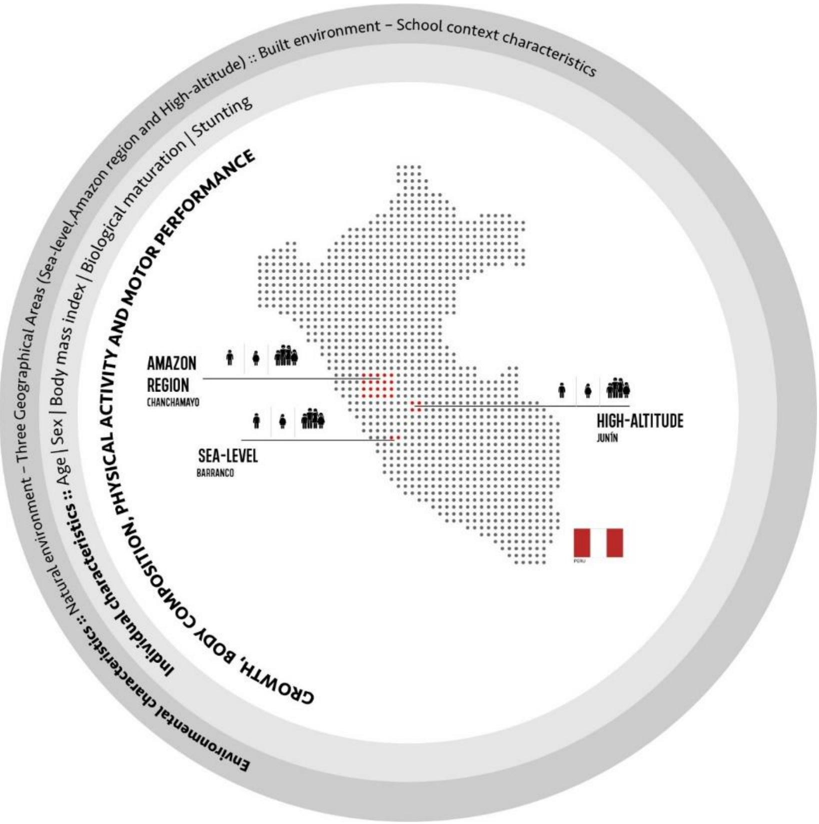

Figure 1. An illustration of the study.

Given the complexity of the issues addressed in this thesis, a set of purposes were firstly outlined based on Peruvian youth data to (1) investigate the variability in growth spurt parameters of Peruvian children and adolescents living at different altitudes; (2) investigate the prevalence of stunting and its influence on physical fitness levels of Peruvian children and adolescents; (3) investigate the variability in body composition, physical fitness and gross motor coordination of Peruvian children and adolescents, adjusted for individual and environmental characteristics. Secondly, we used Peruvian sibling data to investigate the sibling resemblance in physical fitness and physical activity, and joint associations of individual characteristics and shared natural environment in intra pair sibling similarities in each physical fitness component and in each physical activity phenotype.

FORMAL STRUCTURE OF THE THESIS

This thesis was structured under the Scandinavian model and encompasses a compilation of seven original manuscripts that were published/submitted in peer-reviewed journals. Chapter I presents the general introduction of the thesis, its purpose, and formal structure. Chapter II is dedicated to the general methodology. Chapters III and IV comprise the collection of published or submitted original papers based on Peruvian youth and sibling data, respectively. Chapter V provides a general discussion, conclusions, and limitations of the thesis together with some indications for future research. A summary of the thesis formal outline is shown in Table 1.

Table 1. Thesis formal outline.

Chapter I	General introduction, purposes and formal structure of the thesis.
Chapter II	General methodology, in which the sample and the procedures used in data collection are described in detail.
Chapter III	**<u>Paper I</u>** **Growth velocity curves and pubertal spurt parameters of Peruvian children and adolescents living at different altitudes. The Peruvian health and optimist growth study** Aims: (1) to verify if living at sea-level, the Amazon region, or high-altitude influences growth parameters in girls and boys; (2) to explore differences in growth parameters between girls and boys; (3) to compare the growth parameters of Peruvian children with those from other populations. Santos, C., Bustamante, A., Katzmarzyk, P. T., Vasconcelos, O., Garganta, R., Freitas, D., Mirzaei-Salehabadi, S., & Maia, J. (2019). Growth velocity curves and pubertal spurt parameters of Peruvian children and adolescents living at different altitudes. The Peruvian health and optimist growth study. *Am J Hum Biol*, 31(6), e23301. doi:10.1002/ajhb.23301
	<u>Paper II</u>

Stunting and Physical Fitness. The Peruvian Health and Optimist Growth Study

Aims: (1) to investigate the prevalence of stunting in Peruvian youth residing in distinct geographical areas; (2) to scrutinize systematic differences in height and physical fitness levels between stunted and normal-growth youth; (3) to examine whether the impact of stunting in physical fitness levels is consistent across age; and (4) to explore whether this difference is sex-, age- and physical fitness test-specific.

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Santos, C., Bustamante, A., Vasconcelos, O., Pereira, S., Garganta, R., Tani, G., Hedeker, D., Katzmarzyk, P. T., & Maia, J. (2020). Stunting and Physical Fitness. The Peruvian Health and Optimist Growth Study. *Int J Environ Res Public Health*, 17(10). doi:10.3390/ijerph17103440

Paper III

Correlates of Overweight in Children and Adolescents Living at Different Altitudes: The Peruvian Health and Optimist Growth Study

Aims: (1) to determine the prevalence of overweight in Peruvian children and adolescents by age, sex, and geographical area of residence; (2) to examine the importance of biological characteristics (age, sex, maturation, and physical fitness total score), school-level contexts, and geographical area of residence in explaining variation in body mass index categories.

Santos, C., Bustamante, A., Hedeker, D., Vasconcelos, O., Garganta, R., Katzmarzyk, P. T., & Maia, J. (2019). Correlates of Overweight in Children and Adolescents Living at Different Altitudes: The Peruvian Health and Optimist Growth Study. *J Obes*, 2019, 2631713. doi:10.1155/2019/2631713

Paper IV

A multilevel analysis of gross motor coordination of children and adolescents living at different altitudes: the Peruvian Health and Optimist Growth Study

Aims: (1) to examine how sex, age, biological maturation, overweight, stunting, and physical fitness are associated with gross motor coordination in children and adolescents from Peru; (2) to examine associations between geographical area of residence, school-level characteristics, and gross motor coordination.

Santos, C., Bustamante, A., Hedeker, D., Vasconcelos, O., Garganta, R., Katzmarzyk, P. T., & Maia, J. (2020). A multilevel analysis of gross motor coordination of children and adolescents living at different altitudes: the Peruvian

	Health and Optimist Growth Study. *Ann Hum Biol*, 47(4), 355-364. doi:10.1080/03014460.2020.1742378
	Paper V **A multivariate multilevel analysis of youth motor competence. The Peruvian Health and Optimist Growth Study** Aims: (1) to investigate the relationship between physical fitness and gross motor coordination in Peruvian youth; (2) to determine the effects of age, sex, BMI, biological maturation and stunting condition on physical fitness and gross motor coordination; (3) to examine the effects of geographical area of residence on physical fitness and gross motor coordination; (4) to probe the influence of school-level characteristics on physical fitness and gross motor coordination. Dos Santos, C. S. P., Bustamante, A., Hedeker, D., Vasconcelos, O., Garganta, R., Tani, G., Katzmarzyk, P. T., & Maia, J. (2020). A multivariate multilevel analysis of youth motor competence. The Peruvian Health and Optimist Growth Study. *Scand J Med Sci Sports*, 30(12), 2408-2419. doi:10.1111/sms.13807
Chapter IV	**Paper VI** **Sibling resemblance in physical fitness components. The Peruvian Sibling Study on Growth and Health** Aims: (1) to estimate sibling resemblance in health-related physical fitness components; (2) to investigate the joint associations of individual characteristics (age, body mass index, biological maturation and stunting) as well as shared natural environment (geographical areas of residence) in intra pair sibling similarities in each physical fitness component. Carla Santos, Alcibíades Bustamante, Olga Vasconcelos, Sara Pereira, Rui Garganta, J Timothy Lightfoot, Go Tani, Donald Hedeker, Peter T. Katzmarzyk, José Maia *Under review in the Behavior Genetics Journal (2021)*
	Paper VII **Sibling resemblance of physical activity levels. The Peruvian Family Study on Growth and Health** Aims: (1) to estimate sibling resemblance in two PA phenotypes (number of steps and aerobic activity); and (2) investigate the joint associations of individual characteristics (age and body mass index) as well as shared natural environment (geographical areas of residence) in intra pair sibling similarities in each PA phenotype.

	Carla Santos, Alcibíades Bustamante, Olga Vasconcelos, Sara Pereira, Rui Garganta, J Timothy Lightfoot, Go Tani, Donald Hedeker, Peter T. Katzmarzyk, José Maia *Under review in the Annals of Human Biology (2021)*
Chapter V	Presents the general discussion, main conclusions, limitations of the thesis, as well as future research avenues.

REFERENCES

Baker, P. T., & Little, M. A. (1976). *Man in the Andes: a multidisciplinary study of high-altitude Quechua*. Dowden, Hutchinson & Ross, Stroudsburg, Pennsylvania.

Banik, S. D., Salehabadi, S. M., & Dickinson, F. (2017). Preece-Baines Model 1 to Estimate Height and Knee Height Growth in Boys and Girls From Merida, Mexico. *Food Nutr Bull, 38*(2), 182-195. doi:10.1177/0379572117700270

Beall, C. M. (1982). An historical perspective on studies of human growth and development in extreme environments. *A History of American Physical Anthropology. F. Spencer, ed*, 447-465.

Berger, K. (2008). *The Developing Person Through the Lifespan*. New York: Worth.

Bouchard, C., & Shephard, R. J. (1994). Physical activity, fitness, and health: The model and key concepts. In C. Bouchard, R. J. Shephard, & T. Stephens (Eds.), Physical activity, fitness, and health: International proceedings and consensus statement (pp. 77-88). Champaign, IL, England: Human Kinetics Publishers.

Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. Annu Rev Psychol, 53, 371-399. doi:10.1146/annurev.psych.53.100901.135233

Bronfenbrenner, U. (1994). Ecological models of human development. In M. Gauvian & M. Cole (Eds.), International Encyclopedia of Education (Vol. 3, pp. 37-43). Oxford: Elsevier.

Bronfenbrenner, U., & Ceci, S. J. (1994). Nature-nurture reconceptualized in developmental perspective: a bioecological model. Psychol Rev, 101(4), 568-586. doi:10.1037/0033-295x.101.4.568

Bronfenbrenner, U., & Morris, P. A. (1998). The ecology of developmental processes In W. Damon & R. M. Lerner (Eds.), Hanbook of child psychology (Vol. 1). New York: John Wiley.

Campbell, K., Waters, E., O'Meara, S., & Summerbell, C. (2001). Interventions for preventing obesity in childhood. A systematic review. Obes Rev, 2(3), 149-157. doi:10.1046/j.1467-789x.2001.00035.x

Chaves, R., Baxter-Jones, A., Gomes, T., Souza, M., Pereira, S., & Maia, J. (2015). Effects of Individual and School-Level Characteristics on a Child's Gross Motor Coordination Development. *Int J Environ Res Public Health, 12*(8), 8883-8896. doi:10.3390/ijerph120808883

Cossio-Bolaños, M., Campos, R. G., Andruske, C. L., Flores, A. V., Luarte-Rocha, C., Olivares, P. R., . . . de Arruda, M. (2015). Physical Growth, Biological Age, and Nutritional Transitions of Adolescents Living at Moderate Altitudes in Peru. *Int J Environ Res Public Health, 12*(10), 12082-12094. doi:10.3390/ijerph121012082

Courgeau, D. (2003). *Methodology and epistemology of multilevel analysis: approaches from different social sciences* (Vol. 2): Dordrecht: Kluwer Academic Publishers.

de Chaves, R. N., Bustamante Valdívia, A., Nevill, A., Freitas, D., Tani, G., Katzmarzyk, P. T., & Maia, J. A. (2016). Developmental and physical-fitness associations with gross motor coordination problems in Peruvian children. *Res Dev Disabil, 53-54*, 107-114. doi:10.1016/j.ridd.2016.01.003

Dunn, J., & Plomin, R. (1991). Why are siblings so different? The significance of differences in sibling experiences within the family. *Fam Process, 30*(3), 271-283. doi:10.1111/j.1545-5300.1991.00271.x

Ellison, P. T., & Reiches, M. W. (2012). Puberty. In N. Cameron & B. Bogin (Eds.), *Human growth and development.* (pp. 81-108). New York: Academic Press.

Fernald, L. C., Kariger, P., Hidrobo, M., & Gertler, P. J. (2012). Socioeconomic gradients in child development in very young children: evidence from India, Indonesia, Peru, and Senegal. Proc Natl Acad Sci U S A, 109 Suppl 2(Suppl 2), 17273-17280. doi:10.1073/pnas.1121241109

Frisancho, A. R. (1993). *Human Adaptation and Accommodation. Enlarged and Revised Edition of Human Adaptation.* USA: The University of Michigan Press.

Frisell, T., Öberg, S., Kuja-Halkola, R., & Sjölander, A. (2012). Sibling comparison designs: bias from non-shared confounders and measurement error. *Epidemiology, 23*(5), 713-720. doi:10.1097/EDE.0b013e31825fa230

Gabbard, C. (2014). *Lifelong motor development.* (6th ed.). United State of America: Pearson Education Limited.

Gallup, J. L., Gaviria, A., & Lora, E. (2003). *Is Geography Destiny?: Lessons from Latin America*: Stanford University Press.

Gasser, T., Gervini, D., & Molinari, L. (2004). Kernel estimation, shape-invariant modelling and structural analysis. In R. Hauspie, N. Cameron, & L. Molinari (Eds.), *Cambridge Studies in Biological and Evolutionary Anthropology* (pp. 179-204). New York, USA: Cambridge University Press.

Gomes, T. N., dos Santos, F. K., Zhu, W., Eisenmann, J., & Maia, J. A. (2014). Multilevel analyses of school and children's characteristics associated with physical activity. *J Sch Health, 84*(10), 668-676. doi:10.1111/josh.12193

Grotevant, H. D. (1998). Adolescent development in family contexts. In W. Damon & N. Eisenberg (Eds.), *Handbook of child psychology: Social, emotional, and personality development* (pp. 1097–1149): John Wiley & Sons, Inc.

Harris, K. C., Kuramoto, L. K., Schulzer, M., & Retallack, J. E. (2009). Effect of school-based physical activity interventions on body mass index in children: a meta-analysis. Cmaj, 180(7), 719-726. doi:10.1503/cmaj.080966

Hedeker, D., Mermelstein, R. J., & Demirtas, H. (2012). Modeling between-subject and within-subject variances in ecological momentary assessment data using mixed-effects location scale models. *Statistics in medicine, 31*(27), 3328-3336.

Haywood, K. (1986). *Lifespan Motor Development.* Champaign Illinois: Human Kinetics.

Haywood, K. M., & Getchell, N. (2010). *Desenvolvimento Motor ao Longo da Vida* (5ª ed.). Porto Alegre: Artmed Editora.

Heywood, K., & Getchell, N. (2020). Life Span Motor Development (7th ed.): Human Kinetics. Champaign.

Hogan, A. M., Virues-Ortega, J., Botti, A. B., Bucks, R., Holloway, J. W., Rose-Zerilli, M. J., . . . Kirkham, F. J. (2010). Development of aptitude at altitude. *Dev Sci*, 13(3), 533-544. doi:10.1111/j.1467-7687.2009.00909.x

Hoke, M. K., & Leatherman, T. L. (2019). Secular trends in growth in the high-altitude district of Nuñoa, Peru 1964-2015. *Am J Phys Anthropol, 168*(1), 200-208. doi:10.1002/ajpa.23736

Hox, J. J., Moerbeek, M., & Van de Schoot, R. (2018). *Multilevel analysis: Techniques and applications* New York, USA: Routledge.

Hung, L. S., Tidwell, D. K., Hall, M. E., Lee, M. L., Briley, C. A., & Hunt, B. P. (2015). A meta-analysis of school-based obesity prevention programs demonstrates limited efficacy of decreasing childhood obesity. Nutr Res, 35(3), 229-240. doi:10.1016/j.nutres.2015.01.002

Hynynen, S. T., van Stralen, M. M., Sniehotta, F. F., Araújo-Soares, V., Hardeman, W., Chinapaw, M. J., . . . Hankonen, N. (2016). A systematic review of school-based interventions targeting physical activity and sedentary behaviour among older adolescents. Int Rev Sport Exerc Psychol, 9(1), 22-44. doi:10.1080/1750984x.2015.1081706

INEI. (2018). Perfil sociodemográfico del Peru, Informe Nacional. Retrieved from https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1539/index.html

Jacobi, D., Caille, A., Borys, J. M., Lommez, A., Couet, C., Charles, M. A., & Oppert, J. M. (2011). Parent-offspring correlations in pedometer-assessed physical activity. *PloS one, 6*(12), e29195. doi:10.1371/journal.pone.0029195

Jelenkovic, A., Sund, R., Hur, Y. M., Yokoyama, Y., Hjelmborg, J. V., Möller, S., . . . Silventoinen, K. (2016). Genetic and environmental influences on height from infancy to early adulthood: An individual-based pooled analysis of 45 twin cohorts. *Sci Rep, 6*, 28496. doi:10.1038/srep28496

Keyes, K. M., Smith, G. D., & Susser, E. (2013). On sibling designs. *Epidemiology, 24*(3), 473-474. doi:10.1097/EDE.0b013e31828c7381

Kiphard, E. J., & Schilling, F. (1974). Körperkoordinationstest für Kinder. Weinheim: Beltz Test GmbH.

Kriemler, S., Meyer, U., Martin, E., van Sluijs, E. M., Andersen, L. B., & Martin, B. W. (2011). Effect of school-based interventions on physical activity and fitness in children and adolescents: a review of reviews and systematic update. Br J Sports Med, 45(11), 923-930. doi:10.1136/bjsports-2011-090186

Lasker, G. W. (1969). Human biological adaptability. The ecological approach in physical anthropology. *Science, 166*(3912), 1480-1486. doi:10.1126/science.166.3912.1480

Liu, Z., Xu, H. M., Wen, L. M., Peng, Y. Z., Lin, L. Z., Zhou, S., . . . Wang, H. J. (2019). A systematic review and meta-analysis of the overall effects of school-based obesity prevention interventions and effect differences by intervention components. Int J Behav Nutr Phys Act, 16(1), 95. doi:10.1186/s12966-019-0848-8

Mackova, J., Dankulincova Veselska, Z., Filakovska Bobakova, D., Madarasova Geckova, A., van Dijk, J. P., & Reijneveld, S. A. (2019). Crisis in the Family and Positive Youth Development: The Role of Family Functioning. *Int J Environ Res Public Health, 16*(10). doi:10.3390/ijerph16101678

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation and physical activity* (2nd ed. Vol. 2nd). Champaign Ill, IL, USA: Human Kinetics.

Malina, R. M., & Mueller, W. H. (1981). Genetic and environmental influences on the strength and motor performance of Philadelphia school children. Hum Biol, 53(2), 163-179.

Manna, I. (2014). Growth development and maturity in children and adolescent: relation to sports and physical activity. *American Journal of Sports Science and Medicine, 2*(5A), 48-50.

Marceau, K., Ram, N., Houts, R. M., Grimm, K. J., & Susman, E. J. (2011). Individual differences in boys' and girls' timing and tempo of puberty: modeling development with nonlinear growth models. *Dev Psychol, 47*(5), 1389-1409. doi:10.1037/a0023838

Marshall, W. A., & Tanner, J. M. (1970). Variations in the pattern of pubertal changes in boys. *Arch Dis Child, 45*(239), 13-23. doi:10.1136/adc.45.239.13

McMinn, A. M., van Sluijs, E. M., Nightingale, C. M., Griffin, S. J., Cook, D. G., Owen, C. G., . . . Whincup, P. H. (2011). Family and home correlates of children's physical activity in a multi-ethnic population: the cross-sectional Child Heart and Health Study in England (CHASE). *Int J Behav Nutr Phys Act, 8*, 11. doi:10.1186/1479-5868-8-11

Mirwald, R., Baxter-Jones, A., Bailey, D., & Beunen, G. (2002). An assessment of maturity from anthropometric measurements. Med Sci Sports Exerc, 34(4), 689-694.

Mollborn, S., & Lawrence, E. (2018). Family, Peer, and School Influences on Children's Developing Health Lifestyles. *J Health Soc Behav, 59*(1), 133-150. doi:10.1177/0022146517750637

Moran, E. F., & Mastrangelo, S. (2000). *La Ecología Humana de los Pueblos de la Amazonia*. España: Fondo de Cultura Económica.

Moran, E. F. (2008). *Human Adaptability: An Introduction to Ecological Anthropology* (3ª ed.). USA: Westview Press.

Moran, E. F., & Brondizio, E. S. (2013). Introduction to human-environment interactions research. In *Human-Environment Interactions* (pp. 1-24): Springer.

Morgan, P. J., Barnett, L. M., Cliff, D. P., Okely, A. D., Scott, H. A., Cohen, K. E., & Lubans, D. R. (2013). Fundamental movement skill interventions in youth: a systematic review and meta-analysis. *Pediatrics, 132*(5), e1361-1383. doi:10.1542/peds.2013-1167

Newell, K. (1986). Constraints on the development of coordination. In W. H. Wade MG (Ed.), *Motor Development in children: Aspects of coordination and control* (pp. 341-360): Dordrecht: Martinus Nijhoff Publishers.

Nielsen, G., Taylor, R., Williams, S., & Mann, J. (2010). Permanent play facilities in school playgrounds as a determinant of children's activity. *J Phys Act Health, 7*(4), 490-496. doi:10.1123/jpah.7.4.490

O'Malley, P. M., Johnston, L. D., Delva, J., Bachman, J. G., & Schulenberg, J. E. (2007). Variation in obesity among American secondary school students by school and school characteristics. *Am J Prev Med, 33*(4 Suppl), S187-194. doi:10.1016/j.amepre.2007.07.001

Pallan, M. J., Adab, P., Sitch, A. J., & Aveyard, P. (2014). Are school physical activity characteristics associated with weight status in primary school children? A multilevel cross-sectional analysis of routine surveillance data. *Arch Dis Child, 99*(2), 135-141. doi:10.1136/archdischild-2013-303987

Pereira, S., Bustamante, A., Santos, C., Hedeker, D., Tani, G., Garganta, R., . . . Maia, J. (2021). Biological and environmental influences on motor coordination in Peruvian children and adolescents. Sci Rep, 11(1), 15444. doi:10.1038/s41598-021-95075-7

Pereira, S., Santos, C., Katzmarzyk, P. T., & Maia, J. (2019). Familial Resemblance in Body Shape and Composition, Metabolic Syndrome, Physical Activity and Physical Fitness: A Summary of Research in Portuguese Families and Siblings. Twin Res Hum Genet, 22(6), 651-659. doi:10.1017/thg.2019.46

Pereira, S., Katzmarzyk, P. T., Gomes, T. N., Souza, M., Chaves, R. N., dos Santos, F. K., . . . Maia, J. (2017). A multilevel analysis of health-related physical fitness. The Portuguese sibling study on growth, fitness, lifestyle and health. *PloS one, 12*(2), e0172013.

Plomin, R., & Daniels, D. (2011). Why are children in the same family so different from one another? *Int J Epidemiol, 40*(3), 563-582. doi:10.1093/ije/dyq148

Plomin, R., Manke, B., & Pike, A. (1996). Siblings, behavioral genetics, and competence. In G. Brody (Ed.), *Sibling relationships: Their causes and consequences.* Norwood, NJ: Ablex.

Pomeroy, E., Stock, J. T., Stanojevic, S., Miranda, J. J., Cole, T. J., & Wells, J. C. (2014). Stunting, adiposity, and the individual-level "dual burden" among urban lowland and rural highland Peruvian children. *Am J Hum Biol, 26*(4), 481-490. doi:10.1002/ajhb.22551

Preece, M. A., & Baines, M. J. (1978). A new family of mathematical models describing the human growth curve. *Ann Hum Biol, 5*(1), 1-24. doi:10.1080/03014467800002601

Procter, K. L., Rudolf, M. C., Feltbower, R. G., Levine, R., Connor, A., Robinson, M., & Clarke, G. P. (2008). Measuring the school impact on child obesity. *Soc Sci Med, 67*(2), 341-349. doi:10.1016/j.socscimed.2008.02.029

Reiss, D., Plomin, R., Hetherington, E. M., Howe, G. W., Rovine, M., Tryon, A., & Hagan, M. (1994). The separate worlds of teenage siblings: An introduction to the study of the nonshared environment and adolescent development. In E. M. Hetherington, D. Reiss, & R. Plomin (Eds.), Separate social worlds of siblings: The impact of nonshared environments on development (pp. 63-109). Hillsdale, NJ: Erlbaum.

Reyes, A. C., Chaves, R., Baxter-Jones, A. D. G., Vasconcelos, O., Barnett, L. M., Tani, G., . . . Maia, J. (2019). Modelling the dynamics of children's gross motor coordination. *J Sports Sci, 37*(19), 2243-2252. doi:10.1080/02640414.2019.1626570

Roberts, D., Mascie-Taylor, C., & Bogin, B. (1995). Human variability and plasticity. In: Cambridge: Cambridge University Press.

Roche, A., & Sun, S. (2003). Human physical growth. Assessment and interpretation. Cambridge: Cambridge University Press.

Schell, L. M. (1995). Human biological adaptability with special emphasis on plasticity: history, development and problems for future research. In Human variability and plasticity (pp. 213-237).

Sharma, B., Chavez, R. C., & Nam, E. W. (2018). Prevalence and correlates of insufficient physical activity in school adolescents in Peru. *Rev Saude Publica, 52*, 51. doi:10.11606/s1518-8787.2018052000202

Sigelman, C. K., & Rider, E. A. (2021). Life-span human development: Cengage Learning.

Snijders, T. A. B., & Bosker, R. J. (2012). *Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling* (2nd ed.). London: Sage Publishers.

Sylva, K. (1994). School influences on children's development. *J Child Psychol Psychiatry, 35*(1), 135-170. doi:10.1111/j.1469-7610.1994.tb01135.x

Tanner, J. M. (1971). Sequence, Tempo, and Individual Variation in the Growth and Development of Boys and Girls Aged Twelve to Sixteen. *Daedalus, 100(4)*, 907-930.

Tarqui-Mamani, C., Alvarez-Dongo, D., & Espinoza-Oriundo, P. (2018). [Prevalence and factors associated with overweight and obesity in Peruvian primary school children]. *Rev Salud Publica (Bogota), 20*(2), 171-176. doi:10.15446/rsap.V20n2.68082

Ulijaszek, S. J. (2006). The international growth standard for children and adolescents project: environmental influences on preadolescent and adolescent growth in weight and height. *Food Nutr Bull, 27*(4 Suppl Growth Standard), S279-294. doi:10.1177/15648265060274s510

Valdívia, A. B., Henrique, R. S., Pereira, S., Chaves, R. N., Tani, G., Freitas, D., . . . Maia, J. (2018). Familial resemblance in gross motor coordination. The Peruvian Sibling Study on Growth and Health. *Ann Hum Biol, 45*(6-8), 463-469. doi:10.1080/03014460.2019.1568549

Veugelers, P. J., & Fitzgerald, A. L. (2005). Effectiveness of school programs in preventing childhood obesity: a multilevel comparison. Am J Public Health, 95(3), 432-435. doi:10.2105/ajph.2004.045898

Walker, S. P., Wachs, T. D., Gardner, J. M., Lozoff, B., Wasserman, G. A., Pollitt, E., & Carter, J. A. (2007). Child development: risk factors for adverse outcomes in developing countries. Lancet, 369(9556), 145-157. doi:10.1016/s0140-6736(07)60076-2

Werneck, A. O., Oyeyemi, A. L., Fernandes, R. A., Romanzini, M., Ronque, E. R. V., Cyrino, E. S., . . . Silva, D. R. (2018). Regional Socioeconomic Inequalities in Physical Activity and Sedentary Behavior Among Brazilian Adolescents. J Phys Act Health, 15(5), 338-344. doi:10.1123/jpah.2017-0338

Wild, C. P. (2005). Complementing the genome with an "exposome": the outstanding challenge of environmental exposure measurement in molecular epidemiology. *Cancer Epidemiol Biomarkers Prev, 14*(8), 1847-1850. doi:10.1158/1055-9965.Epi-05-0456

Woolcott, O. O., Gutierrez, C., Castillo, O. A., Elashoff, R. M., Stefanovski, D., & Bergman, R. N. (2016). Inverse association between altitude and obesity: A prevalence study among andean and low-altitude adult individuals of Peru. *Obesity (Silver Spring), 24*(4), 929-937. doi:10.1002/oby.21401

Zhu, W., Boiarskaia, E. A., Welk, G. J., & Meredith, M. D. (2010). Physical education and school contextual factors relating to students' achievement and cross-grade differences in aerobic fitness and obesity. *Res Q Exerc Sport, 81*(3 Suppl), S53-64. doi:10.1080/02701367.2010.10599694

CHAPTER II

General Methodology

GENERAL METHODOLOGY

Communities

Peru is characterized by impressive heterogeneity across its three regions (sea-level, Amazon area, and high-altitude), which are also shaped by cultural diversity as well as distinct geographical, demographical, socio-economic, political and educational characteristics (Gallup, Gaviria, & Lora, 2003; INEI, 2018). On the coast, Barranco (58 m) is one of the 43 districts of Lima Province, located on the shore of the Pacific Ocean, corresponding to 11.7% of the national territory. In turn, the Amazon region is the largest of the Peruvian territory and occupies ~60% of its surface, and we sampled from La Merced and San Ramon (751 m) districts with geographical continuity and integrating the Chanchamayo province. Lastly, at high-altitude, the Andean region is located in the central part of the Andes Mountains and comprises 28.0% of the national territory. Junín was the chosen site (4107m), and is the capital of the Junín province, and it is located on the southern shore of Lake Junín or Chinchaycocha.

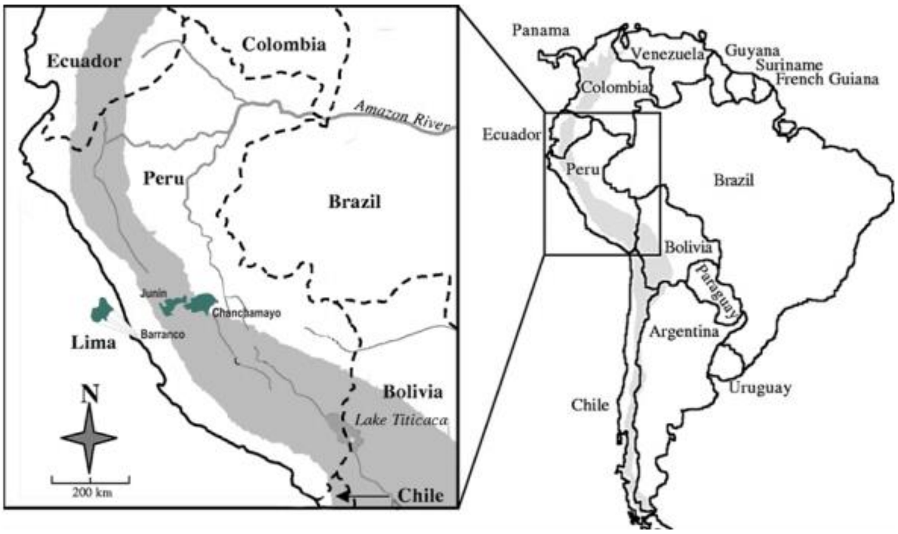

Figure 1. Geographical location of the three areas in the central region of Peru.

Research Projects

The data used in this thesis come from the three research projects: "*The Peruvian Health and Optimist Growth Study"*, "*The Peruvian Sibling Study on Growth and Health"*, and *"The Peruvian Family Study on Growth and Health"* (Bustamante, Beunen, & Maia, 2011).

The Peruvian Health and Optimist Growth Study

This project aims to investigate the main sources of variation in physical growth, motor development, and health in Peruvian children and adolescents living at different altitudes. The data collection was conducted between November 2009 and July 2010, during the school year, and comprises ~11800 children and adolescents, aged 3-17 years, from 31 public schools, located in urban areas, of which 13 were kindergartens, 10 were primary schools, and 8 were secondary schools. The sample comes from three distinct geographical areas located at different altitudes in the central region of Peru: Barranco, located at sea-level (58 m), Chanchamayo, in the Amazon region (751 m), and Junín, located at high-altitude (4107 m). The study variables are as follows: anthropometry (height, weight, sitting-height, perimeters, diameters and skinfold thickness); biological maturation (maturity offset); physical fitness (AAHPERD and EUROFIT battery tests for children and adolescents aged 6 to 17 years, and Preschool Test Battery (PTB) for kindergarten children aged 3 to 5 years); gross motor coordination (KöperkoordinationsTest für Kinder test battery); and physical activity (Baecke questionnaire). Under the umbrella of this project we wrote five papers: papers I to V.

The Peruvian Sibling Study on Growth and Health

This project aims to investigate Peruvian sibling's resemblance in their physical growth, motor development, and health. The sample is an integral part of the previous project, since children and adolescents who had their siblings studying in the same school were invited to take part in this study. A total sample of 2689 biological siblings, aged 6 to 17 years, from 18 public schools, were considered. The study variables are as follows: anthropometry (height, weight, sitting-height, perimeters, diameters and skinfolds thickness); biological maturation (maturity offset); physical fitness (AAHPERD and EUROFIT battery tests); gross motor coordination (KöperkoordinationsTest für Kinder test battery); and physical activity (Baecke questionnaire). Under the umbrella of this project we wrote paper VI.

The Peruvian Family Study on Growth and Health

This project aims to investigate the impact of different correlates in Peruvian families´ resemblance in their body composition, somatotype, metabolic syndrome and physical activity. The sample comprises 234 nuclear families, aged 3-84 years. For the present thesis, only sibling’s data between 6 to 17 years, were considered. The study variables are as follows: anthropometry (height, weight, sitting-height, perimeters, diameters and skinfold thickness); metabolic syndrome markers (high-density lipoprotein cholesterol, triglycerides, fasting glucose, heart rate, systolic and diastolic blood pressures; and physical activity (objectively measured using pedometers). Under the umbrella of this project we wrote paper VII.

Sample

In sum, a total sample of 10 795 children and adolescents, as well as 1865 biological siblings, aged 6 to 17 years, were considered. Participants were sampled from 18 random public schools (10 primary schools and 8 secondary schools), located in Barranco, Chanchamayo, and Junín. The sample was selected according to the following criteria: (1) all participants were native to their respective regions (i.e. no migrants were included, regardless of whether their parents or grandparents were migrants). We gathered information about their birth place and current place of residence or address and cross-checked this information with participants’ identity cards; and (2) all participants had complete data on all study variables. Further, children and adolescents with chronic diseases, physical handicaps or psychological disorders were excluded.

After initial political and educational contacts with local authorities in each city, formal permission was obtained from schools’ governmental bodies to participate in the project. Informed consent was provided by parents/legal guardians. The Ethics Committee of the National University of Education Enrique Guzman y Valle (UNE EGyV) as well as all school authorities approved the project.

Procedures

Individual domain

Anthropometry

Anthropometric measures [height (cm) and sitting height (cm)] were assessed using standardized protocols (Lohman, Roche, & Martorell, 1988). Height as well as sitting height were measured with a portable stadiometer (Sanny, Model ES-2060) holding the child’s head in the Frankfurt plane. Body weight was measured with a digital scale (Pesacon, Model IP68), and body mass index (BMI) was computed using the standard formula [weight (kg)/height (m) ^{2}].

Biological maturation

Biological maturation was assessed by predicting peak height velocity (PHV). Years from, or after, attainment of PHV was estimated using a prediction equation from anthropometric measures (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). The equation uses a specific formula based on age, sex, height, sitting height and body mass to predict years from or after the occurrence of PHV, a variable named *“maturity offset”*. A positive (+) maturity offset represents the predicted number of years the participant is beyond their age of PHV, whereas a negative (–) value represents the predicted number of years before the attainment of their PHV.

Stunting

Stunting condition (height-for-age) was computed using age- and sex-specific WHO Child Growth Standards references for children and adolescents, aged 5-19 years, as advocated by Onis et al. (2007). Two groups were formed: normal growth [height-for-age Z score ≥ -2 standard deviation (SD)], and stunting (height-for-age Z score < -2 SD), using STATA software syntax provided by the World Health Organization (2007).

Physical fitness

Based on the health-related physical fitness (PF) model proposed by Bouchard and Shephard (1994), four components were assessed using tests from American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD, 1980) and EUROFIT (1993) batteries:

(i) Morphological component: waist circumference was measured, in cm, with a non-stretchable fibreglass tape (Sanny, model 4010) at the midpoint between the edge of the lowest rib and the superior iliac crest during shallow apnea. Skinfold thickness (biceps, triceps, subscapular, abdominal, suprailiac, calf and thigh) was measured using a Holtain skinfold caliper (Crosswell, Crymych, UK) and recorded to the nearest 0.2 mm following the ISAK protocol (Norton, 1996);

(ii) Muscular component: muscular strength (static strength) was assessed with the handgrip strength test using a hand-held dynamometer (Takei Hand Grip Dynamometer®, Takei Scientific Instruments Co., Ltd, Nigata, Japan), and the result was recorded in kg^f. The participants gripped the dynamometer with maximum force for 5 to 10 seconds and the best score was recorded from two trials. Muscular power was obtained with the standing long jump test and the results were recorded in centimetres (cm). Each subject was instructed to jump as far as possible and the maximum jumping distance was recorded from two trials;

(iii) Motor component: agility was assessed with the shuttle-run test, and the time was recorded in seconds (s). Each subject performed five cycles (round-trip) at maximum speed between two lines separated by five meters;

(iv) Cardiorespiratory component: cardiorespiratory fitness was assessed using 12-minute run test. In a previously delimited field, each subject ran/walked the maximum possible distance in 12 minutes.

Gross motor coordination

Gross motor coordination (GMC) was assessed using the KöperkoordinationsTest für Kinder battery (KTK), developed in German by Kiphard and Schilling (1974) for children and adolescents, aged 5-14.99 years. All four tests were performed according to their standardized protocols:

(1) Walking backwards on balance beams (WB): each subject walked three times along each of three balance beams, each with a different width; for each balance beam, a maximum of 24 steps (eight per trial, and 3 trials) were counted, with a maximum of 72 steps (24 steps in 3 beams) for this test;

(2) Moving sideways (MS): each subject moved across the floor for 20 s (two trials) by stepping from one plate to the next, transferring to the first plate, stepping on it; the number of relocations was counted and summed over trials;

(3) Hopping for height on one foot (HH): each subject jumped from one leg over an increasing pile of pillows after a short run-up; the successful performance on the first trial corresponds to 3 points, on the second to 2 points and on the third trial to 1 point with a maximum of 39 points (maximum of 12 pillows) being scored for each leg, yielding a possible maximum score of 78 points;

(4) Jumping sideways (JS): each subject stand jumped laterally as many times as possible over a wooden slat in 15 s, in two trials. The number of jumps over the two trials was summed.

Physical activity

Physical activity (PA) as objectively measured using pedometers, a body movement sensor that validly and reliably assesses PA among children and youth (Clemes & Biddle, 2013; Lubans, Morgan, & Tudor-Locke, 2009). Subjects used the Omron pedometers Model Walking style II (Omron Healthcare, Inc, Japan) over five consecutive days (three week-days, and two weekend days). These pedometers have a multiday memory function that automatically stores the total number of steps each day, the number of steps done uniformly called aerobic, which are counted separately when walking at a pace of more than 60 steps per minute and during more than 10 minutes continuously. Subjects were instructed in the use of the pedometer, learning to remove it only for bathing and before sleeping at night. The devices were attached to the trouser belt (strap) using a clip, leaving the unit perpendicular to the ground. Only data from children with complete information from five consecutive days (Wednesday to Sunday) with an average of 12 hours/day of pedometer use were considered.

Environmental domain

Natural environment – Socio-geographic context

The three geographical areas of residence (as previously described) were considered: sea-level (58 m), Amazon region (751 m) and high-altitude (4107 m). We use a coding scheme with two dummies: sea-level, the reference category, was coded as 0 0, high-altitude was 1 0 and Amazon region was 0 1.

Built environment – School context

The description and inventory of characteristics associated with the school contexts was obtained via an objective school audit, using modified and locally adapted versions of the Healthy Eating and Physical Activity modules of the Healthy School Planner designed by the Joint Consortium for School Health (2012). This audit was led by the experienced research team members and maps various domains: (a) school characterization (school size – number of students);

(b) policies and practices for physical activity (specifically, the existence of policies and practices issued by the state, school board, or any other government agency to promote physical activity, health, and well-being of students and are organized by the school); (c) physical structure of the school (playground area, multipurpose hall, multi-sports roofed; (d) physical education classes (frequency and duration); and (e) extracurricular activities.

Data quality control

To ensure data quality, a five-step procedure was used: (i) all measurements were performed by experienced researchers in the correct use of the technical procedures of body measurement; (ii) a pilot study was conducted to assess the quality of data collection; (iii) random retests were conducted on each assessment day; (iv) reliability estimates were computed – the technical error of measurement (TEM) and ANOVA-based intraclass correlation coefficient; (v) systematic checks of all data entry, and identification/correction of putative punching errors.

Statistical analysis

All exploratory analyses (normality checks and data cleaning) and descriptive statistics (means, standard deviations, counts and percentages) were done with IBM SPSS v.26 (IBM Corp., Armonk, NY, USA). This software was also used to perform analyses of variance (ANOVA), chi-square tests, as well as to compute measures of effect size and z-score transformations whenever necessary. The significance level was set at 5%.

The Preece-Baines Growth Model I (PBGM-I) (Preece & Baines, 1978) was used to estimate pubertal spurt parameters. All calculations and graphical representations of the growth curves were computed using R software.

Given the hierarchical structure of the data, i.e., children nested within schools which are nested within regions, a multilevel analysis was used (Snijders

& Bosker, 2012). A three-level structure was considered, however, with only three regions, it is not recommended to treat region as a level in a multilevel analysis (Snijders & Bosker, 2012). Instead, dummy variables for region were always included as predictors of dependent variable and were included in the fixed part of the models. Models were developed using a stepwise approach and model fit was simultaneously estimated using a full maximum likelihood procedure implemented in the SuperMix 2.0 software (Hedeker, Gibbons, Toit, & Cheng, 2008).

Finally, multilevel models were also used to handle sibling data. Specifically, separate within- and between sib-ship variances, and therefore different intraclass correlations (ρ), with corresponding 95% confidence intervals (95% CI) were estimated following an approach described by Hedeker, Mermelstein, and Demirtas (2012). All calculations were done using STATA 14 software (StataCorp., 2017).

REFERENCES

AAHPERD. (1980). *Health related physical fitness: Test manual*. Reston, VA: American Alliance for Health, Physical Education, Recreation and Dance.

Bouchard, C., & Shephard, R. J. (1994). Physical activity, fitness, and health: The model and key concepts. In C. Bouchard, R. J. Shephard, & T. Stephens (Eds.), *Physical activity, fitness, and health: International proceedings and consensus statement* (pp. 77-88). Champaign, IL, England: Human Kinetics Publishers.

Bustamante, A., Beunen, G., & Maia, J. (2011). Como crecen y se desarrollan los niños y adolescentes en La Merced y San Ramón. Alcances para la Educación Física, el Deporte y la Salud. Lima, Perú: Universidad Nacional de Educación Enrique Guzmán y Valle, La Cantuta.

Clemes, S. A., & Biddle, S. J. (2013). The use of pedometers for monitoring physical activity in children and adolescents: measurement considerations. *J Phys Act Health, 10*(2), 249-262. doi:10.1123/jpah.10.2.249

EUROFIT. (1993). *Handbook for the EUROFIT tests of physical fitness* (2nd ed.). Strasbourg: Committee of Experts on Sports Research.

Hedeker, D., Gibbons, R., Toit, M. D., & Cheng, Y. (2008). *Supermix: Mixed effects models*. Lincolnwood, IL, USA: Scientific Software International, Inc.

Hedeker, D., Mermelstein, R. J., & Demirtas, H. (2012). Modeling between-subject and within-subject variances in ecological momentary assessment data using mixed-effects location scale models. *Stat Med, 31*(27), 3328-3336. doi:10.1002/sim.5338

Joint Consortium for School Health. (2012). Healthy School Planner. Retrieved from www.healthyschoolplanner.uwaterloo.ca

Kiphard, E. J., & Schilling, F. (1974). *Körperkoordinationstest für Kinder*. Weinheim: Beltz Test GmbH.

Lohman, T. G., Roche, A. F., & Martorell, R. (1988). *Anthropometric standardization reference manual* (Vol. 177): Human kinetics books Champaign, IL.

Lubans, D. R., Morgan, P. J., & Tudor-Locke, C. (2009). A systematic review of studies using pedometers to promote physical activity among youth. *Prev Med, 48*(4), 307-315. doi:10.1016/j.ypmed.2009.02.014

Mirwald, R., Baxter-Jones, A., Bailey, D., & Beunen, G. (2002). An assessment of maturity from anthropometric measurements. *Med Sci Sports Exerc, 34*(4), 689-694.

Norton, K., Whittingham, N., Carter, L., Kerr, D., Gore, C., Marfell-Jones, M. (1996). *Measurement Techniques in Anthropometry*: Anthropometrica Sydney: University of New South Wales Press.

Onis, M., Onyango, A., Borghi, E., Siyam, A., Nishida, C., & Siekmann, J. (2007). Development of a WHO growth reference for school-aged children and adolescents. *Bull. World Health Organ., 85*, 660-667.

Preece, M. A., & Baines, M. J. (1978). A new family of mathematical models describing the human growth curve. *Ann Hum Biol, 5*(1), 1-24. doi:10.1080/03014467800002601

Snijders, T. A. B., & Bosker, R. J. (2012). *Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling* (2nd ed.). London: Sage Publishers.

StataCorp. (2017). *Stata Statistical Software_ Release 15*. College Station, TX: StataCorp LLC.

World Health Organization. (2007). WHO Reference 2007 STATA macro package Retrieved from https://www.who.int/childgrowth/software/readme_stata.pdf

CHAPTER III

Research Articles Based on Peruvian Youth Data

Paper I

Growth velocity curves and pubertal spurt parameters of Peruvian children and adolescents living at different altitudes. The Peruvian Health and Optimist Growth Study

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ABSTRACT

Objetive: To estimate the growth parameters of Peruvian children and adolescents living at different altitudes.

Methods: The sample comprised 10,795 Peruvian children and adolescents (5,781 girls, aged 6 to 17 years) from sea-level, the Amazon region, and high-altitude. Height was measured with standardized techniques. Mathematical and biological growth parameters were estimated using the Preece-Baines growth model I.

Results: Sea-level children and adolescents experienced peak height velocity (PHV) at an earlier age (girls, 8.56±2.37 years; boys, 12.03±0.58 years), were taller at the time of PHV (girls, 144.1±1.9 cm; boys, 154.3±1.4 cm), had higher PHV (girls, 6.23±3.87 cm/year; boys, 7.52±2.31 cm/year), and had a taller estimated final height (girls, 154.2±0.3 cm; boys, 166.3±1.0 cm) compared to those living at high-altitude (girls, 152.7±0.7 cm; boys, 162.8±0.8 cm) or in the Amazon region (152.1±0.4 cm; boys, 162.2±0.6 cm). Across all geographical areas, PHV occurred approximately two years earlier in girls (9.68±0.99 years) than in boys (12.61±0.42 years), their estimated PHV was 5.88±1.92 cm/year *versus* 6.45±1.09 cm/year, their size at PHV was 142.2±1.4 cm *versus* 152.8±0.7 cm and their final adult height was estimated to be 153.1±0.3 cm *versus* 164.2±0.7 cm.

Conclusions: Peruvian children and adolescents' physical growth timing and tempo were influenced by their living altitudes. Those living at sea-level experienced an earlier age at PHV, were taller at time of PHV, had a higher PHV, and had a taller estimated final height compared to those living at higher altitudes. Girls and boys also differed significantly in their growth parameters.

Keywords: growth velocity curves; pubertal spurt parameters; Preece-Baines Growth Model I; children and adolescents.

INTRODUCTION

Human physical growth is characterized by its extraordinary plasticity and population heterogeneity (Ulijaszek, 2006), and is one of the best mirrors reflecting the living conditions and prosperity of different groups within a population (Tanner, 1987).

The influence of environmental factors on the physical growth and development of children and adolescents from different geographical areas has been previously described (Eveleth & Tanner, 1990; Schell, Gallo, & Ravenscroft, 2009; Silventoinen, 2003). In the presence of adverse environmental conditions, such as living at high-altitudes, the physical growth of children may be impaired, leading to shorter adult height (Cossio-Bolaños, de Arruda, Núñez Álvarez, & Lancho Alonso, 2011; Frisancho & Baker, 1970; Yip, Binkin, & Trowbridge, 1988). For example, Artiningrum, Suryobroto, and Widiyani (2014) reported that children living at low altitude (sea-level) in Lombok Island, Indonesia, were taller than those living at medium (525 to 628 m) and high altitudes (1130 to 1213 m). On the contrary, Clegg, Pawson, Ashton, and Flinn (1972), using Ethiopia children’s data, found that highland children (living at ~3000 m), particularly boys, were taller, heavier and bigger in most physical dimensions than were lowland children (living at ~1500 m). Furthermore, the effect of socioeconomic inequalities on height have been consistently observed within and between populations, with disadvantaged groups tending to be shorter in adulthood (Crespo, Valera, Gonzales, & Guerra García, 1995; Howe et al., 2010; McCrory et al., 2017; Silva et al., 2012).

The influence of environmental factors on growth velocity vary according to chronological age in childhood and adolescence (Ulijaszek, 2006). Further, children grow at different rates (Gerver & De Bruin, 2003) and specific body parts demonstrate differential timing (the moment in which a given growth event occurs) and tempo (the rhythm with which this growth event manifests itself) (Gasser, Kneip, Binding, Prader, & Molinari, 1991). For example, girls generally have an earlier pubertal growth spurt and also reach their final size earlier than boys of the same chronological age (Banik, Salehabadi, & Dickinson, 2017;

Marceau, Ram, Houts, Grimm, & Susman, 2011). The variability in growth velocities can be investigated by constructing growth velocity curves and estimating relevant parameters, using adequate mathematical models (Gasser, Gervini, & Molinari, 2004; Preece & Baines, 1978), which allows for the collection of information about timing and tempo.

Growth velocities are mostly available for height in boys and girls. However, this information is relatively dated because longitudinal studies and their main results were produced in the 70s, 80s and 90s of the last century (Byard, Guo, & Roche, 1993; Prader, Largo, Molinari, & Issler, 1989). Additionally, most population growth studies are cross-sectional, but when sample sizes are sufficiently large this type of data can be used to approximate longitudinal growth patterns (Tanner, 1985).

Mathematical growth models, such as Preece and Baines (1978), have been successfully applied to cross-sectional data to make inferences about the timing of the adolescent growth spurt, and the age when adult stature is attained. In Spanish youth, Rosique and Rebato (1995) derived growth parameters through the Preece-Baines growth model I (PBGM-I) and found that age at PHV in girls living in an urban area occurred later than in their semi-urban peers. This was also true for boys, except for those living in Barcelona-I. Datta Banik et al. (2017) applied the same model to cross-sectional data for Mexican youth, and reported that girls experienced their PHV at a mean age of 11.0 years and boys at 12.4 years. These results were similar to those found by Mao et al. (2011) in Chinese youth.

Despite the importance of understanding population differences in growth (Banik et al., 2017; Gerver & De Bruin, 2003), there is apparently no information regarding differences in pubertal growth parameters of Peruvian children living at different altitudes. Hence, the main aim of this study was to estimate the physical growth parameters of Peruvian children and adolescents using the PBGM-I. Three other aims were (1) to verify if living at sea-level, the Amazon region, or high-altitude influences growth parameters in girls and boys; (2) to explore differences in growth parameters between girls and boys; and (3) to compare the growth parameters of Peruvian children with those from other populations.

METHODS

Communities

Geographical heterogeneity in Peru is broadly expressed in three geographical areas with different altitudes: (1) sea-level: the coast or coastal desert, located between the western mountain and the Pacific Ocean, corresponding to 11.7% of the national territory. On the coast, Barranco (58 m), our chosen site, is one of the 43 districts of Lima Province, and is located on the shore of the Pacific Ocean; (2) Amazon region: the jungle is the largest of the Peruvian territory and occupies ~60% of its surface. Here, we chose two sites, La Merced and San Ramon (751 m), which are districts that have geographical continuity and integrate the Chanchamayo province; and (3) high-altitude: the Andean region is located in the central part of the Andes Mountains and comprises 28.0% of the national territory. In this region, Junín was the chosen site, and is the capital of the Junín province. It is located on a plateau at 4107 m on the southern shore of Lake Junín or Chinchaycocha. Geographic, demographic, socio-economic and educational characteristics of these areas (INEI, 2018) are presented in Table 1.

Table 1. Geographic, demographic, socioeconomic and educational characteristics of the three geographical areas located in the central region of Peru.

Characteristics	**Sea-level** (Barranco)	**Amazon region** (La Merced and San Ramon)	**High-altitude** (Junín)
Geographic			
Area (km²)	3.33	5 315.07	883.80
Altitude (m)	58	751	4107
Demographic			
Total population	34378	53590	10796
Population density (people/km²)	10.13	10.08	12.22
Official language	Spanish	Spanish/Quechua	Spanish/Quechua
Climate	Arid; semi-warm	Rainy; warm	Rainy; cold
Average annual temperature	18°C	24°C	7°C-12°C
Socioeconomic			
Human Development Index (HDI)	0.72	0.52	0.44
Life expectancy at birth (y)	79.08	65.49	69.14
Education (%)[1]	86.94	86.61	76.56
Literacy (%)[2]	99.35	90.97	89.84
Per capita family income (dollars)	1440.6	785.1	512.7
Primary production	Trade/Tourism	Agriculture/Tourism	Stockbreeding/Agriculture
Educational			
School age children	15.829	13.960	2.703
Boys	7.118 (45.0%)	7.172 (51.4%)	1.359 (50.3%)
Girls	8.711 (55.0%)	6.788 (48.6%)	1.344 (49.7%)
Public	8.881 (56.1%)	11.126 (79.7%)	2.601 (96.2%)
Private	6.948 (43.9%)	2.834 (20.3)	102 (3.8%)
Urban	15.829 (100%)	12.927 (92.6%)	2.678 (99.1%)
Rural	0 (0%)	1.033 (7.4%)	25 (0.9%)

[1] School age population; [2] Children and adults 15 years of age or more who know how to read and write

Study participants

The present cross-sectional sample comes from the *Peruvian Health and Optimist Growth Study* which, in summary, investigates growth, development and health of children and adolescents (Bustamante, Beunen, & Maia, 2011). A total sample of 10,795 children and adolescents, 5,014 boys and 5,781 girls, aged 6 to 17 years, was selected from 18 public schools belonging to the coast, Barranco (sea-level - 58 m), the jungle, La Merced and San Ramon (Amazon region - 751 m), and in the Andean mountains, Junín (high-altitude - 4107 m), of which 10 were primary-schools and 8 were secondary-schools. Thirty-eight percent of the total number of students were enrolled in the study, that is, 4 out of every 10 students who regularly attended school. The sample only included native children and adolescents from their respective regions (i.e., no migrants were included), regardless of whether their parents or grandparents were migrants or not. We gathered information about their birth place and current place of residence or address residence and cross-checked this information with the participants' identity cards. It is important to note that, in Barranco, there is a low percentage of internal migration, while in Junín the migration from the coast or the Amazon region is non-existent. On the other hand, in La Merced and San Ramon there is a strong internal migration, mainly from the mountains (INEI, 2018). All assessments were carried out in Barranco between November and December, 2009, and April and July, 2010, in La Merced and San Ramon between May and August, and in Junín between September and October of 2009. The ethical committee of the National University of Education Enrique Guzmán y Valle and the school directors approved the project. Informed consent was obtained from parents and/or legal guardians of the participants. Table 2 shows the number of children and adolescents by age, sex, and altitude.

Table 2. Children and adolescents sampled in the three geographical areas of the central region of Peru. Data by age and sex.

Age (y)†	**Sea-level** (Barranco)		**Amazon region** (La Merced and San Ramon)		**High-altitude** (Junín)		**All areas**	
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
6	124	93	210	193	59	73	393	359
7	96	66	192	259	92	72	380	397
8	117	81	254	234	80	98	451	413
9	163	91	255	261	110	123	528	475
10	129	99	308	264	109	116	546	479
11	164	141	268	273	124	94	556	508
12	126	152	330	210	208	143	664	505
13	94	72	300	189	122	145	516	406
14	155	122	257	171	156	164	568	457
15	137	166	206	205	155	122	498	493
16	165	95	180	161	146	117	491	373
17	71	43	56	55	63	51	190	149
Total	**1541**	**1221**	**2816**	**2475**	**1424**	**1318**	**5781**	**5014**

†Age was used as decimals of a year and children aged 5.5 to 6.49 years were designated as 6, children aged 6.50 to 7.49 years as 7, and so on (Eveleth & Tanner, 1990).

Anthropometry

All measurements were made according to standardized techniques (T. Lohman, A. Roche, & R. Martorell, 1988). Stretched stature with head positioned to the Frankfurt plane was measured to the nearest 0.1 cm with a portable stadiometer (Sanny, Model ES-2060).

Data quality control

To ensure data quality, the following procedures were used: (1) training of all team members by experienced researchers in the correct use of the technical procedures of body measurement; (2) conducting a pilot study to assess the quality of data collection; (3) retesting of a random sample of 29 children and adolescents, and (4) calculating the technical error of measurement (TEM) and ANOVA-based intraclass correlation coefficient to estimate the degree of precision and the proportion of the intra-individual variation in measurements. For stature, TEM was 0.20 and intraclass correlation coefficient was 0.92.

Statistical Analysis

Firstly, data cleaning, exploratory analysis, outlier identification and normality checks were done. Secondly, growth parameters were estimated using the version I of the PBGM (Preece & Baines, 1978) which is a multiplicative exponential-logistic model of the form:

$$\text{Height} = \frac{2(h_1 - h_\theta)}{e^{s0(t-\theta)} + e^{s1(t-\theta)}}$$

where t is age, h_1, h_θ, s_0, s_1 and θ are the five function parameters. Adult height was given by the parameter h_1. Parameters h_θ and θ were related to the height and age at peak velocity. The parameters s_0 and s_1 were growth-rate constants, related to pre-pubertal and pubertal velocity. For the sake of identifiability, it was assumed that $s_0<s_1$. It was further assumed that the values of all parameters were positive and the ratio of s_1/s_0 had to be greater than a constant value of about

5.828 (Salehabadi & Sengupta, 2013). In the present study, two biological parameters were estimated: age at PHV and PHV. Calculations and graphical representations of growth curves were obtained in a computational program implemented in R software. Thirdly, Student t-tests were used to identify mean differences in these growth parameters of the overall sample of boys and girls. Fourthly, differences across all altitudes within each sex were be tested with an analysis of variance, and the Tukey HSD test used for multiple comparisons. Statistical significance was set at 5%.

RESULTS

Descriptive statistics for height by age, sex and geographical area are provided in Table 3. The growth pattern is similar to other studies, namely, girls are taller than boys at 10-12 y of age, and boys are taller than girls from 13 y of age onwards.

Table 3. Descriptive statistics (Mean±SD) for height (cm) by age, sex and geographical area.

Age (y)	**Sea-level** (Barranco)		**Amazon region** (La Merced and San Ramon)		**High-altitude** (Junín)		**All areas**	
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
6	115.2±5.5	116.2±4.7	111.7±5.5	112.1±5.6	111.6±3.9	113.2±4.3	112.8±5.5	113.4±5.4
7	121.1±6.1	123.0±5.9	117.7±5.2	117.8±5.1	116.5±4.9	117.5±5.1	118.3±5.6	118.6±5.6
8	127.4±6.4	127.3±5.7	122.5±5.8	121.7±6.3	124.6±5.1	123.3±5.1	124.1±6.2	123.2±6.3
9	133.6±7.3	132.0±5.5	128.1±6.1	127.8±5.6	127.6±5.5	128.1±4.9	129.7±6.9	128.7±5.6
10	139.9±7.6	136.6±6.7	133.8±7.0	132.1±6.1	133.5±6.1	131.4±5.2	135.2±7.5	132.8±6.3
11	144.9±6.8	141.2±6.2	140.8±7.4	137.1±6.6	138.9±6.8	136.5±6.9	141.6±7.4	138.2±6.8
12	148.0±5.0	151.3±8.7	145.3±7.0	141.7±7.5	144.2±5.5	142.3±5.7	145.5±6.4	144.8±8.6
13	151.9±5.8	157.3±7.8	149.7±5.3	148.8±8.7	147.5±5.2	146.7±7.4	149.6±5.6	149.6±8.9
14	152.8±5.2	161.8±7.3	150.0±5.3	154.4±7.2	150.1±5.0	154.4±8.1	150.8±5.3	156.4±8.2
15	153.7±5.2	163.1±6.5	151.7±5.2	158.8±5.9	151.3±5.2	159.9±6.3	152.1±5.3	160.5±6.6
16	153.9±5.2	166.5±5.9	152.4±5.3	160.9±5.4	152.3±4.3	162.3±6.0	152.9±5.0	162.8±6.1
17	153.7±5.6	166.7±6.8	151.8±4.5	161.5±5.1	152.6±5.5	161.8±6.5	152.8±5.3	163.1±6.5

The mathematical and the biological parameters estimates for girls from the different geographical areas are shown in Table 4, and in Figure 1. Estimated adult final height (h_1) was higher for girls living at sea-level (154.2±0.3 cm), followed by high-altitude (152.7±0.7 cm) and Amazon region (152.1±0.4 cm), and they had a larger size at PHV (h_θ) (144.10±1.89 cm) in comparison with their peers from the other areas (high-altitude, 142.37±2.82 cm *versus* Amazon region, 141.93±1.25 cm). Differences in girls of each area were observed for the two biological parameters (p<0.001). Sea-level girls experienced their PHV at an earlier age (8.56±2.37 y) than those from living in Amazon region (10.35±0.63 y) and at high-altitude (10.11±3.76 y), and their velocity achieved at PHV (6.23±3.87 cm/y) was only significantly higher in comparison with high-altitude girls (5.31±2.91 cm/y).

Boys' mathematical and the biological growth parameters are presented in Table 5, and in Figure 1. Estimated adult final height (h_1) was higher for boys living at sea-level (166.3±0.9 cm), followed by high-altitude (162.8±0.8 cm) and Amazon region (162.2±0.6 cm), and they had a larger size at PHV (h_θ) (154.26±1.40 cm) in comparison with their peers from the other areas (high-altitude, 152.83±0.69 cm *versus* Amazon region, 151.79±0.54 cm). Significant differences were observed in the two biological parameters (p<0.001). Boys living at sea-level experienced their PHV at an earlier age (12.03±0.58 y), than those from living at high-altitude (13.32±0.32 y) and in Amazon region (12.85±0.33 y), and their velocity achieved at PHV (7.52±2.31 cm/y) was higher in comparison with their peers from the other areas (high-altitude, 7.17±1.45 cm/y *versus* Amazon region 6.47±0.97 cm/y).

Statistically significant differences were found between girls' and boys' biological parameters from all geographical areas (p<0.001) (illustrated in Figure 1). PHV occurred approximately two years earlier in girls (9.68±0.99 y) than in boys (12.61±0.42 y), their estimated PHV (5.88±1.92 cm/y *versus* 6.45±1.09 cm/y) as well as their size at PHV (h_θ) (142.24±1.39 cm *versus* 152.79±0.66 cm) were lower, and they reached a lower final adult height (h_1) than boys (153.1±0.3 cm *versus* 164.2±0.7 cm).

Table 4. Mean values (±SD) and analysis of variance of the parameters and derived biological variables for height in girls by fitting Preece-Baines growth model I to different geographical areas.

PB models' parameter	**All areas**	**Sea-level (S)** Barranco	**Amazon region (A)** La Merced and San Ramon	**High-altitude (H)** Junín	**F**	***p-value***	***Post hoc* among altitudes**
Mathematical Parameters							
s_0	0.12±0.02	0.12±0.03	0.13±0.02	0.15±0.03			
s_1	0.82±0.09	0.76±0.11	1.00±0.13	0.87±0.21			
θ	11.21±0.30	10.50±0.57	11.27±0.25	12.06±0.48			
h_θ	142.24±1.39	144.10±1.89	141.93±1.25	142.37±2.82			
h_1	153.06±0.29	154.20±0.34	152.07±0.36	152.70±0.72			
Residual standard error	0.34	0.41	0.53	0.78			
Biological Parameters							
Age at peak velocity (y)	9.68±0.99	8.56±2.37	10.35±0.63	10.11±3.76	325.43	<0.001	S<A; S<H; A>H
Peak height velocity (cm/y)	5.88±1.92	6.23±3.87	6.32±1.79	5.31±2.91	67.25	<0.001	S>H; A>H

Abbreviations: h_1, estimated final adult height in cm; h_θ, size at age θ in cm; θ, age at peak velocity in y; s_0 and s_1, prepubertal and pubertal rate constants controlling growth velocity, respectively, in cm/y.

Table 5. Mean values (±SD) and analysis of variance of the parameters and derived biological variables for height in boys by fitting Preece-Baines growth model I to different geographical areas.

PB models' parameter	**All areas**	**Sea-level (S)** Barranco	**Amazon region (A)** La Merced and San Ramon	**High-altitude (H)** Junín	**F**	***p-value***	**Post hoc among altitudes**
Mathematical Parameters							
s_0	0.11±0.01	0.11±0.02	0.12±0.01	0.12±0.01			
s_1	0.94±0.10	1.07±0.22	1.04±0.11	1.25±0.19			
θ	13.38±0.15	12.58±0.26	13.51±0.13	13.75±0.16			
h_θ	152.79±0.66	154.26±1.40	151.79±0.54	152.83±0.69			
h_1	164.24±0.67	166.33±0.96	162.20±0.58	162.84±0.80			
Residual standard error	0.53	1.16	0.51	0.80			
Biological Parameters							
Age at peak velocity (y)	12.61±0.42	12.03±0.58	12.85±0.33	13.32±0.32	3371.75	<0.001	S<A; S<H; A<H
Peak height velocity (cm/y)	6.45±1.09	7.52±2.31	6.47±0.97	7.17±1.45	223.45	<0.001	S>A; S>H; A<H

Abbreviations: h_1, estimated final adult height in cm; h_θ, size at age θ in cm; θ, age at peak velocity in y; s_0 and s_1, prepubertal and pubertal rate constants controlling growth velocity, respectively, in cm/y.

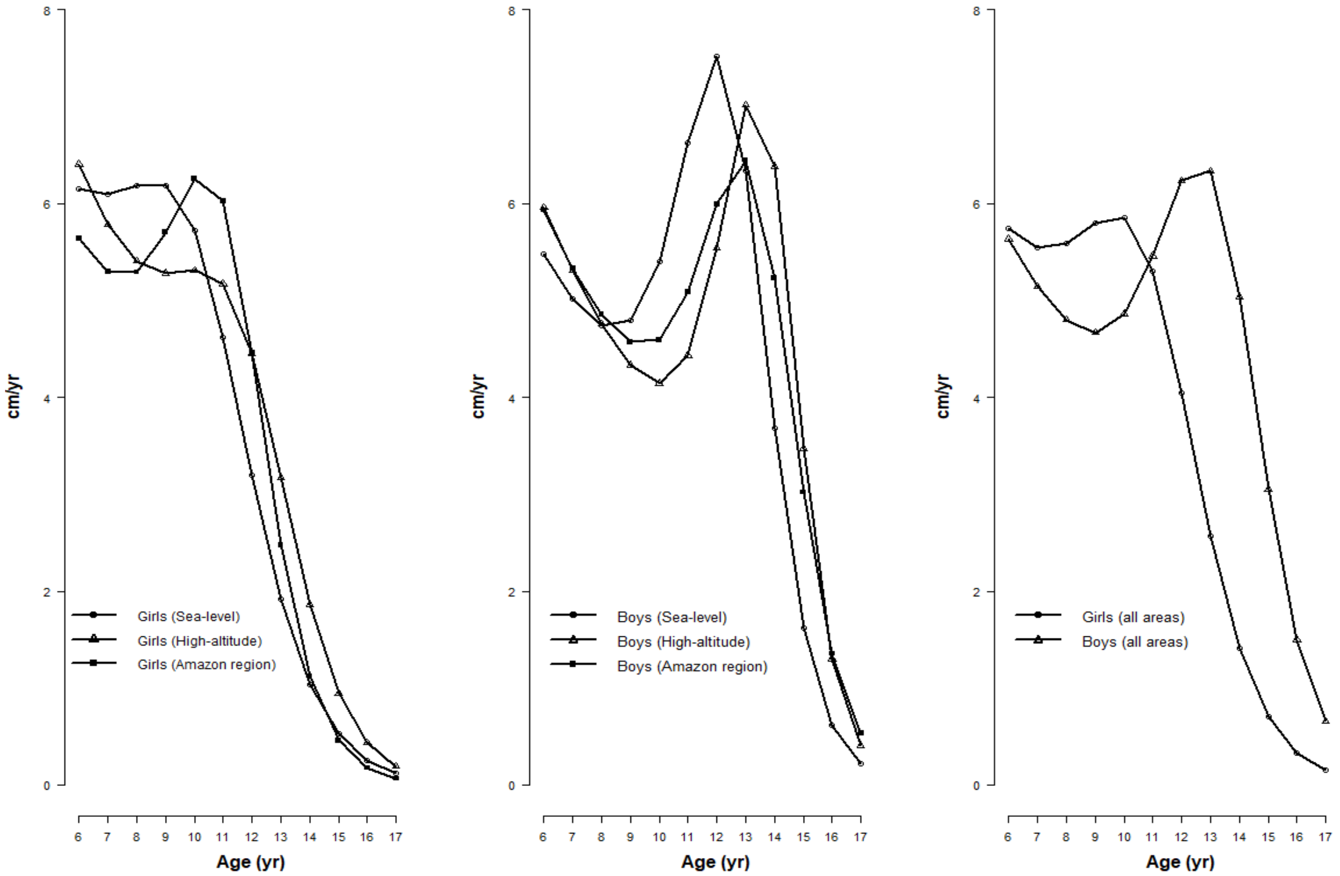

Figure 1. Boys and girls height velocity curves living at sea level, Amazon region, and high-altitude, as well as from all geographical areas together.

Table 6 displays biological parameter estimates from studies carried out in countries with different geographic and socio-demographic conditions. Height at PHV was similar among British and Guatemalan girls; also similar, but with lower values than the previous samples, were Peruvian, Japanese, Chinese, and Taiwanese and Mexican girls. In boys, Peruvians' age at PHV was 12.6 years and was similar to other populations. However, age at PHV in British boys was estimated at 14.2 years, and their estimated PHV (cm/year) was also lower than Peruvian peers. In girls, our sample experienced their PHV at an earlier age. This is also true for Japanese and Chinese girls, who had a similarly estimated PHV (cm/year).

Table 6. Pubertal growth parameters in different populations.

Biological parameters	Longitudinal studies				Cross-sectional studies		
	British (1978)	Japanese (1981)	Guatemalan (1990)	Taiwanese (1997)	Chinese (2011)	Mexican (2017)	Our study (2018)
Boys							
Age at PHV (y)	14.2	12.9	13.6	12.5	12.6	12.3	12.6
Height at PHV (cm)	159.6	150.1	160.4	154.6	155.8	150.8	152.7
PHV (cm/y)	8.2	6.8	9.5	8.0	6.9	7.1	6.4
Girls							
Age at PHV (y)	11.9	10.6	12.0	10.5	10.6	11.0	9.6
Height at PHV (cm)	148.4	137.1	148.1	143.0	140.2	143.4	142.2
PHV (cm/y)	7.5	6.0	7.6	7.0	6.6	5.1	5.8

British (Preece & Baines, 1978); Japanese (Ali, Lestrel, & Ohtsuki, 2001); Guatemalan (Bogin, Wall, & Macvean, 1990); Taiwanese (Lee et al., 2004); Chinese (Mao et al., 2011); Mexican (Banik et al., 2017)

DISCUSSION

To the best of our knowledge, there is no information published about the growth parameters of Peruvian children and adolescents living at different altitudes. Hence, this study is novel in providing such information. We found that: (1) living at different altitudes was associated with the timing and tempo of height growth in Peruvian children and adolescents; (2) girls and boys differed significantly in their growth parameters; and (3) our results on age at PHV, height at PHV and PHV showed widespread variation when compared with other populations.

Our results can be explained by the socioeconomic situation of Peru and existing differences among geographical areas. To begin with, Peru belongs to a class of emerging economies and developing countries with a human development index (HDI) of 0.75 and a life expectancy at birth of 74.98 years. However, the disparities in Peruvian life conditions characterized by inequalities in the distribution of, and access to, economic, educational, nutritional and health resources, still exist between the three areas (INEI, 2018), which is reflected in the dynamics of children and adolescents' growth. Second, it is well recognized that Peruvian life conditions at high-altitude are constrained by environmental stressors that are not expressed in the Amazon region or at sea-level. At high altitutde, the HDI is 0.44, almost 0.28 points lower than at sea-level, and life expectancy is also lower, ~10 yrs less (INEI, 2018). The population deals with hypoxic stress, low temperatures and relative humidity, and high cosmic radiation. Moreover, the main livelihood is stockbreeding and non-diversified agriculture, which limits nutritional intake and, consequently, affects children and adolescent's health and growth status (Beall, 2003; Beall, Baker, Baker, & Haas, 1977; Frisancho & Baker, 1970; Moore, 2001).

Previous studies have reported stunting among Peruvian natives living at high-altitude when compared with natives living at sea-level (Frisancho, 1978; Frisancho & Baker, 1970). The same trend was found in our sample, in which children and adolescents living at high-altitude had a higher stunting prevalence (15.2%) in comparison with their peers from the Amazon region (14.0%) and sea-level (5.2%). Furthermore, negative secular trends in physical growth characterized by shorter statures in populations living at high-altitude have also been reported. Pawson and Huicho (2010) investigated Peruvian children living in a high-altitude community over a 35-year period and showed that the stunting prevalence decreased from 1964 to 1999, but still approached 60% in both sexes, which are among the highest rates recorded in the modern era. The authors argued that the relatively poor growth status of the children could be a consequence of food disruption, together with the political instability of the country. Thus, the adverse living conditions of children living in high-altitude areas might be responsible for shorter statures during childhood, low heights at adulthood, and smaller sizes at PHV, when compared to those living at sea-level and in the Amazon region.

A slower pace of economic change associated with somewhat poor life conditions may also be responsible for the later onset of the adolescent growth spurt at high-altitude. In our study, we found that children living at high-altitude experience their PHV at a later mean age, almost 1 year later than their peers living at sea-level, and have a lower velocity at PHV. Thus, they seem to experience a slower and more prolonged period of growth than the sea-level and Amazon region groups, in which the differences are relatively modest. Hence, these results can apparently be explained by the multiple constraints of their environments. Among Peruvian adolescents living in Arequipa (~2.328 m of altitude), Cossio-Bolaños et al. (2015) found that delayed maturity was associated with the stunting condition. Since we were not able to locate any published data relating to the pubertal growth spurt parameters of Peruvian children and adolescents living at different altitudes, we relied on Bogin, Wall, and MacVean (1992) who found differences between Mayan school children living under poor conditions and Ladino peers living under favorable conditions. Mayan children were malnourished and less healthy and suffer from higher average rates of morbidity from chronic and infectious diseases. Consequently, they had significantly delays in the timeline of developmental milestones, such as age at PHV (15.26 years), height at PHV (152.89 cm), and PHV (8.75 cm/year) in comparison with Ladino children (age at PHV, 13.58 years; height at PHV, 160.15 cm; and PHV, 9.63 cm/year). An unfavorable environment was also used to explain the deficits in growth patterns among rural Gambian children (Billewicz & McGregor, 1982) when compared to British data (Preece & Baines, 1978). Because of the wide geographic, ethnic, and sociocultural differences among studies, the shared negative environment seems to produce similar growth patterns between Peruvian children who live at high-altitude, Mayan children of low SES, and rural Gambian children.

In our study, Peruvian girls and boys differed significantly in their growth parameters. PHV occurred approximately two years earlier in girls than in boys, girls’ estimated PHV as well as their size at PHV were lower, and they reach a lower final adult height than boys. This was no surprise since it is well documented that age at PHV is earlier in girls than in boys on average (R.M. Malina, Bouchard, & Bar-Or, 2004). This further indicates that the girls would reach final or adult size earlier than boys. Sex differences in growth parameters of children and adolescents in developed countries have been reported in the literature (Gasser, Sheehy, Molinari, & Largo, 2000). Our results were comparable with some estimates of the timing and tempo of growth in children and adolescents from Great Britain, Guatemala, Japan, Taiwan, China and Mexico (see Table 6), using PBGM-I. The Peruvian sample experienced their PHV at an earlier mean age (boys, 12.6 years; girls 9.6 years) than British (boys, 14.2 years; girls, 11.9 years) and Guatemalan (boys, 13.6 years; girls, 12.0 years) children; yet, they approach Japanese, Taiwanese, Chinese and Mexican results (Peruvians are about 1 year earlier). It is possible that this may be the result of an eventual secular trend seen in different countries (Aksglaede, Olsen, Sørensen, & Juul, 2008; Ali, Lestrel, & Ohtsuki, 2000; Karlberg, 2002; Liu, Wikland, & Karlberg, 2000; Virani, 2005) but never reported in Peruvian children and adolescents. For example, Ali et al. (2000) reported that the mean age at PHV was 14.1 years in Japanese boys and 11.6 years in Japanese girls born in 1943, whereas, in 1963, boys' age at PHV was 12.5 years, and in girls it was 10.3 years. The same trend occurred in Sweden (Liu et al., 2000) and Denmark (Aksglaede et al., 2008).

For boys, PHV in our sample (6.4 cm/year) is within the range reported in Japanese (6.8 cm/year), Chinese (6.9 cm/year) and Mexican (7.1 cm/year) peers, but much lower than those from Guatemala (9.5 cm/year). A similar trend occurs in girls, i.e., Mexican girls had the lowest PHV (5.1 cm/year), followed by the Peruvians (5.8 cm/year), yet the highest value was from Guatemalans (7.6 cm/year). Regarding height at PHV, our estimates in boys and girls were similar to those reported in Japanese (Ali et al., 2001), Chinese (Mao et al., 2011), Taiwanese (Lee et al., 2004) and Mexican (Banik et al., 2017) children. However, our values were lower than their peers from Great Britain (Preece & Baines, 1978) and Guatemala (Bogin et al., 1990).

The current study provides important information regarding how children and adolescents living in different socio-geographical contexts, namely distinct altitudes, have grown and developed. Notwithstanding the relevance of our findings, this study has at least two limitations. First, the sample is not representative of the Peruvian population of school children, which limits the generalizability of the results. Second, the cross-sectional nature of the study does not allow a dynamic analysis of intraindividual changes and interindividual differences occurring during the adolescent growth spurt. Despite these limitations, this study has several strengths: the use of an appropriate mathematical model to estimate growth parameters (PBGM-I), and the inclusion of children aged 6-17 years, which represents an important time window in their growth and development. The use of a standard measurement protocol and reliable data is an additional strength. Finally, the inclusion of Peruvian children and adolescents living at sea-level, the Amazon region, and high-altitude allows for an examination of issues of human variability.

In conclusion, sea-level Peruvian children and adolescents experienced an earlier age at PHV, were taller at time of PHV, had a higher PHV, and had a taller estimated final height compared to those living at higher altitudes. Across all geographical areas, PHV occurred approximately two years earlier in girls than in boys. Girls' estimated PHV, size at PHV, and final adult height were lower than in boys. Our results on age at PHV, height at PHV and PHV also showed widespread variation when compared with other populations. We anticipate that an important line of research will deal with the putative links between the stunting condition, nutritional habits and patterns, biological maturation, and physical performance of children and adolescents living at high altitudes in contrast with those living at sea-level. This would certainly provide important information for educators and health professionals in order to eradicate abnormal growth and health conditions.

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CONFLICT OF INTEREST STATEMENT

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

AUTHOR CONTRIBUTIONS

CS, SM and JM analyzed the data. CS and JM drafted the manuscript. CS, SM and JM designed the study and directed its implementation. JM provided necessary logistical support. AB, PTK, OV, RG, DF and SM provided extensive critical comments and did the final editing of the manuscript.

REFERENCES

Aksglaede, L., Olsen, L. W., Sørensen, T. I., & Juul, A. (2008). Forty years trends in timing of pubertal growth spurt in 157,000 Danish school children. *PloS one, 3*(7), e2728.

Ali, M. A., Lestrel, P. E., & Ohtsuki, F. (2000). Secular trends for takeoff and maximum adolescent growth for eight decades of Japanese cohort data. *American Journal of Human Biology: The Official Journal of the Human Biology Association, 12*(5), 702-712.

Ali, M. A., Lestrel, P. E., & Ohtsuki, F. (2001). Adolescent growth events in eight decades of Japanese cohort data: sex differences. *American Journal of Human Biology: The Official Journal of the Human Biology Association, 13*(3), 390-397.

Artiningrum, N. T., Suryobroto, B., & Widiyani, T. (2014). Physical Growth of Sasak Children at Different Altitudes in Lombok Island. *Hayati Journal of Biosciences, 21*(3), 101-110.

Datta Banik, S., Salehabadi, S. M., & Dickinson, F. (2017). Preece-Baines Model 1 to Estimate Height and Knee Height Growth in Boys and Girls From Merida, Mexico. *Food and Nutrition Bulletin, 38*(2), 182-195.

Beall, C. M. (2003). High-altitude adaptations. *The lancet, 362*, s14-s15.

Beall, C. M., Baker, P. T., Baker, T. S., & Haas, J. D. (1977). The effects of high altitude on adolescent growth in southern Peruvian Amerindians. *Human biology*, 109-124.

Billewicz, W., & McGregor, I. (1982). A birth-to-maturity longitudinal study of heights and weights in two West African (Gambian) villages, 1951–1975. *Annals of human biology, 9*(4), 309-320.

Bogin, B., Wall, M., & Macvean, R. B. (1990). Longitudinal growth of high socioeconomic status Guatemalan children analyzed by the Preece-Baines function: An international comparison. *American Journal of Human Biology, 2*(3), 271-281.

Bogin, B., Wall, M., & MacVean, R. B. (1992). Longitudinal analysis of adolescent growth of Ladino and Mayan school children in Guatemala: effects of environment and sex. *American journal of physical Anthropology, 89*(4), 447-457.

Bustamante, A., Beunen, G., & Maia, J. (2011). Como crecen y se desarrollan los niños y adolescentes en La Merced y San Ramón. *Alcances para la Educación Física, el Deporte y la Salud. Lima: Universidad Nacional de Educación*, 174.

Byard, P., Guo, S., & Roche, A. (1993). Family resemblance for Preece-Baines growth curve parameters in the Fels Longitudinal Growth Study. *American Journal of Human Biology, 5*(2), 151-157.

Clegg, E. J., Pawson, I., Ashton, E., & Flinn, R. (1972). The growth of children at different altitudes in Ethiopia. *Phil. Trans. R. Soc. Lond. B, 264*(864), 403-437.

Cossio-Bolaños, M., Campos, R., Andruske, C., Flores, A., Luarte-Rocha, C., Olivares, P., . . . de Arruda, M. (2015). Physical growth, biological age, and nutritional transitions of adolescents living at moderate altitudes in Peru. *International journal of environmental research and public health, 12*(10), 12082-12094.

Cossio-Bolaños, M., de Arruda, M., Núñez Álvarez, V., & Lancho Alonso, J. (2011). Efectos de la altitud sobre el crecimiento físico en niños y adolescentes. *Revista Andaluza de Medicina del Deporte, 4*(2).

Crespo, I., Valera, J., Gonzales, G., & Guerra García, R. (1995). Crecimiento y desarrollo de niños y adolescentes a diversas alturas sobre el nivel del mar. *Acta andin, 4*(1), 53-64.

Eveleth, P., & Tanner, J. (1990). *Worldwide Variation in Human Growth* (2nd ed.). Cambridge: Cambridge University Press.

Frisancho, A. R. (1978). Human growth and development among high-altitude populations. *The biology of high altitude peoples*, 117-171.

Frisancho, A. R., & Baker, P. T. (1970). Altitude and growth: a study of the patterns of physical growth of a high altitude Peruvian Quechua population. *American journal of physical Anthropology, 32*(2), 279-292.

Gasser, T., Gervini, D., & Molinari, L. (2004). Kernel estimation, shape-invariant modelling and structural analysis. *Cambridge Studies in Biological and Evolutionary Anthropology*, 179-204.

Gasser, T., Kneip, A., Binding, A., Prader, A., & Molinari, L. (1991). The dynamics of linear growth in distance, velocity and acceleration. *Annals of human biology, 18*(3), 187-205.

Gasser, T., Sheehy, A., Molinari, L., & Largo, R. H. (2000). Sex dimorphism in growth. *Annals of human biology, 27*(2), 187-197.

Gerver, W., & De Bruin, R. (2003). Growth velocity: a presentation of reference values in Dutch children. *Hormone Research in Paediatrics, 60*(4), 181-184.

Howe, L. D., Tilling, K., Galobardes, B., Smith, G. D., Gunnell, D., & Lawlor, D. A. (2010). Socioeconomic differences in childhood growth trajectories: at what age do height inequalities emerge? *Journal of Epidemiology & Community Health*, jech. 2010.113068.

INEI. (2017). Perfil Sociodemográfico del Perú. Informe nacional. Retrieved from https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1539/index.html

Karlberg, J. (2002). Secular trends in pubertal development. *Hormone Research in Paediatrics, 57*(Suppl. 2), 19-30.

Lee, T.-S., Chao, T., Tang, R.-B., Hsieh, C.-C., Chen, S.-J., & Ho, L.-T. (2004). A longitudinal study of growth patterns in school children in Taipei area I: growth curve and height velocity curve. *Journal-Chinese Medical Association, 67*(2), 67-72.

Liu, Y., Wikland, K. A., & Karlberg, J. (2000). New reference for the age at childhood onset of growth and secular trend in the timing of puberty in Swedish. *Acta paediatrica, 89*(6), 637-643.

Lohman, T., Roche, A., & Martorell, R. (1988). Anthropometric standarization reference manual. *Champaign, IL: Human Kinetics Books*.

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation and physical activity*.

Mao, S. H., Li, H. B., Jiang, J., Sun, X., Cheng, J. C., & Qiu, Y. (2011). An updated analysis of pubertal linear growth characteristics and age at menarche in ethnic Chinese. *American Journal of Human Biology, 23*(1), 132-137.

Marceau, K., Ram, N., Houts, R. M., Grimm, K. J., & Susman, E. J. (2011). Individual differences in boys' and girls' timing and tempo of puberty: Modeling development with nonlinear growth models. *Developmental psychology, 47*(5), 1389.

McCrory, C., O’leary, N., Fraga, S., Ribeiro, A. I., Barros, H., Kartiosuo, N., . . . Layte, R. (2017). Socioeconomic differences in children’s growth trajectories from infancy to early adulthood: evidence from four European countries. *J Epidemiol Community Health, 71*(10), 981-989.

Moore, L. G. (2001). Human genetic adaptation to high altitude. *High altitude medicine & biology, 2*(2), 257-279.

Pawson, I. G., & Huicho, L. (2010). Persistence of growth stunting in a Peruvian high altitude community, 1964–1999. *American Journal of Human Biology, 22*(3), 367-374.

Prader, A., Largo, R. H., Molinari, L., & Issler, C. (1989). Physical growth of Swiss children from birth to 20 years of age. First Zurich longitudinal study of growth and development. *Helvetica paediatrica acta. Supplementum, 52*, 1-125.

Preece, M., & Baines, M. (1978). A new family of mathematical models describing the human growth curve. *Annals of human biology, 5*(1), 1-24.

Rosique, J., & Rebato, E. (1995). Comparative study of statural growth in Spanish populations. *American Journal of Human Biology, 7*(5), 553-564.

Salehabadi, S. M., & Sengupta, D. (2013). A new technique for estimating population distribution of growth curve parameters with longitudinal and cross-sectional data. In *Advances in Growth Curve Models* (pp. 171-183): Springer.

Schell, L. M., Gallo, M. V., & Ravenscroft, J. (2009). Environmental influences on human growth and development: historical review and case study of contemporary influences. *Annals of human biology, 36*(5), 459-477.

Silva, L. M., van Rossem, L., Jansen, P. W., Hokken-Koelega, A. C., Moll, H. A., Hofman, A., . . . Raat, H. (2012). Children of low socioeconomic status show accelerated linear growth in early childhood; results from the Generation R Study. *PloS one, 7*(5), e37356.

Silventoinen, K. (2003). Determinants of variation in adult body height. *Journal of biosocial science, 35*(2), 263-285.

Tanner, J. M. (1985). Use and abuse of growth standards. *Human growth, 3*, 95-109.

Tanner, J. M. (1987). Growth as a mirror of the condition of society: secular trends and class distinctions. *Pediatrics International, 29*(1), 96-103.

Ulijaszek, S. J. (2006). The international growth standard for children and adolescents project: environmental influences on preadolescent and adolescent growth in weight and height. *Food and Nutrition Bulletin, 27*(4_suppl5), S279-S294.

Virani, N. (2005). Growth patterns and secular trends over four decades in the dynamics of height growth of Indian boys and girls in Sri Aurobindo Ashram: a cohort study. *Annals of human biology, 32*(3), 259-282.

Yip, R., Binkin, N. J., & Trowbridge, F. L. (1988). Altitude and childhood growth. *The Journal of pediatrics, 113*(3), 486-489.

Paper II

Stunting and Physical Fitness. The Peruvian Health and Optimist Growth Study

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ABSTRACT

Stunting, defined as linear growth retardation, is a serious public health problem in developing countries. We aimed to (1) describe the prevalence of stunting in Peruvian youth living in three geographical regions, and to (2) determine height and physical fitness (PF) differences between stunted and normal-growth children across age and sex. We sampled 7918 subjects (7074 normal-growth and 844 stunted), aged 6–15 year, from sea-level, Amazon and high-altitude regions of Peru. PF was assessed with standardized tests, and stunting was computed following World Health Organization (WHO) standards. A two-factor analysis of variance (ANOVA) model was used. Results showed that stunting prevalence increased with age (from 6% at 6 year to 18.4% at 15 year in girls, and 9.3% at 6 year to 16.4% at 15 year in boys); was higher in boys (12.3%) than in girls (9.3%), and was higher in the Amazon region (25.3%), followed by high-altitude (24.3%) and sea-level (8.1%). Stunting had a negative overall impact on girls' and boys' statures. Further, the age-by-stunting interactions were statistically significant for both sexes, and significant differences in height varied to some degree across age. Stunted children performed worse in handgrip and standing long jump, but outperformed their normal-growth peers in shuttle-run (only boys), and in 12 min run. Further, significant differences in the age-by-stunting interaction occurred in all PF tests, varying to some degree across age. In conclusion, stunting significantly affects Peruvian youth's PF levels, and this influence is sex-, age- and PF test-specific.

Keywords: children and adolescents; growth; stunting; physical fitness

INTRODUCTION

Stunting, i.e., impaired growth and development mostly resulting from poor nutrition, is a serious public health problem during childhood and adolescence in both low and middle income countries [1]. Across the lifespan, stunting has been associated with increased risk of morbidity and mortality, as well as increased risk of obesity [2]. It also expresses itself in physical, cognitive and motor development delays, with multiple consequences in adulthood [2]. Consequently, stunting tends to lead to lower economic productivity and constrained social functioning, being a direct impediment to achieving sustainable developmental goals, such as achieving gender equality, as well as reducing inequality within and between countries [3].

A secular trend investigation [4] using available data from 1990 to 2015 showed that stunting affects 171 million children worldwide, and that most of those affected live in developing countries. Further, it was also reported that childhood stunting decreased from 39% in 1990 to 24.1% in 2015, and that different patterns occur in developing and developed countries. For example, in developed countries, stunting has been stable at 6% since 1990 and is expected to remain at this level, whereas in developing countries a decrease from 44.4% in 1990 to 26.2% in 2015 was found, and it is also expected to decrease further to 23.7% by 2020. Although in Latin America the stunting prevalence (11.6%, or 6 million in 2015) is lower than in Africa (37.6%) and Asia (22.9%) [4], it is considered a very serious health problem, and Peru is no exception. For example, Urke et al. [5], using data from Peruvian Demographic and Health Surveys, revealed that in 2011, the prevalence of stunting increased with increasing age in both sexes: from 20.5% at ages 6–11 year to 25.4% at ages 12–23 year in boys, and from 14% at ages 6–11 year to 21.1% at ages 12–23 year in girls; additionally, the prevalence was somewhat higher in boys (19.8%) than in girls (18.8%). Importantly, there are geographic differences in stunting in Peru: children living on the coast (8.3% of boys and 6.8% of girls) are less stunted than those from the Andean (29.7% of boys and 29.6% of girls) and Amazon (26.5% of boys and 23.5% of girls) regions [5]. Disparities in Peruvian life conditions, characterized by economic, educational, nutritional, and health resources inequalities, still exist today, and may help explain these differences in stunting prevalence. It has been consistently reported that stunting adversely affects health markers, like loss of physical growth potential, reduced neural development and cognitive function, as well as an elevated risk of chronic disease in adulthood [2,6]. However, very few studies have investigated the impact of stunting on physical fitness (PF) among children and adolescents. Further, although it is well acknowledged that PF is an important health marker [7], this information is not available for Peruvian youth. It has also been shown that adequate PF levels during childhood and adolescence are linked to a higher cognitive development [8], academic performance [9], and a healthier cardiovascular profile during adulthood [10]. Moreover, in developing countries like Mozambique [11], Senegal [12], México [13] and Colombia [14], stunted children tend to have worse performance levels in a variety of PF tasks. This influence is apparently sex-, age- and PF test-specific. For example, Malina, Pena Reyes, Tan and Little [13] showed that stunted Mexican youth of both sexes, aged 6 to 13 year, significantly differ from their normal-growth peers in both handgrip strength and standing long jump, whereas Arsenault, Mora-Plazas, Forero, Lopez-Arana, Jáuregui, Baylin, Gordon and Villamor [14] reported that stunted Colombians, aged 5 to 12 year, scored significantly lower in the shuttle-run test in both sexes, but in the standing long jump test this relationship was only significant in boys. Similar results were described in Mozambican [15], Macedonian [16] and South African [17] children and adolescents. Bearing in mind James Tanner´s maxim that “growth is a mirror of the society” [18], we believe that the identification of Peruvian children’s impaired growth is of utmost importance in educational and public health terms. Further, as far as we know, no studies have scrutinized how Peruvians’ PF levels, as suitable health markers, depend on their stunting condition. Hence, we intend to answer the following questions: (1) What is the prevalence of stunting in Peruvian youth residing in distinct geographical areas? (2) Are there systematic differences in height and PF levels between stunted and normal-growth youth? (3) Is the impact of stunting in physical fitness levels consistent across age? (4) Is this difference sex-, age- and physical fitness test-specific?

MATERIALS AND METHODS

Design and participants

The sample of this study is part of a larger project titled *“The Peruvian Health and Optimist Growth Study”* [19], carried out between 2009 and 2010, and in which participants were randomly sampled from schools in three geographical areas in the central region of Peru: sea-level (Barranco – 58 m), Amazon region (La Merced and San Ramon – 751 m), and high-altitude (Junín – 4107 m). We sampled 7918 children and adolescents (4388 girls, aged 6–15 year), with complete data on PF tests. The percentage of missing data varied from 4% to 10% in PF tests, and did not significantly differ ($p> 0.05$) from those considered in the present paper. The sample only included children and adolescents with complete data on all variables, and who also were natives to their respective regions (i.e., no immigrants were identified). Information about the participant’s birth place and current place of residence or address was collected and cross-checked with their identity cards. All assessments were carried out in Barranco between November and December (2009); in April and July (2010) in La Merced and between May and August in San Ramon; and between September and October of 2009 in Junín. Formal permissions from school governmental bodies and written informed consent from parents/legal guardians were obtained. The project was approved by the Ethics Committee of the National University of Education Enrique Guzmán y Valle (UNE EGyV).

Measurements and Tests

Anthropometry

Height (cm) and sitting height (cm) were measured to the nearest 0.1 cm according to standardized procedures [20], using a portable stadiometer (Personal Caprice Sanny®, Model ES-2060, São Bernardo do Campo, SP, Brazil) holding the child´s head in the Frankfurt plane. Body weight was measured to the nearest 0.1 kg with a digital scale (Pesacon, Model IP68).

Biological Maturation

Biological maturation was assessed with the maturity offset [21], which estimates time before or after age-at-peak height velocity (APHV). A sex-specific formula based on age, sex, height, sitting height, and weight was used. A positive (+) maturity offset represents the number of estimated years a child is beyond APHV; a negative (–) value represents the number of estimated years a child is before APHV, whereas a zero value indicates that a child is experiencing his/her APHV.

Physical Fitness

PF was assessed with a variety of measures. Handgrip strength (kg^f – marker of static strength) was measured using a hand dynamometer (Takei Hand Grip Dynamometer®, Takei Scientific Instruments Co., Ltd, Nigata, Japan) – all participants gripped the dynamometer with maximum force for 5 to 10 s. Standing long jump (centimeters – marker of lower body explosive strength) was assessed via a maximum jump distance recorded from two trials. A shuttle-run (seconds – marker of agility) was performed where children completed five cycles (round-trip) at maximum speed between two lines separated by five meters. A 12 min run (meters – marker of aerobic fitness) was performed in a previously delimited field where schoolchildren ran/walked the maximum possible distance in 12 min. The first three tests were from EUROFIT [22], and the 12 min run from The American Alliance for Health, Physical Education and Recreation (AAHPERD) [23].

Stunting

Stunting was computed using references for children and adolescents 5 to 19 year of age as advocated by Onis et al. [24]. Thus, subjects were classified as stunted (height-for-age Z score < −2 Standard Deviation (SD) using age- and sex-specific reference heights according to the WHO standards [25], according to the STATA software syntax provided by the WHO [26].

Data Quality Control

Data quality control was assured by a series of steps. Firstly, all team members were trained on the technical procedures of body measurements, and the PF tests and assessment protocols were strictly followed by all team members and supervised by the principal investigator. Secondly, a pilot study was conducted to assess the quality of data collection. Thirdly, a random sample was retested.

Statistical Procedures

Basic descriptive statistics [means, standard deviations (SD), and percentages (%)] were computed. Normality checks for the distributions of height and PF were examined using the D'Agostino et al. [27] test implemented in STATA software, and no violations were encountered. A two-factor ANOVA model, adjusted for geographical location, was used to test for height and PF differences across age and stunting condition (main effects), as well as an interaction of age-by-stunting within each sex, and the partial eta squared (η^2) was used as a measure of effect size. Further, differences between conditions (stunted versus non-stunted) for each age group within each sex were tested with the margins procedure implemented in STATA v14 software, which was also the software used in all analysis. The significance level was set at 5%.

RESULTS

Table 1 provides descriptive information about the prevalence of stunting by age, sex and geographical area of residence. In the total sample, the prevalence of stunting was 11%. The prevalence seems to increase with increasing age in both sexes, from 6% at 6 year to 18.4% at 15 year in girls, and from 9.3% at 6 year to 16.4% at 15 year in boys. Further, it is higher in boys (12.3%) than in girls (9.3%), and was higher among children and adolescents living in the Amazon region (13.0%), followed by high-altitude (12.0%) and sea-level (4.0%).

Table 1. Sample size and prevalence of stunting (%) by age, sex and geographical area of residence.

	Age(y)†	**Sea-Level** (Barranco)		**Amazon region** (La Merced and San Ramon)		**High-Altitude** (Junín)		**All Areas**	
		Normal	Stunted (%)	Normal	Stunted (%)	Normal	Stunted (%)	Normal	Stunted (%)
Girls	6	102	2 (1.8)	159	18 (10.2)	50	0 (0.0)	311	20 (6.0)
	7	74	0 (0.0)	155	5 (3.1)	78	4 (4.9)	307	9 (2.8)
	8	82	5 (5.7)	224	14 (5.9)	70	0 (0.0)	376	19 (4.8)
	9	121	5 (4.0)	201	15 (6.9)	85	7 (7.6)	407	27 (6.2)
	10	95	4 (4.0)	244	44 (15.3)	85	9 (9.6)	424	57 (11.9)
	11	141	2 (1.4)	214	28 (11.6)	97	15 (13.4)	452	45 (9.1)
	12	115	0 (0.0)	280	40 (12.5)	171	20 (10.5)	566	60 (9.6)
	13	88	1 (1.1)	268	23 (7.9)	91	21 (18.8)	447	45 (9.1)
	14	138	11 (7.4)	210	39 (15.7)	122	29 (19.2)	470	79 (14.4)
	15	78	13 (14.3)	69	24 (25.8)	71	12 (14.5)	218	49 (18.4)
	Total	1034	43 (4.0)	2024	250 (11.0)	920	117 (11.3)	3978	410 (9.3)
		Normal	Stunted (%)	Normal	Stunted (%)	Normal	Stunted (%)	Normal	Stunted (%)
Boys	6	44	0 (0.0)	133	21 (13.6)	57	3 (5.0)	234	24 (9.3)
	7	28	0 (0.0)	218	23 (9.5)	59	1 (1.7)	305	24 (7.3)
	8	36	0 (0.0)	182	37 (16.9)	80	4 (4.8)	298	41 (12.1)
	9	42	1 (2.3)	231	16 (6.5)	105	5 (4.5)	378	22 (5.5)
	10	39	3 (7.1)	217	30 (12.1)	96	9 (8.6)	352	42 (10.7)
	11	78	4 (4.9)	219	30 (12.0)	69	11 (13.8)	366	45 (10.9)
	12	99	3 (2.9)	156	36 (18.8)	120	9 (7.0)	375	48 (11.3)
	13	32	0 (0.0)	138	39 (22.0)	103	33 (24.3)	273	72 (20.9)
	14	71	2 (2.7)	128	34 (21.0)	107	39 (26.7)	306	75 (19.7)
	15	75	10 (11.8)	78	18 (18.8)	56	13 (18.8)	209	41 (16.4)
	Total	544	23 (4.1)	1700	284 (14.3)	852	127 (13.0)	3096	434 (12.3)

Note: †Age was used as decimals of a year, and children aged 5.5 to 6.49 y were designated as 6, children aged 6.50 to 7.49 y as 7, and so on [28].

Table 2 and Figure 1 show the two-factor ANOVA model results for differences in height between stunted and normal-growth children in both sexes, respectively. Stunting means are statistically significant with negative overall impacts in girls´ [F(1, 4366) = 1277.20, $p < 0.01$, $\eta^2 = 0.23$], as well as in boys´ [F(1, 3508) = 1716.15, $p < 0.01$, $\eta^2 = 0.33$] statures. The age-by-stunting interactions proved to be statistically significant for girls [F(9, 4366) = 4.50, $p < 0.01$, $\eta^2 = 0.01$] and boys [F(9, 3508) = 3.03, $p < 0.01$, $\eta^2 = 0.01$]. Marked significant differences in height varied to some degree across the ages, starting at 6 y through 15 y [in girls, the lowest difference was found at 15 y (9.1 cm), and the highest at 11 y (14.0 cm); in boys, the lowest difference was found at 7 y (10.0 cm), and the highest at 13 y (14.5 cm)].

Table 2. Mean differences (Mean ± SD, F tests and Dif) and two-factor analysis of variance (ANOVA) model results for height between stunted and normal-growth children of both sexes.

	Height (cm)							
	Girls				**Boys**			
Age (y)	Normal	Stunted	F	Dif	Normal	Stunted	F	Dif
6	113.3 ± 0.3	101.6 ± 1.1	101.23	11.7 *	114.0 ± 0.3	103.4 ± 1.1	91.09	10.6 *
7	118.4 ± 0.3	108.9 ± 1.7	31.66	9.5 *	119.5 ± 0.3	109.5 ± 1.1	81.73	10.0 *
8	124.5 ± 0.3	112.6 ± 1.2	101.18	11.9 *	124.1 ± 0.3	113.0 ± 0.8	164.11	11.1 *
9	130.0 ± 0.2	118.4 ± 1.0	134.30	11.6 *	129.1 ± 0.3	117.1 ± 1.1	111.63	12.0 *
10	136.4 ± 0.2	123.9 ± 0.7	309.88	12.5 *	133.2 ± 0.3	122.7 ± 0.8	154.13	10.5 *
11	142.7 ± 0.2	128.7 ± 0.7	313.31	14.0 *	139.2 ± 0.3	126.9 ± 0.8	222.67	12.3 *
12	147.0 ± 0.2	134.1 ± 0.7	356.82	12.9 *	145.2 ± 0.3	132.1 ± 0.7	270.17	13.1 *
13	150.7 ± 0.2	140.9 ± 0.8	156.24	9.8 *	152.1 ± 0.3	137.6 ± 0.6	448.21	14.5 *
14	152.2 ± 0.2	142.7 ± 0.6	240.42	9.5 *	158.0 ± 0.3	144.7 ± 0.6	392.70	13.3 *
15	153.9 ± 0.3	144.8 ± 0.7	132.72	9.1 *	161.0 ± 0.4	148.8 ± 0.8	188.80	12.2 *
Two-Factor ANOVA Model Results								
Age	F(9, 4366) = 894.06, $p < 0.01$, $\eta^2 = 0.65$				F(9, 3508) = 1206.54, $p < 0.01$, $\eta^2 = 0.76$			
Stunted	F(1, 4366) = 1277.20, $p < 0.01$, $\eta^2 = 0.23$				F(9, 3508) = 1206.54, $p < 0.01$, $\eta^2 = 0.76$			
Age by Stunted	F (9, 4366) = 4.50, $p < 0.01$, $\eta^2 = 0.01$				F(9, 3508) = 3.03, $p < 0.01$, $\eta^2 = 0.01$			

Note: * $p < 0.05$

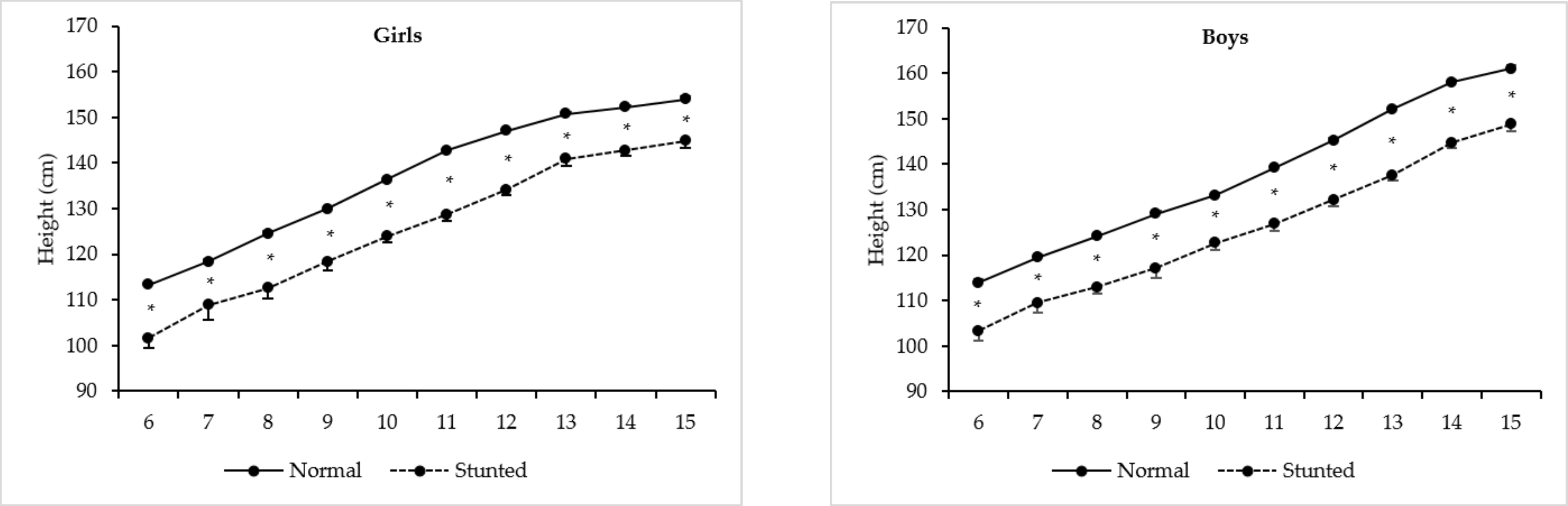

Figure 1. Mean levels for height between stunted and normal-growth Peruvian girls and boys (* marks statistically significant differences; 95% Confidence intervals)

Table 3 and Figure 2 show two-factor ANOVA model results for each PF test between stunted and normal-growth girls. With increasing age, girls were significantly stronger in handgrip [F(9, 4366) = 294.43, $p < 0.01$, $\eta^2 = 0.38$], with more explosive lower body strength [F(9, 4366) = 48.66, $p < 0.01$, $\eta^2 = 0.09$], as well as more agile [F(9, 4366) = 16.72, $p < 0.01$, $\eta^2 = 0.03$], and with higher aerobic fitness [F(9, 4366) = 14.57, $p < 0.01$, $\eta^2 = 0.03$]. Stunting is statistically significant, with negative impacts in handgrip [F(1, 4366) = 181.07, $p < 0.01$, $\eta^2 = 0.04$] and standing long jump [F(1, 4366) = 26.57, $p < 0.01$, $\eta^2 = 0.01$], but with positive impact in 12 min run test [F(1, 4366) = 11.00, $p < 0.01$, $\eta^2 = 0.003$]. Further, it was not statistically significant for shuttle-run [F(1, 4366) = 2.13, $p = 0.14$, $\eta^2 = 0.000$]. The age-by-stunting interactions proved to be statistically significant for all PF tests [handgrip: F(9, 4366) = 3.36, $p < 0.01$, $\eta^2 = 0.01$; standing long jump: F(9, 4366) = 2.99, $p < 0.01$, $\eta^2 = 0.01$; shuttle-run: F(9, 4366) = 2.48, $p < 0.01$, $\eta^2 = 0.01$; and 12 min run: F(9, 4366) = 3.56, $p < 0.01$, $\eta^2 = 0.01$]. Marked significant differences in the interaction occurred in all PF tests, though varied to some degree across the ages. In handgrip, significant differences occurred from 8 to 15 year [the lowest difference was found at 9 year (1.9 kg^f), and the highest at 12 year (4.5 kg^f)]. In standing long jump, significant differences occurred at 6, 9, 10, 11, 12 and 14 year [the lowest difference was found at 10 year (6.6 cm), and the highest at 11 year (11.2 cm)], while in 12 min run, significant differences occurred at 10 year till 12 year [the lowest difference was found at 12 year (−117.3 m), and the highest at 11 year (−230.8 m)]. Finally, in shuttle-run, significant differences in the age-by-stunting interaction only occurred at 12 year (−0.9 s).

Table 3. Mean differences (Mean ± SD, F tests and Dif) and two-factor ANOVA model results for each physical fitness test between stunted and normal-growth girls.

Age (y)	**Handgrip** (kg^f)				**Standing Long Jump** (**cm**)				**Shuttle-Run** (**s**)				**12 min run** (**m**)			
	Normal	**Stunted**	**F**	**Dif**	**Normal**	**Stunted**	**F**	**Dif**	**Normal**	**Stunted**	**F**	**Dif**	**Normal**	**Stunted**	**F**	**Dif**
6	6.6 ± 0.2	5.6 ± 0.7	2.10	1.0	85.7 ± 1.1	73.2 ± 4.3	8.10	12.5 *	27.3 ± 0.1	27.8 ± 0.5	0.85	−0.5	1087.9 ± 17.9	1161.4 ± 70.5	1.02	−73.5
7	7.8 ± 0.2	6.8 ± 1.0	0.83	1.0	93.7 ± 1.1	97.1 ± 6.3	0.27	−3.4	26.3 ± 0.1	26.8 ± 0.4	6.28	−0.5	1203.8 ± 18.0	1242.2 ± 105.0	0.13	−38.4
8	9.2 ± 0.2	6.8 ± 0.7	11.39	2.4 *	104.9 ± 1.0	99.9 ± 4.4	1.28	5.0	25.6 ± 0.1	26.0 ± 0.5	0.38	−0.4	1334.3 ± 16.3	1408.4 ± 72.3	1.00	−74.1
9	10.8 ± 0.2	8.9 ± 0.6	9.51	1.9 *	110.3 ± 0.9	98.7 ± 3.7	9.37	11.6 *	25.0 ± 0.1	24.2 ± 0.4	2.56	0.8	1332.8 ± 15.6	1299.3 ± 60.6	0.29	33.5
10	13.0 ± 0.1	10.5 ± 0.4	34.73	2.5 *	118.1 ± 0.9	111.5 ± 2.5	6.01	6.6 *	24.8 ± 0.1	24.4 ± 0.3	1.07	0.4	1449.5 ± 15.3	1585.8 ± 41.8	9.40	−136.3 *
11	15.5 ± 0.1	12.3 ± 0.5	45.40	3.2 *	121.6 ± 0.9	110.4 ± 2.8	14.09	11.2 *	24.4 ± 0.1	23.9 ± 0.3	2.40	0.5	1379.8 ± 14.8	1610.6 ± 47.0	21.91	−230.8 *
12	17.7 ± 0.1	13.2 ± 0.4	113.59	4.5 *	124.7 ± 0.8	115.5 ± 2.5	12.76	9.2 *	24.5 ± 0.1	25.4 ± 0.3	8.42	−0.9 *	1375.4 ± 13.3	1492.7 ± 40.7	7.50	−117.3 *
13	19.4 ± 0.1	15.8 ± 0.5	53.84	3.6 *	121.6 ± 0.9	125.7 ± 2.8	1.90	−4.1	24.2 ± 0.1	23.9 ± 0.3	0.49	0.3	1339.6 ± 14.9	1415.4 ± 47.0	2.36	−75.8
14	20.2 ± 0.1	17.3 ± 0.3	60.05	2.9 *	121.9 ± 0.9	111.6 ± 2.1	20.0	10.3 *	24.8 ± 0.1	24.9 ± 0.3	0.02	−0.1	1402.9 ± 14.5	1329.9 ± 35.5	3.63	73.0
15	21.3 ± 0.2	18.4 ± 0.4	36.14	2.9 *	124.0 ± 1.3	121.6 ± 2.7	0.64	2.4	24.7 ± 0.2	24.7 ± 0.3	0.02	0.0	1451.8 ± 21.4	1466.5 ± 45.0	0.09	−14.7
	Two-Factor ANOVA Model Results															
Age	F(9, 4366) = 294.43, $p < 0.01$, $\eta^2 = 0.38$				F(9, 4366) = 48.66, $p < 0.01$, $\eta^2 = 0.09$				F(= 9, 4366) = 16.72, $p < 0.01$, $\eta^2 = 0.03$				F(9, 4366) = 14.57, $p < 0.01$, $\eta^2 = 0.03$			
Stunted	F(1, 4366) = 181.07, $p < 0.01$, $\eta^2 = 0.04$				F(1, 4366) = 26.57, $p < 0.01$, $\eta^2 = 0.01$				F(1, 4366) = 2.13, $p = 0.14$, $\eta^2 = 0.000$				F(1, 4366) = 11.00, $p < 0.01$, $\eta^2 = 0.003$			
Age by Stunted	F(9, 4366) = 3.36, $p < 0.01$, $\eta^2 = 0.01$				F(9, 4366) = 2.99, $p < 0.01$, $\eta^2 = 0.01$				F(9, 4366) = 2.48, $p < 0.01$, $\eta^2 = 0.01$				F(9, 4366) = 3.56, $p < 0.01$, $\eta^2 = 0.01$			

Note: *$p < 0.05$.

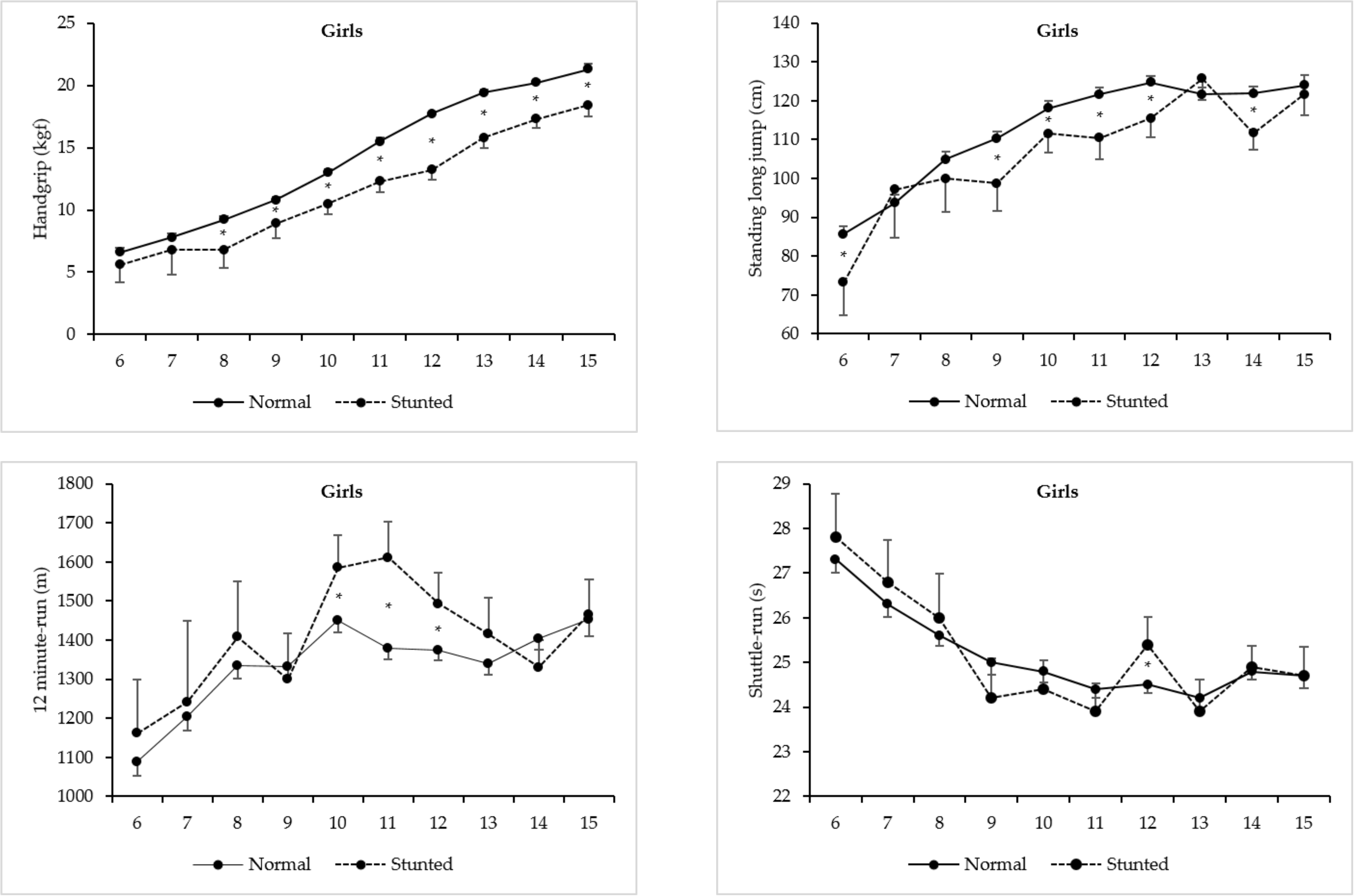

Figure 2. Mean levels for each physical fitness test between stunted and normal-growth Peruvian girls (* marks statistical significant differences; 95% Confidence intervals).

Table 4 and Figure 3 show two-factor ANOVA model results comparing PF levels between stunted and normal-growth boys. Older boys were significantly stronger in handgrip [F(9, 3508) = 571.24, $p < 0.01$, $\eta^2 = 0.59$], had more explosive lower body strength [F(9, 3508) = 109.14, $p < 0.01$, $\eta^2 = 0.22$], were more agile [F(9, 3508) = 44.24, $p < 0.01$, $\eta^2 = 0.10$], and showed higher aerobic fitness [F(9, 3508) = 40.36, $p < 0.01$, $\eta^2 = 0.09$]. Stunting is statistically significant with negative impacts in handgrip [F(1, 3508) = 351.53, $p < 0.01$, $\eta^2 = 0.09$] and standing long jump [F(1, 3508) = 37.81, $p < 0.01$, $\eta^2 = 0.01$], but with positive effects in shuttle-run [F(1, 3508) = 11.51, $p < 0.01$, $\eta^2 = 0.003$] and 12 min run test [F(1, 3508) = 10.14, $p < 0.01$, $\eta^2 = 0.003$]. The age-by-stunting interactions were statistically significant for all PF tests [handgrip: F(9, 3508) = 14.99, $p < 0.01$, $\eta^2 = 0.04$; standing long jump: F(9, 3508) = 2.10, $p < 0.01$, $\eta^2 = 0.01$; shuttle-run: F(9, 3508) = 2.43, $p < 0.01$, $\eta^2 = 0.01$; and 12 min run: F(9, 3508) = 2.43, $p < 0.01$, $\eta^2 = 0.01$]. As with girls, marked significant differences in the interaction also occurred in all PF tests, though varied to some degree across the ages. In handgrip, significant differences occurred from 9 to 15 y [the lowest difference was found at 10 y (2.5 kg^f), and the highest at 14 y (7.5 kg^f)]. In standing long jump, significant differences occurred at 7, 14 and 15 y [the lowest difference was found at 15 y (9.2 cm), and the highest at 14 y (14.7 cm)], while in shuttle-run, significant differences occurred at 6, 9, 12 and 15 year [the lowest differences was found at 12 (−0.7 s) and 15 year (−0.7 s), and the highest at 6 y (−1.5 s). Finally, in 12 min run, significant differences occurred at 7, 9, and 11 year [the lowest difference was found at 11 year (−205.4 m), and the highest at 9 year (−248.0 m).

Table 4. Mean differences (Mean ± SD, F tests and Dif) and two-factor ANOVA model results for each physical fitness test between stunted and normal-growth boys.

Age (y)	**Handgrip** (kg^f)				**Standing Long Jump** (**cm**)				**Shuttle-Run** (**s**)				**12 min run** (**m**)			
	Normal	**Stunted**	**F**	**Dif**	**Normal**	**Stunted**	**F**	**Dif**	**Normal**	**Stunted**	**F**	**Dif**	**Normal**	**Stunted**	**F**	**Dif**
6	7.5 ± 0.2	5.8 ± 0.7	5.33	1.7	94.7 ± 1.4	87.8 ± 4.2	2.47	6.9	25.3 ± 0.1	26.8 ± 0.4	10.63	−1.5 *	1120.3 ± 25.9	1101.8 ± 80.9	0.05	−18.5
7	8.5 ± 0.2	7.1 ± 0.7	3.37	1.4	105.6 ± 1.2	92.7 ± 4.2	8.67	12.9 *	24.9 ± 0.1	25.4 ± 0.4	1.05	−0.5	1295.5 ± 22.8	1503.0 ± 81.0	6.10	−207.7 *
8	10.1 ± 0.2	8.5 ± 0.6	7.32	1.6	112.5 ± 1.2	111.2 ± 3.2	0.13	1.3	24.2 ± 0.1	24.2 ± 0.3	0.00	0.0	1363.0 ± 22.9	1355.6 ± 62.0	0.01	7.4
9	12.1 ± 0.2	8.9 ± 0.8	17.12	3.2 *	116.4 ± 1.1	111.0 ± 4.4	1.40	5.4	23.5 ± 0.1	24.4 ± 0.5	3.45	−0.9 *	1418.7 ± 20.4	1666.7 ± 84.4	8.16	−248.0 *
10	13.6 ± 0.2	11.1 ± 0.6	18.57	2.5 *	123.6 ± 1.1	119.2 ± 3.2	1.73	4.4	23.1 ± 0.1	23.0 ± 0.3	0.02	0.1	1624.8 ± 21.1	1635.7 ± 61.1	0.03	−10.9
11	15.7 ± 0.2	13.0 ± 0.5	23.15	2.7 *	130.4 ± 1.1	124.1 ± 3.1	3.74	6.3	22.8 ± 0.1	22.3 ± 0.3	4.81	0.5	1658.1 ± 20.7	1863.5 ± 59.0	10.77	−205.4 *
12	18.8 ± 0.2	14.1 ± 0.5	71.80	4.7 *	131.9 ± 1.1	126.1 ± 3.0	3.37	5.8	22.8 ± 0.1	23.5 ± 0.3	3.81	−0.7 *	1641.0 ± 20.6	1731.9 ± 57.2	2.23	−90.9
13	23.2 ± 0.2	16.9 ± 0.4	176.27	6.3 *	137.9 ± 1.3	134.2 ± 2.4	1.83	3.7	22.4 ± 0.1	22.6 ± 0.3	0.64	−0.2	1623.2 ± 24.0	1667.4 ± 46.8	0.71	−44.2
14	28.4 ± 0.2	20.9 ± 0.4	262.57	7.5 *	151.8 ± 1.2	137.1 ± 2.4	30.20	14.7 *	22.0 ± 0.1	22.4 ± 0.2	2.87	−0.4	1793.6 ± 22.7	1756.7 ± 45.9	0.52	36.9
15	31.4 ± 0.3	25.8 ± 0.6	84.11	5.6 *	159.5 ± 1.4	150.3 ± 3.2	6.87	9.2 *	21.6 ± 0.2	22.3 ± 0.3	3.08	−0.7 *	1924.5 ± 27.6	1881.6 ± 61.9	0.40	42.9
Two-Factor ANOVA Model Results																
Age	F(9, 3508) = 571.24, $p < 0.01$, $\eta^2 = 0.59$				F(9, 3508) = 109.14, $p < 0.01$, $\eta^2 = 0.22$				F(9, 3508) = 44.24, $p < 0.01$, $\eta^2 = 0.10$				F(9, 3508) = 40.36, $p < 0.01$, $\eta^2 = 0.09$			
Stunted	F(1, 3508) = 351.53, $p < 0.01$, $\eta^2 = 0.09$				F(1, 3508) = 37.81, $p < 0.01$, $\eta^2 = 0.01$				F(1, 3508) = 11.51, $p < 0.01$, $\eta^2 = 0.003$				F(1, 3508) = 10.14, $p < 0.01$, $\eta^2 = 0.003$			
Age by stunted	F(9, 3508) = 14.99, $p < 0.01$, $\eta^2 = 0.04$				F(9, 3508) = 2.10, $p < 0.01$, $\eta^2 = 0.01$				F(9, 3508) = 2.43, $p < 0.01$, η2 = 0.01				F(9, 3508) = 2.43, $p < 0.01$, $\eta^2 = 0.01$			

Note: *$p < 0.05$

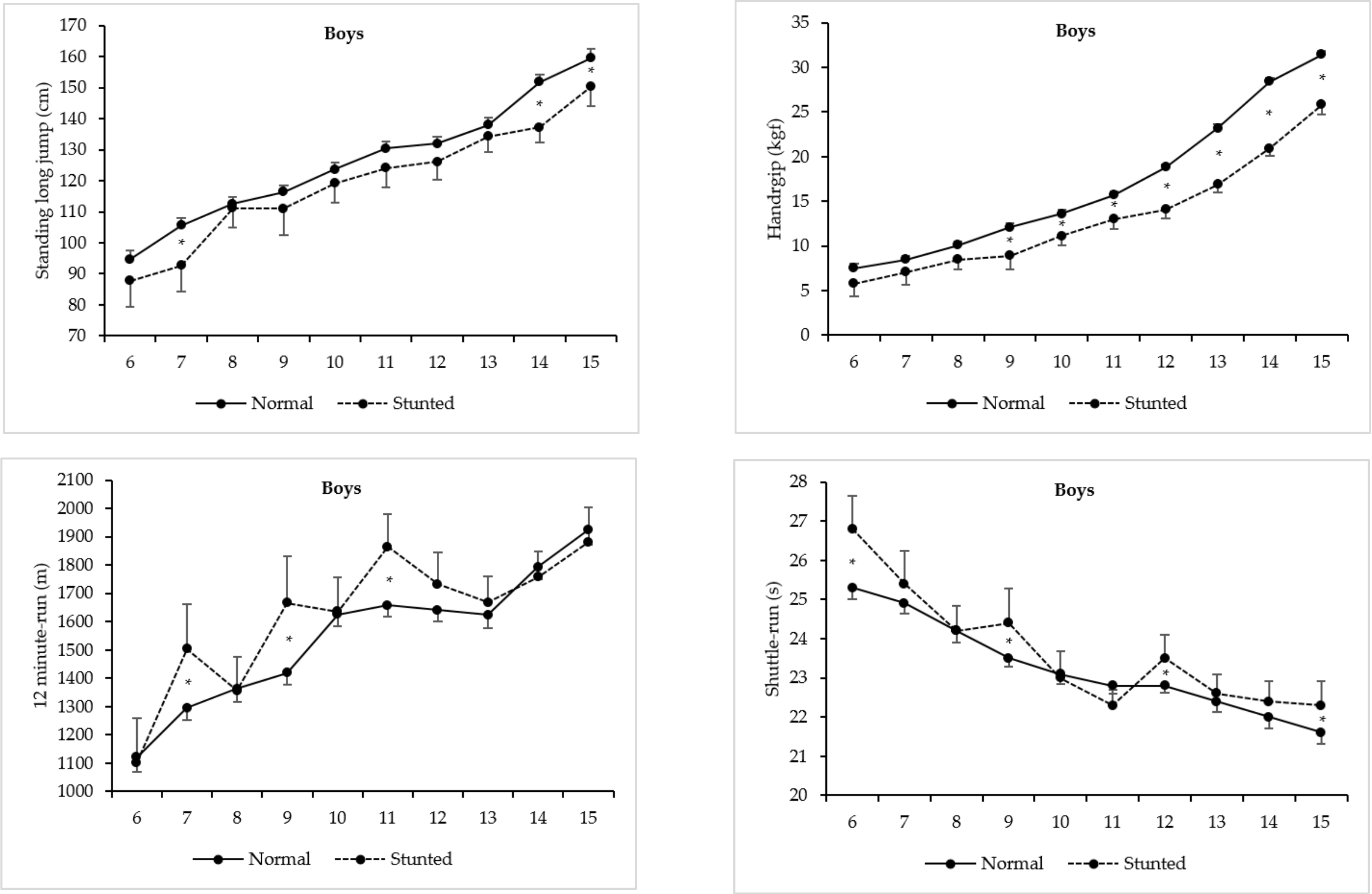

Figure 3. Mean levels for each physical fitness test between stunted and normal-growth Peruvian boys (* marks statistical significant differences; 95% Confidence intervals)

DISCUSSION

We found a stunting prevalence of 11% in Peruvian children and adolescents aged 6 to 15 year, with significant increases with increasing age in both sexes, as well as a higher prevalence in boys than in girls. Similar trends were also reported by Urke, Mittelmark and Valdivia [5] in 2011, in a study conducted on Peruvian youth, where stunting intensifies with age in both sexes, from 20.5% at age range of 6 –11 years to 25.4% at 12–23 years in boys, and from 14% at 6–11 y to 21.1% at 12–23 year in girls; and boys (19.8%) were also more stunted than girls (18.8%). It is possible that the presence of sex-differences in these cases of prevalence may be related to cultural dissimilarities existing in the distribution of, and access to, nutritional and health resources. For example, in sub-Saharan Africa, Wamani et al. [29] stated that male children under five years of age were more likely to become stunted because they are more vulnerable to health inequalities than their female peers. Further, it has also been reported that in societies where boys are favored over girls, the reverse effect is often found, reflecting a higher female vulnerability [30]. Of significance is that in Peru, stunting decreased across time, since later-born children also presented lower prevalence. This might suggest an improvement in Peruvian children's quality of life across time (namely, better feeding practices, enhanced household sanitation practices, maternal nutrition, etc.) [31,32].

We also observed geographic variations in stunting prevalence favoring those living at sea-level, followed by high-altitude and Amazon region peers. Urke, Mittelmark and Valdivia [5] also described lower stunting rates among Peruvian children living at the coast (8.3% of boys and 6.8% of girls) than those from the Andean (29.7% of boys and 29.6% of girls) and Amazon (26.5% of boys and 23.5% of girls) regions. These geographical differences may be explained by higher poverty observed at moderate and high altitudes, where the market penetration is less common, and the main livelihoods are predominantly stockbreeding and non-diversified agriculture, reflecting a poor quality of the families' diet, with a restricted nutritional intake, which, consequently, affects children and adolescent's health and growth status [33,34]. The stunting phenomenon may be related to environmental stressors, since children living at high-altitude have to deal with hypoxic stress, as well as an adverse mountain climate, which could considerably affect their linear growth patterns [35–37]. Although the present study was carried out about 10 years ago, socio-geographical differences have remained among the three areas, in terms of economic, educational, nutritional and health resource inequalities. Recent data by the World Bank in Peru [38] showed that the country had a sustained economic growth between 2002 and 2013, with an average gross domestic product (GDP) growth rate of 6.1% per year, generating a high-growth and low-inflation scenario. However, sustained macroeconomic growth at this stage was not reflected in the microeconomics of most Peruvian families. The expansion of the economy slowed to an average of 3.1% per year between 2014 and 2019, mainly due to changes in international commodity prices, with a temporary fall in private investment, lower tax revenues and a slowdown in consumption. Thus, as our sample corresponds to 76.7% of public schoolchildren, this indicates that in most Peruvian families, no substantial and systematic changes in socioeconomic conditions occurred in the last decade.

As expected, with increasing age, Peruvian children and adolescents become significantly taller, but stunting has a negative overall effect on their statures. This is completely expected, as the definition of stunting is a low height-for-age. We found that children from both sexes and all ages experienced stunting. That said, the highest differences occurred between 9 and 12 year in girls and between 12 and 14 y in boys. This timing apparently coincides with the growth spurt in height, which may help explain the highest differences in stature in this specific age group. We have recently reported [31] that peak height velocity occurred approximately at 9.68 y of age in Peruvian girls, and approximately two years later in boys (~12.61 year) living at different altitudes (sea-level, Amazon region and high-altitude). A similar trend was also described by Cossio-Bolanos, Campos, Andruske, Flores, Luarte-Rocha, Olivares, Garcia-Rubio and de Arruda [34], where Peruvian girls living at moderate altitude (~2.328 m) experienced their peak high velocity (PHV) at 12.7 year and boys at 15.2 year, which coincides with the moment of greatest delay in their linear growth (from 12 to 14 year in girls, and from 15 to 17 year in boys). It is possible that different sample sizes, different regions considered, as well as the mathematical model used, may be responsible for the differences in Peruvian boys and girls mean ages at PHV in these both studies.

Another important finding was that stunting significantly affected PF levels, and this influence was sex-, age- and PF test-specific. In handgrip, normal-growth girls and boys outperformed their stunted peers, and significant differences occurred from childhood to adolescence. These results emphasize the consequences of reduced body size and muscle mass associated with stunting early in life. Stunted children were, on average, “deficient” in muscle tissue needed to generate force [13]. In turn, normal-growth children also seemed to be favored in standing long jump, with significant differences between sexes across age. Since this test requires children to rapidly change their center of mass and reach a maximum jumping distance, it is expected that those with shorter lower extremities are usually less capable to do so effectively, and the net result is their lower performance. Although reduced body size and muscle mass also influence jumping performance, stunted children are also expected to mature later, and in all likelihood, this affects their jumping patterns. Fundamental movement skills (running, kicking, throwing, hopping, skipping, etc.) are generally mature by about 6–8 year in normal-growth children, but in the standing long jump, the mature form is reached by 9–10 year [39]. Thus, later maturation, and perhaps motor coordination developmental delay linked to early growth “retardation”, may be additional factors explaining the poorer jumping performances of stunted Peruvians when compared with their normal-growth peers. These results were corroborated by Malina, Pena Reyes, Tan and Little [13], showing that stunted Mexican youth of both sexes, aged 6 to 13 year, significantly differ from their normal-growth peers in both handgrip strength and standing long jump, whereas Arsenault, Mora-Plazas, Forero, Lopez-Arana, Jáuregui, Baylin, Gordon and Villamor [14] reported that stunted Colombians aged 5 to 12 year scored significantly lower in the standing long jump, even though this relationship was only statistically significant in boys.

Our results also revealed that stunted boys and girls have an apparent mechanical advantage in PF tasks involving greater energy expenditure, spending less time to complete the shuttle-run test, as well as covering a greater distance in running/walking the 12 min test. One possible explanation may be linked to the fact that a greater body size also means a greater body weight, and consequently greater fat mass (mainly in girls), which may negatively affect children’s motor performance. This has been shown to be true in tasks that require agility, with rapid changes of direction [40], as well as tasks that require more cardiorespiratory capacity [40]. However, we found that significant differences only occurred within specific ages in shuttle-run (only at 12 year in girls and at 6, 9, 12 and 15 year in boys), and in 12 min run test (starting at 10 y till 12 year in girls, and at 7, 9 and 11 y in boys), which suggest that, in some ages, the stunting condition did not affect their motor performance. We think that Peruvians’ general improvements in agility and in cardiorespiratory capacity are associated with their body build and shape, as well as physiological characteristics resulting from adaptation to environmental conditions. It is also possible that demands of their daily chores and manifold physical activities may help explain these results [41]. Similarly, Tambalis et al. [42] found that thin Greek schoolchildren aged 4–17 year (considering thinness as related to holdup in somatic growth and development among children) performed better than normal weight peers in aerobic fitness test (multi-stage 20 m shuttle run test). Similarly, thin Mozambican children, aged 6–18 y, performed better in endurance tests, and equally in agility test, as compared to the normal weight group [15]. The same trend was found among Egyptian [43] and South African under-nourished children [17]. Differently, Nhantumbo, Ribeiro Maia, Dos Santos, Jani, Gudo, Katzmarzyk and Prista [11] reported that Mozambican stunted children performed less well in the one mile run test in both sexes, and in the 10 × 5 m agility run test, but only in girls. In sum, this issue remains controversial, requiring more studies to best explain the relationship between agility and cardiorespiratory PF components in stunted boys and girls.

The present study is not without limitations. First, the sample is not representative of the Peruvian population, which restricts the generalization of the results. However, we have a fairly large sample (7918 subjects), aged 6–15 year, covering an important time window in Peruvians' growth and development. Second, no information was collected about children's nutritional habits, as well as about the putative influence of family income and/or socioeconomic status. However, the financial costs associated with collecting data on 8000 families made this option unfeasible. Thirdly, the time of day of measurements was not the same for all children, given known geographical constraints, as well as school schedules. In fact, measuring thousands of children and adolescents from different socio-geographic areas at precisely the same time of the day, during their school-time, was impossible. However, of all studies consulted in this report, only one [43] mentioned this issue, but did not measure their subjects at the same time of the day. Despite these limitations, the strong point of this study is that it included a large sample of Peruvian children and adolescents from three different geographical locations, and provides relevant information about their impaired growth, as well as how their PF levels depend on their stunting condition.

CONCLUSIONS

In summary, stunting prevalence increased with age, was higher in boys than in girls, and was also higher in children and adolescents living in the Amazon region, followed by high-altitude and sea-level. Stunting had a negative overall impact on girls´ and boys´ statures. The age-by-stunting interactions proved to be statistically significant for both sexes, and significant differences in height varied to some degree across the ages. Stunted children performed worse in handgrip and standing long jump, but outperformed their normal-growth peers in shuttle-run (only boys), and in 12 min run. Further, significant differences in the age-by-stunting interaction occurred in all PF tests, varying to some degree across the ages. In conclusion, stunting significantly affects Peruvian youth's PF levels, and this influence is sex-, age- and PF test-specific. Our results provide valuable information that should be considered, on the one hand, by Peruvian political authorities when designing more efficient strategies to combat the stunting problem, creating a sustained and equitable implementation of multisector interventions, with focus on the poorest regions of the country. On the other hand, Peruvian school principals, councils and Physical Education teachers have to bear in mind the significance of these results when designing local intervention programs to help stunted children to increase their PF levels.

AUTHOR CONTRIBUTIONS

Conceptualization, C.S., and J.M.; methodology, C.S., A.B., and J.M.; formal analysis, C.S., D.H., and J.M.; investigation, C.S., A.B., O.V., S.P., R.G., G.T., D.H., P.T.K., and J.M.; resources, C.S., A.B., and J.M.; data curation, C.S., A.B., and J.M.; writing—original draft preparation, C.S., P.T.K., A.B. and J.M.; writing—review and editing, A.B., O.V., S.P., R.G., G.T., D.H., P.T.K., and J.M.; visualization, A.B., O.V., S.P., R.G., G.T., D.H., P.T.K., and J.M.; supervision, A.B., P.T.K., and J.M.; project administration, C.S., A.B., P.T.K., and J.M.; funding acquisition, C.S., and J.M. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

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

REFERENCES

1. De Onis, M.; Branca, F. Childhood stunting: A global perspective. Matern. Child Nutr. 2016, 12, 12–26. [CrossRef] [PubMed]

2. Hoddinott, J.; Behrman, J.R.; Maluccio, J.A.; Melgar, P.; Quisumbing, A.R.; Ramirez-Zea, M.; Stein, A.D.; Yount, K.M.; Martorell, R. Adult consequences of growth failure in early childhood. Am. J. Clin. Nutr. 2013, 98, 1170–1178. [CrossRef] [PubMed]

3. Hossain, M.; Choudhury, N.; Abdullah, K.A.B.; Mondal, P.; Jackson, A.A.; Walson, J.; Ahmed, T. Evidence-based approaches to childhood stunting in low and middle income countries: A systematic review. Arch. Dis. Child. 2017, 102, 903–909. [CrossRef] [PubMed]

4. De Onis, M.; Blössner, M.; Borghi, E. Prevalence and trends of stunting among pre-school children, 1990–2020. Publ. Health Nutr. 2012, 15, 142–148. [CrossRef]

5. Urke, H.B.; Mittelmark, M.B.; Valdivia, M. Trends in stunting and overweight in Peruvian pre-schoolers from 1991 to 2011: Findings from the Demographic and Health Surveys. Publ. Health Nutr. 2014, 17, 2407–2418. [CrossRef]

6. Dewey, K.G.; Begum, K. Long-term consequences of stunting in early life. Matern. Child Nutr. 2011, 7, 5–18. [CrossRef]

7. Ortega, F.; Ruiz, J.; Castillo, M.; Sjöström, M. Physical fitness in childhood and adolescence: A powerful marker of health. Int. J. Obes. 2008, 32, 1–11. [CrossRef]

8. Galván, M.; Uauy, R.; López-Rodríguez, G.; Kain, J. Association between childhood obesity, cognitive development, physical fitness and social-emotional wellbeing in a transitional economy. Ann. Hum. Biol. 2014, 41, 101–106. [CrossRef]

9. Eveland-Sayers, B.M.; Farley, R.S.; Fuller, D.K.; Morgan, D.W.; Caputo, J.L. Physical fitness and academic achievement in elementary school children. J. Phys. Act. Health 2009, 6, 99–104. [CrossRef]

10. Twisk, J.; Kemper, H.; Van Mechelen, W. The relationship between physical fitness and physical activity during adolescence and cardiovascular disease risk factors at adult age. The Amsterdam Growth and Health Longitudinal Study. Int. J. Sports Med. 2002, 23, 8–14. [CrossRef]

11. Nhantumbo, L.; Ribeiro Maia, J.A.; Dos Santos, F.K.; Jani, I.V.; Gudo, E.S.; Katzmarzyk, P.T.; Prista, A. Nutritional status and its association with physical fitness, physical activity and parasitological indicators in youths from rural Mozambique. Am. J. Hum. Biol. 2013, 25, 516–523. [CrossRef] [PubMed]

12. Benefice, E. Growth and motor performances of rural Senegalese children. In Physical Fitness and Nutrition During Growth: Studies in Children and Youth in Different Environments; Parizková, J., Hills, A.P., Eds.; Krager Publishers: Basel, Switzerland, 1998; Volume 43, pp. 117–131.

13. Malina, R.M.; Pena Reyes, M.E.; Tan, S.K.; Little, B.B. Physical fitness of normal, stunted and overweight children 6-13 years in Oaxaca, Mexico. Eur. J. Clin. Nutr. 2011, 65, 826–834. [CrossRef] [PubMed]

14. Arsenault, J.E.; Mora-Plazas, M.; Forero, Y.; Lopez-Arana, S.; Jáuregui, G.; Baylin, A.; Gordon, P.M.; Villamor, E. Micronutrient and anthropometric status indicators are associated with physical fitness in Colombian schoolchildren. Br. J. Nutr. 2011, 105, 1832–1842. [CrossRef] [PubMed]

15. Prista, A.; Maia, J.A.R.; Damasceno, A.; Beunen, G. Anthropometric indicators of nutritional status: Implications for fitness, activity, and health in

school-age children and adolescents from Maputo, Mozambique. Am. J. Clin. Nutr. 2003, 77, 952–959. [CrossRef] [PubMed]

16. Gontarev, S.; Kalac, R.; Velickovska, L.A.; Stojmanovska, D.S.; Misovski, A.; Milenkovski, J. Health-related physical fitness of normal, stunted and overweight children aged 6-14 years in Macedonia. Nutr. Hosp. 2018, 35, 1208–1214. [CrossRef] [PubMed]

17. Armstrong, M.E.G.; Lambert, M.I.; Lambert, E.V. Relationships between different nutritional anthropometric statuses and health-related fitness of South African primary school children. Ann. Hum. Biol. 2017, 44, 208–213. [CrossRef]

18. Tanner, J.M. Growth as a mirror of the condition of society: Secular trends and class distinctions. Acta Paediatr. Jpn. 1987, 29, 96–103. [CrossRef]

19. Bustamante, A.; Beunen, G.; Maia, J. Como crecen y se desarrollan los niños y adolescentes en La Merced y San Ramón. In Alcances Para la Educación Física, el Deporte y la Salud; Universidad Nacional de Educación Enrique Guzmán y Valle, La Cantuta: Lima, Perú, 2011; p. 174.

20. Lohman, T.G.; Roche, A.F.; Martorell, R. Anthropometric Standardization Reference Manual; Human Kinetics Books: Champaign, IL, USA, 1988; Volume 177.

21. Mirwald, R.; Baxter-Jones, A.; Bailey, D.; Beunen, G. An assessment of maturity from anthropometric measurements. Med. Sci. Sports Exerc. 2002, 34, 689–694.

22. Council of Europe. Eurofit: Handbook for the Eurofit Tests of Physical Fitness; Council of Europe, Committee for the Development of Sport: Strasbourg, France, 1993.

23. AAHPERD. Physical Educations, Recreation and Dance. In Health Related Physical Fitness Manual; AAHPERD: Washington, DC, USA, 1980.

24. Onis, M.; Onyango, A.; Borghi, E.; Siyam, A.; Nishida, C.; Siekmann, J. Development of a WHO growth reference for school-aged children and adolescents. Bull. World Health Organ. 2007, 85, 660–667. [CrossRef]

25. WHO Multicentre Growth Reference Study Group. WHO Child Growth Standards: Length/Height-for-Age, Weight-for-Age, Weight-for-Length, Weight-for-Height and Body Mass Index-for-Age: Methods and Development; World Health Organization: Geneva, Switzerland, 2006.

26. World Health Organization. WHO Reference 2007 STATA macro package. Available online: https: //www.who.int/childgrowth/software/readme_stata.pdf (accessed on 27 February 2020).

27. D’Agostino, R.B.; Belanger, A.; D’Agostino, R.B., Jr. A suggestion for using powerful and informative tests of normality. Am. Stat. 1990, 44, 316–321.

28. Eveleth, P.; Tanner, J. Worldwide Variation in Human Growth, 2nd ed.; Cambridge University Press: Cambridge, UK, 1990.

29. Wamani, H.; Åstrøm, A.N.; Peterson, S.; Tumwine, J.K.; Tylleskär, T. Boys are more stunted than girls in sub-Saharan Africa: A meta-analysis of 16 demographic and health surveys. BMC Pediatr. 2007, 7, 17. [CrossRef] [PubMed]

30. Khatun, M.; Stenlund, H.; Hörnell, A. BRAC initiative towards promoting gender and social equity in health: A longitudinal study of child growth in Matlab, Bangladesh. Publ. Health Nutr. 2004, 7, 1071–1079. [CrossRef] [PubMed]

31. Acosta, A.M. Analysing success in the fight against malnutrition in Peru. IDS Work. Pap. 2011, 2011, 2–49. [CrossRef]

32. Huicho, L.; Segura, E.R.; Huayanay-Espinoza, C.A.; de Guzman, J.N.; Restrepo-Mendez, M.C.; Tam, Y.; Barros, A.J.; Victora, C.G. Child health and nutrition in Peru within an antipoverty political agenda: A Countdown to 2015 country case study. Lancet Glob. Health 2016, 4, e414–e426. [CrossRef]

33. Pomeroy, E.; Stock, J.T.; Stanojevic, S.; Miranda, J.J.; Cole, T.J.; Wells, J.C. Stunting, adiposity, and the individual-level “dual burden” among urban lowland and rural highland peruvian children. Am. J. Hum. Biol. 2014, 26, 481–490. [CrossRef] [PubMed]

34. Cossio-Bolanos, M.; Campos, R.G.; Andruske, C.L.; Flores, A.V.; Luarte-Rocha, C.; Olivares, P.R.; Garcia-Rubio, J.; de Arruda, M. Physical Growth,

Biological Age, and Nutritional Transitions of Adolescents Living at Moderate Altitudes in Peru. Int. J. Env. Res. Publ. Health 2015, 12, 12082–12094. [CrossRef]

35. Frisancho, A.R. Human growth and development among high-altitude populations. In The Biology of High Altitude Peoples; Baker, P.T., Ed.; Cambridge University Press: New York, NY, USA, 1978; pp. 117–171.

36. Beall, C.M.; Baker, P.T.; Baker, T.S.; Haas, J.D. The effects of high altitude on adolescent growth in southern Peruvian Amerindians. Hum. Biol. 1977, 49, 109–124.

37. Cossio-Bolaños, M.; de Arruda, M.; Núñez Álvarez, V.; Lancho Alonso, J. Efectos de la altitud sobre el crecimiento físico en niños y adolescentes. Rev. Med. Deport. 2011, 4, 71–76.

38. Banco Mundial. Perú Panorama General. Available online: https://www.bancomundial.org/es/country/peru/ overview#1 (accessed on 9 May 2020).

39. Seefeldt, V.; Haubenstricker, J. Patterns, phases, or stages: An analytical model for the study of developmental movement. In The Development of Movement Control and Coordination; Kelso, J.A.S., Clark, J.E., Eds.; Wiley: New York, NY, USA, 1982; pp. 309–318.

40. Malina, R.M.; Bouchard, C.; Bar-Or, O. Growth, Maturation, and Physical Activity; Human Kinetics: Champaign, IL, USA, 2004.

41. Bustamante Valdivia, A.; Maia, J.; Nevill, A. Identifying the ideal body size and shape characteristics associated with children’s physical performance tests in Peru. Scand. J. Med. Sci. Sports 2015, 25, e155–e165. [CrossRef]

42. Tambalis, K.; Panagiotakos, D.; Psarra, G.; Sidossis, L. Prevalence, trends and risk factors of thinness among Greek children and adolescents. Int. J. Prev. Med. 2019, 60, E386.

43. Abdelkarim, O.; Ammar, A.; Trabelsi, K.; Cthourou, H.; Jekauc, D.; Irandoust, K.; Taheri, M.; Bös, K.; Woll, A.; Bragazzi, N.L. Prevalence of Underweight and

Overweight and Its Association with Physical Fitness in Egyptian Schoolchildren. Int. J. Env. Res. Publ. Health 2020, 17(1), 75.

Paper III

Correlates of Overweight in Children and Adolescents Living at Different Altitudes: The Peruvian Health and Optimist Growth Study

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ABSTRACT

Background and Aim: Overweight prevalence in children and adolescents shows great variability which is related to individual and environmental-level factors. The present study aimed to determine the prevalence of and factors associated with overweight in Peruvian children and adolescents living at different altitudes.

Methods: 8568 subjects, aged 6-16 years, from sea-level, Amazon and high-altitude regions were sampled. Overweight was identified using BMI; biological maturation and physical fitness were measured; school characteristics were assessed via an objective audit.

Results: Overweight prevalence decreased with age (28.3% at 6 y to 13.9% at 16 y); was higher in girls (21.7%) than boys (19.8%); and was higher at sea-level (41.3%), compared with Amazon (18.8%) and high-altitude (6.3%) regions. Approximately 79% of the variance in overweight was explained by child-level characteristics. In model 1, all child-level predictors were significant ($p<0.001$); in model 2, six out of nine added school-level predictors (number of students, existence of policies and practices for physical activity, multi-sports roofed, duration of Physical Education classes, extracurricular activities) were significant ($p<0.001$); in model 3, subjects living at high-altitude were less likely to be overweight than those living at sea-level.

Conclusions: Child- and school-level variables played important roles in explaining overweight variation. This information should be take into account when designing more efficient strategies to combat the overweight and obesity epidemic.

INTRODUCTION

The prevalence of childhood overweight and obesity has systematically increased in developed and developing countries over the last few decades (Ng et al., 2014). It is considered a global epidemic and a public health crisis (Lobstein, Baur, & Uauy, 2004) given the adverse health consequences throughout the life-course (Guh et al., 2009), as well as the related economic costs placing an undue strain on healthcare systems (Withrow & Alter, 2011).

A systematic analysis (Ng et al., 2014) of available data from 1980 to 2013 showed that the combined prevalence of overweight and obesity has substantially increased in children and adolescents in developed countries from 16.9% to 23.8% in boys, and from 16.2% to 22.6% in girls; in developing countries, this increase was from 8.1% to 12.9% in boys and from 8.4% to 13.4% in girls. This prevalence has also increased rapidly in low-and middle-income countries (Abarca-Gómez et al., 2017). Recently, Yang et al. (2018) reported overall prevalences of 13.4% for underweight and 21% for overweight (including obesity) among young adolescents in 58 low-and middle-income countries.

It has been suggested that increases in childhood overweight have been steeper in Latin-American countries (Filozof, Gonzalez, Sereday, Mazza, & Braguinsky, 2001). Currently, more than 20% (approximately 42.5 million) of Latin American children aged 0 to 19 yrs are overweight or obese (Rivera et al., 2014), and Peru is no exception to the growing problem of childhood under- and overnutrition (E. Pomeroy et al., 2014). For example, Pajuelo-Ramírez, Sanchez-Abanto, Alvarez-Dongo, Tarqui-Mamani, and Agüero-Zamora (2013) investigated the prevalence of overweight (including obesity) and chronic malnutrition in 6- to 9-year-old Peruvian children, and showed values of 21.5% and 17.8%, respectively.

The development of overweight and obesity is multifaceted, involving biological and environmental factors (Narciso et al., 2019). Further, girls tend to be more overweight and obese than boys (Wells, 2007); overweight tends to be higher in older age-groups (Hanley et al., 2000), and those ahead in their maturity status are more likely to be overweight and/or obese (Wang, 2002). High levels of physical fitness have been shown to be an important contributing factor in maintaining healthier body weights during childhood (Kim et al., 2005).

It is likely that context-specific information is important to explain why children vary in their weight status (Riedel et al., 2013), and this is apparently evident in Peru. Its territory spreads across three main areas (sea-level, Amazon region and high-altitude) with their multifaceted geographical and socio-economic features. Further, Peru is facing different stages of nutritional (Mispireta, Rosas, Velásquez, Lescano, & Lanata, 2007) and epidemiological (Huynen, Vollebregt, Martens, & Benavides, 2005) transitions. Available information (Torres-Roman, Urrunaga-Pastor, Avilez, Helguero-Santin, & Malaga, 2018) shows differences in overweight and obesity prevalences in children living in different regions, with a very high prevalence in Lima (the capital city). Tarqui-Mamani, Alvarez-Dongo, and Espinoza-Oriundo (2018), using data from children aged 5-13 yrs, concluded that living in the urban areas and in Metropolitan Lima was related to a greater likelihood of being overweight than living in the Amazon region or at high altitudes. These results were consistent to those reported by Álvarez-Dongo, Sánchez-Abanto, Gómez-Guizado, and Tarqui-Mamani (2012) in children and adolescents aged from 5 to 19 yrs of age.

Children and adolescents spend most of their awake time at school, and identifying school-related factors that may be associated to overweight/obesity is of importance. It has recently been suggested that the school context has links with child/adolescent overweight and obesity (Procter et al., 2008). For example, O’Malley, Johnston, Delva, Bachman, and Schulenberg (2007) showed that USA schools with a high concentration of students from low socioeconomic status households have a greater chance of having higher proportions of obesity students. On the other hand, Pallan, Adab, Sitch, and Aveyard (2014) reported that, in United Kingdom schools, the only school-level variable associated with BMI z-score was time spent in Physical Education classes (minutes/week).

Very few studies have investigated the combined links of individual- and environmental-level correlates of childhood and adolescent overweight, and this information is not available in Peruvian youth. Further, using a multilevel approach to tackle this complex issue could provide new insights for the development of intervention programs to prevent childhood overweight and obesity. Therefore, the present study has the following aims: (1) to determine the prevalence of overweight in Peruvian children and adolescents by age, sex and geographical area of residence; (2) to examine the importance of biological characteristics (age, sex, maturation, and physical fitness total score), school-level contexts and geographical area of residence in explaining variation in BMI categories.

METHODS

Communities

Geographical heterogeneity in Peru is largely expressed in three areas with different altitudes: (1) sea-level: in the coast, Barranco (58 m) is one of the 43 districts of Lima Province, and is located on the shore of the Pacific Ocean; (2) Amazon region: in the jungle area La Merced and San Ramon (751 m) are districts with geographical continuity and integrate the Chanchamayo province; (3) in high-altitude Junín is localized on a plateau at 4107 m in the central part of the Andes mountain. Geographic, demographic, socio-economic and educational characteristics of these areas (INEI, 2018) are reported in Table 1.

Table 1. Geographic, demographic, socioeconomic and educational characteristics of the three geographical areas located in the central region of Peru.

Characteristics	**Sea-level** (Barranco)	**Amazon region** (La Merced and San Ramon)	**High-altitude** (Junín)
Geographic			
Area (km²)	3.33	5 315.07	883.80
Altitude (m)	58	751	4107
Demographic			
Total population	34378	53590	10796
Population density (people/km²)	10.13	10.08	12.22
Official language	Spanish	Spanish/Quechua	Spanish/Quechua
Climate	Arid; semi-warm	Rainy; warm	Rainy; cold
Average annual temperature	18°C	24°C	7°C-12°C
Socioeconomic			
Human Development Index (HDI)	0.72	0.52	0.44

Life expectancy at birth (y)	79.08	65.49	69.14
Education (%)[1]	86.94	86.61	76.56
Literacy (%)[2]	99.35	90.97	89.84
Per capita family income (dollars)	1440.6	785.1	512.7
Primary production	Trade/Tourism	Agriculture/Tourism	Stockbreeding/Agriculture
Educational			
School age children	15.829	13.960	2.703
Boys	7.118 (45.0%)	7.172 (51.4%)	1.359 (50.3%)
Girls	8.711 (55.0%)	6.788 (48.6%)	1.344 (49.7%)
Public	8.881 (56.1%)	11.126 (79.7%)	2.601 (96.2%)
Private	6.948 (43.9%)	2.834 (20.3)	102 (3.8%)
Urban	15.829 (100%)	12.927 (92.6%)	2.678 (99.1%)
Rural	0 (0%)	1.033 (7.4%)	25 (0.9%)

[1] School age population; [2] Children and adults 15 years of age or more who know how to read and write

Study participants

The present cross-sectional sample comes from *The Peruvian Health and Optimist Growth Study* which, in summary, scrutinizes the main sources of variation in physical growth, motor development and health in Peruvian children and adolescents living at different altitudes (Bustamante et al., 2011). For this paper, we used a sample of 8568 children and adolescents (3914 boys, 4654 girls, aged 6-16 yrs) from 31 public schools located at sea-level, Amazon region and high-altitude. The analytical sample was selected based on the availability of complete data of anthropometry, biological maturation, and three physical fitness tests (standing long jump, shuttle-run and 12 minute run test); further, we did not consider subjects classified as underweight (n_{total}=384; 4.5% ot the overall sample) because their frequency within each age category (2.2% at age 6, 3.6% at age 7, 6.2% at age 8, 3.7% at age 9, 3.8% at age 10, 4.5% at age 11, 4.1% at age 12, 5.7% at age 13, 4.3% at age 14; 2.6% at age 15, and 4.4% at age 16) and sex (from 3.5% in boys, to 4.6% in girls) was very low.

Based on information obtained from the Ministry of Education (ESCALE, 2010) on the distribution of students enrolled in the 2009-10 academic year (date of data collection), it was decided to intentionally select 31 public education institutions located in urban areas, of which 13 belonged to kindergarten, 10 at the primary-school and 8 at the secondary-school. A total of 38% of the total number of students enrolled in the study, that is, 4 out of every 10 students who regularly attended school. The sample only included native children and adolescents from their respective regions (i.e., no migrants were included), regardless of whether their parents or grandparents were migrants or not. We gathered information about their birth place and current place of residence or address residence and cross-checked this information with the participants' identity card. All assessments were carried out in Barranco between November and December (2009) and April and July (2010), in La Merced and San Ramon between May and August, and in Junín between September and October of 2009.

After initial political and educational contacts with local authorities in each city, formal permission was obtained from schools´ governmental bodies to participate in the study. Informed consent was provided by parents/legal guardians. The ethics committee of the National University of Education Enrique Guzmán y Valle (UNE EGyV), as well as all school directors approved the project. Table 2 shows the number of children and adolescents by age, sex and geographical area of residence. The information about sample size and frequencies for BMI categories (normal weight and overweight) according to IOTF (Cole, Bellizzi, Flegal, & Dietz, 2000) and WHO (Onis et al., 2007) cut-off points, by age, sex and geographical area of residence can be found in Supplementary Tables 1 and 2, respectively (please see these tables in the Supplementary Material for comprehensive data analysis).

Table 2. Children and adolescents sampled in the three geographical areas of the central region of Peru. Data by age and sex.

Age (yrs)†	**Sea-level** (Barranco)		**Amazon region** (La Merced and San Ramon)		**High-altitude** (Junín)		**All areas**	
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
6	103	45	176	151	49	56	328	252
7	78	39	158	233	77	57	313	329
8	94	69	231	208	59	68	384	345
9	139	64	209	239	81	105	429	408
10	101	71	272	247	85	102	458	420
11	136	110	231	234	107	80	474	424
12	114	105	300	191	182	125	596	421
13	85	31	272	168	102	132	459	331

14	149	74	228	159	144	141	521	374
15	120	119	190	192	138	112	448	423
16	81	36	88	89	75	62	244	187
Total	**1200**	**763**	**2355**	**2111**	**1099**	**1040**	**4654**	**3914**

†Age was used as decimals of a yr and children aged 5.5 to 6.49 yrs were designated as 6, children aged 6.50 to 7.49 yrs as 7, and so on (Eveleth & Tanner, 1990).

Child-level correlates

Anthropometry

All measurements were made according to standardized techniques (T. Lohman et al., 1988). Height and sitting height were measured with the head positioned to the Frankfurt plane to the nearest 0.1 cm with a portable stadiometer (Sanny, Model ES-2060); body weight was measured at the nearest 0.1 kg using a digital scale (Pesacon, Model IP68). Body mass index (BMI) was computed using the standard formula [weight (kg)/height (m)^2] and subjects were classified as either normal weight or overweight (including obesity) according to the International Obesity Task Force (IOTF) (Cole et al., 2000) and World Health Organization (WHO) (Onis et al., 2007) cut-off points. A dummy coding was created, with normal weight coded as 0 (reference category), and overweight (including obesity) coded as 1.

Biologial maturation

Biological maturation was assessed with the maturity offset (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002) which estimates the distance, in decimal yrs, each subject is from age at peak height velocity (PHV). Formulas are sex-specific and use chronological age, height, sitting height, and leg length. A positive (+) maturity offset indicates the number of estimated yrs a child is beyond PHV; a negative (-) maturity offset is the number of estimated yrs a child is before the PHV, whereas a zero value indicates that a child is experiencing his/her PHV.

Physical fitness

Three measures of physical fitness were used. Muscular strength (standing long jump), agility (shuttle-run), and cardiorespiratory fitness (12 minute run) were obtained from two well-known test batteries – AAHPERD (1980) and

EUROFIT (EUROFIT, 1993). All tests were performed according their standardized protocols: (1) standing long jump test: each subject stood with feet apart behind the take-off line and, without a preparatory run, were instructed to jump as far as possible. The maximum jumping distance was recorded. Two trials were given and the best score was recorded as the maximum jumping distance in centimetres; (2) shuttle-run test: each subject performed five cycles (round-trip) at maximum speed between two lines separated by five meters; and (3) 12 minute run test: in a previously delimited field, schoolchildren ran/walked the maximum possible distance in 12 minutes. All physical fitness test results were converted to z-scores using a grand-mean centering, and a total physical fitness score (PF_Z) was obtained by summing all individual z-scores as suggested (Y. Huang & R. M. Malina, 2007).

Socio-geographic context

Geographical areas of residence were located at different altitudes: sea-level (58 m), Amazon region (751 m) and high-altitude (4107 m). A coding scheme was generated with two dummies: sea-level, the reference category, was coded as 0 0, high-altitude was 1 0 and Amazon region was 0 1.

School-level correlates

The description and inventory of characteristics associated with the school contexts were obtained via an objective school audit, using a modified and locally adapted version of the Healthy Eating and Physical Activity modules of the Healthy School Planner designed by the Joint Consortium for School Health (Joint Consortium for School Health, 2012). This audit was led by the experienced research team members and maps various domains: (1) school characterization (school size – number of students were divided by 10 so that to have a more interpretable odds ratio; and school setting – mixed is the reference category, and urban); (2) policies and practices for physical activity (specifically the existence of policies and practices issued by the state, school board, or any other government agency to promote physical activity, health and well-being of students and are organized by the school). No policies and practices was the reference category; (3) physical structure of the school (playground area – with obstacles was the reference category; and multi-sports roofed – yes was the reference category); (4) Physical Education classes (frequency – one was the reference category; and duration – 90 min was the reference category); and (5) extracurricular activities (yes was the reference category).

Data quality control

To certify data quality, the following procedures were used: (1) training of all team members by experienced researchers in the correct use of the technical procedures of body measurement and physical fitness test protocols (2) conducting a pilot study to assess the quality of data collection; (3) retesting of a random sample of 29 children and adolescents, and (4) estimating the inter-observer technical error of the measurement for anthropometric data (height TEM=0.2 cm; sitting height TEM=0.1 cm; body mass TEM=0.1 kg) and ANOVA-based intraclass correlation coefficient (ICC) for physical fitness tests (standing long jump: ICC=0.85) shuttle-run (ICC=0.81), and 12 minute run (ICC=0.79).

Statistical Analysis

Exploratory analyses, outlier identification and normality checks were completed prior to further analyses. Differences in frequencies of overweight by age, sex and geographical area of residence were computed using a chi-square (χ^2) test. Differences in means and frequencies of child-level variables between geographical areas of residence were computed using analysis of variance (ANOVA), as well as χ^2 test, respectively. Additionally, the Tukey HSD test was used for multiple comparisons. All analyses were performed in SPSS software version 24.0.

Because our data had a hierarchical structure, i.e., children nested within schools, we used a two-level random intercept (multilevel) logistic regression model for BMI categories (normal weight versus overweight). A three-level structure was considered – subjects nested within schools which are nested within regions. However, with only three regions, it is not recommended to treat region as a level in a multilevel analysis (Snijders & Bosker, 2012). Instead, dummy variables for region were included as predictors of BMI categories and were included in the fixed part of the model.

A series of nested models were fit to explain variation in BMI categories using the Deviance statistic as a measurement of relative fit (Hox, Moerbeek, & Van de Schoot, 2018); differences in Deviances follow a χ^2 distribution with degrees of freedom equal to the difference in the number of estimated parameters from both models. It is expected that better fitting models have lower Deviance values. Modelling was done in a sequencial manner as generally advocated (Hox et al., 2018; Snijders & Bosker, 2012). Firstly, a null model (M_0) was fit to the data to compute the intraclass correlation coefficient to estimate the variance accounted for by the random school effects in BMI categories. Secondly, Model 1 (M_1) using child-level BMI predictors (age, sex, age-by-sex interaction, maturity offset and PF_z) was fit. Thirdly, in the Model 2 (M_2), school-level covariates were added (number of students, school setting, policies and practices for physical activity, playground area, multi-sports roofed, frequency and duration of Physical Education classes, and extracurricular activities). In the last model, Model 3 (M_3), the predictor of geographical area of residence was added. Covariates were centered at their grand mean when necessary as is common in multilevel analysis (Hox et al., 2018). Results are presented as odds ratios and their 95% confidence intervals (95%CI). The multilevel analyses was performed in SuperMix software (D. Hedeker, Gibbons, Toit, & Cheng, 2008), allowing a simultaneous estimation of all model parameters using maximum likelihood procedures. Statistical significance was set at 5%.

RESULTS

Table 3 provides information about the prevalence of overweight (including obesity) among Peruvian children and adolescents, by age, sex and geographical area of residence, based on IOTF and WHO cut-off points. Using a χ^2 test, significant differences ($p<0.05$) in the prevalence of overweight were found by age ($\chi^2=125.53$, $p<0.05$), sex ($\chi^2=4.68$, $p<0.05$) and geographical area of residence ($\chi^2=782.51$, $p<0.05$). In the total sample, the prevalence of overweight was 20.8% (95%CI=20.0-21.7). Further, the prevalence descreased with age (from 28.3%, 95%CI=24.8-32.2 at 6 yrs to 13.9%, 95%CI=10.4-17.4 at 16 yrs); was higher in girls (21.7%, 95%CI=20.6-22.9) than in boys (19.8%, 95%CI=18.5-21.0); and was higher among sea-level children and adolescents (41.3%, 95%CI=39.1-43.7), followed by Amazon region (18.8%, 95%CI=17.6-19.9) and high-altitude (6.3%, 95%CI=5.3-7.3).

Table 3. Prevalence of overweight (including obesity) (n, % and 95% Confidence Intervals), based on IOTF and WHO cut-off points, by age, sex and geographical area of residence.

	Overweight (including obesity)			
	IOTF		WHO	
	N	% (95% CI)	N	% (95% CI)
Age				
6	164	28.3 (24.8-32.2)	199	34.3 (30.5-38.3)
7	158	24.6 (21.3-28.0)	196	30.5 (27.1-34-0)
8	174	23.9 (20.9-27.0)	215	29.5 (26.6-34.3)
9	220	26.3 (23.5-29.4)	267	31.9 (28.8-34.9)
10	163	18.6 (15.6-21.4)	204	23.2 (20.5-26.1)
11	240	26.7 (23.8-29.6)	275	30.6 (27.6-34.0)
12	207	20.4 (17.9-22.7)	252	24.8 (22.0-27.6)
13	138	17.5 (14.9-20.3)	162	20.5 (17.7-23.3)
14	139	15.5 (13.2-18.1)	149	16.6 (14.3-19.0)
15	120	13.8 (11.5-16.1)	127	14.6 (12.4-17.0)
16	60	13.9 (10.4-17.4)	63	14.6 (11.4-18.1)
Sex				
Girls	1009	21.7 (20.6-22.9)	1105	25.7 (24.3-27.0)
Boys	774	19.8 (18.5-21.0)	1004	23.7 (22.5-25.0)
Geographical area of residence				
Sea-level	810	41.3 (39.1-43.7)	894	45.5 (42.5-47.7)
Amazon region	838	18.8 (17.6-19.9)	1025	23.0 (21.7-24.2)
High-altitude	135	6.3 (5.3-7.3)	190	8.9 (7.8-10.1)
All	1783	20.8 (20.0-21.7)	2109	24.6 (23.7-25.5)

$^{*}p<0.05$

Table 4 provides descriptive statistics for the child-level variables. Statistically significant differences (p<0.05) were found for all variables among subjects living at different altitudes. High-altitude subjects are relatively older than their peers from the other areas (F=62.45, p<0.05; 11.6 *versus* 11.2 and 10.8 yrs). On average, Amazon region subjects lag behind their peers in biological maturation (F=75.19, p<0.05), and sea-level children are more physically fit compared with their peers from high-altitude (F=1371.35, p<0.05). The frequency of girls is higher than boys in the three geographical regions (sea-level: girls 61.1%, boys 38.9%; Amazon region: girls 52.7%, boys 47.3%; hig-altitude: girls 51.4%, boys 48.6%) (χ^2 = 48.69, p<0.05).

Table 4. Descriptive statistics for child-level variables

Child-level variables	**Sea-level (S)** (n=1963)	**Amazon region (A)** (n=4466)	**High-altitude (H)** (n=2139)	***F***	***Post hoc* among areas**
	Mean±SD	Mean±SD	Mean±SD		
Biological characteristics					
Age (yrs)	11.20±2.98	10.78±2.87	11.61±2.84	62.45*	H>S>A
Maturity offset (yrs to PHV)	-1.27±2.30	-1.89±2.28	-1.30±2.25	75.19*	A<S; A<H
PF_z	0.46±1.76	0.52±1.53	-1.46±1.13	1371.35*	H<S; H<A
	Frequencies n (%)			χ^2	
Sex					
Girls	1200 (61.1)	2355 (52.7)	1099 (51.4)	48.69*	
Boys	763 (38.9)	2111 (47.3)	1040 (48.6)		

*p<0.05; PF_z = total physical fitness score

Descriptive statistics for the school-level variables are presented in Table 5. The number of students in the schools ranged from 96 to 1200; 83.3% of the schools were located in an urban region; 16.7% had policies and 38.9% had practices for physical activity. Further, 83.3% of schools had a recreation space without obstacles and 66.7% did not have multi-sports roofed complexes. In 94.4% of schools, Physical Education classes were conducted once per week and 55.6% of them lasted >90 min. Finally, 77.8% of schools provided extracurricular activities for schoolchildren.

Table 5. Descriptive statistics for school-level variables

School-level variables	Mean±SD	Range
School characterization		
School size		
Number of students	453±263	96-1200
	Frequencies n (%)	
School setting		
Mixed	3 (16.7)	
Urban	15 (83.3)	
Policies and practices for physical activity		
Policies and practices		
Only Policies	3 (16.7)	
Only Practices	7 (38.9)	
No	8 (44.4)	
Physical structure of the school		
Playground area		
With obstacles	3 (16.7)	
Without obstacles	15 (83.3)	
Multi-sports roofed		
Yes	6 (33.3)	
No	12 (66.7)	
Physical Education classes		
Physical Education class frequency		
1 per week	17 (94.4)	
2 per week	1 (5.6)	
Physical Education class duration		
90 minutes	8 (44.4)	
>90 minutes	10 (55.6)	
Extracurricular activities		
Yes	14 (77.8)	
No	4 (22.2)	

The results of the multilevel models, based on IOTF cut-off points, are presented in Table 6. The results are very similar (in magnitude and direction) for both criteria (for WHO results please see Supplementary Table 3 in the Supplementary Material for comprehensive data analysis). The M_0 indicated that school-level effects expressed by the intraclass correlation coefficient was 0.209, meaning that ~21% of the total variance in BMI categories among subjects was at the school-level, and that ~79% of the variance was explained by child-level characteristics, respectively.

Results from M_1 (child-level predictors), showed that younger subjects (OR=0.16, 95% CI=0.14-0.18) as well as those ahead in their maturity status were more likely to be overweight (OR=14.19, 95% CI=12.00-16.78). The age-by-sex interaction was statistically significant (OR=0.74; 95% CI=0.70-0.78) revealing that boys tend to be less likely to be overweight than girls as they get older. Further, being more physically fit (OR=0.80; 95% CI=0.76-0.84) protects subjects from being overweight. There was a significant reduction in Deviance from M_0 to M_1 (from 7927.97 to 6524.56; $\chi^2_{(5)}$= 1403.41, p<0.001), showing the better fit of M_1.

In M_2, school-level predictors were added. Six out of nine predictors were statistically significant (p<0.001). Children from schools with higher number of students (OR=1.02; 95% CI=1.01-1.03) and without multi-sports roofed (OR=2.44; 95% CI=1.53-3.89) were more likely to be overweight. Surprisingly, children and adolescents from schools with physical activity policies (OR=5.09; 95% CI=2.61-9.94) and practices (OR=2.83; 95% CI=1.83-4.38), with Physical Education classes with more than 90 minutes of duration (OR=3.02; 95% CI=1.84-4.96), as well as with extracurricular activities (OR=0.59; 95% CI=0.37-0.92) had a greater likelihood of being overweight. There was a reduction in Deviance from M_1 to M_2 (from 6524.56 to 6480.93; $\chi^2_{(9)}$= 43.63, p<0.001) showing the better fit of M_2.

In the last model (M_3) geographical area of residence was added and results showed that subjects living at high-altitude (OR=0.08; 95% CI=0.04-0.18) were less likely to be overweight than those living at sea-level. In this model, subject-level covariates remained similar as in M_1 and M_2, but the importance of some school-level covariates changed. Children and adolescents from schools with lower number of students (OR=0.97; 95% CI=0.96-0.98), with playground areas with obstacles (OR=0.09; 95% CI=0.04-0.24), with multi-sports roofed (OR=0.40; 95% CI=0.24-0.66), and with only one Physical Education class per week (OR=0.03; 95% CI=0.01-0.13) were more likely to be overweight. There was a reduction in Deviance from M_2 to M_3 (from 6480.93 to 6453.66; $\chi^2_{(2)}$= 27.27, p<0.001), showing the better fit of M_3.

Table 6. Multilevel modelling results: odds ratios (OR) and 95% confidence intervals (95% CI) for child- and school-level characteristics

IOTF				
Parameters	Null model (M$_0$)	Model 1 (M$_1$)	Model 2 (M$_2$)	Model 3 (M$_3$)
Regression coefficients (fixed effects)				
Level-1 child-level				
Intercept	0.18 (0.12-0.28)*	5.71 (3.35-9.74)*	1.23 (0.41-3.74)^{ns}	33.48 (11.56-96.98)*
Age		0.16 (0.14-0.18)*	0.15 (0.14-0.18)*	0.15 (0.14-0.17)*
Sex (boys)*		2.71 (2.25-3.25)*	2.74 (2.30-3.27)*	2.94 (2.49-3.46)*
Interaction (age-by-sex)		0.74 (0.70-0.78)*	0.74 (0.70-0.78)*	0.75 (0.72-0.79)*
Maturity offset (yrs to PHV)		14.19 (12.00-16.78)*	14.35 (12.14-16.97)*	14.34 (12.12-16.96)*
PF$_z$		0.80 (0.76-0.84)*	0.80 (0.76-0.84)*	0.80 (0.76-0.83)*
Geographical area of residence (High-altitude)¤				0.08 (0.04-0.18)*
Geographical area of residence (Amazon region)				1.50 (0.94-2.40)^{ns}
Level-2 school-level				
Number of students†			1.02 (1.01-1.03)*	0.97 (0.96-0.98)*
School setting (urban)ϴ			0.58 (0.32-1.05)^{ns}	1.19 (0.81-1.74)^{ns}
Existence policies or/and practices for physical activity (policies)∞			5.09 (2.61-9.94)*	5.64 (3.37-9.45)*
Existence policies or/and practices for physical activity (practices)			2.83 (1.83-4.38)*	1.40 (1.01-1.93)*
Playground area (without obstacles)£			1.67 (0.62-4.51)^{ns}	0.09 (0.04-0.24)*
Multi-sports roofed (no)¥			2.44 (1.53-3.89)*	0.40 (0.24-0.66)*
Frequency of physical education classes (two)α			1.87 (0.43-8.19)^{ns}	0.03 (0.01-0.13)*
Duration of physical education classes (>90 min)§			3.02 (1.84-4.96)*	4.16 (3.04-5.69)*
Extracurricular activities (no)Δ			0.59 (0.37-0.92)*	0.82 (0.60-1.12)^{ns}
Variance components (random effects)				
Intercept	0.87±0.30	1.07±0.38	0.07±0.03	0.00±0.00
Model summary				
Deviance	7927.97	6524.56	6480.93	6453.66
Number of estimated parameters	2	7	16	18

*p<0.001; ^{ns}= non-significant; *Girls are the reference; ¤Sea-level is the reference; †Divided by 10; ϴMixed is the reference; ∞No policies and practices is the reference; £with obstacles is the reference; ¥Yes is the reference; αOne is the reference; §90 min is the reference; ΔYes is the reference; PF$_z$ = total physical fitness score

DISCUSSION

Since the last century, Peru has been experiencing epidemiological and nutritional transitions with unforeseen changes in the prevalences of overweight and obesity. Here, we reported a combined prevalence of 20.8% for overweight and obesity in children aged 6 to 16 yrs, as well as significantly lower prevalences at higher ages. Moreover, we found that children and adolescents living at sea-level had the highest overweight prevalence, followed by those from the Amazon region and high-altitude. Álvarez-Dongo et al. (2012), using WHO cut-off points, reported a combined prevalence of 24.4% in children aged 5 to 9 yrs, decreasing to 14.2% in youth aged 10 to 19 yrs, which are smaller than what we reported using the same cut-off points within the age range of 6 to 9 yrs (31.6%) and 10 to 16 yrs (20.7%). In addition, they also reported a similar trend, with the highest prevalence of overweight and obesity found among children and adolescents living in the coastal regions. These geographical differences may be due to the differences in urbanization levels and lower poverty observed in coastal districts, which may lead to changes in lifestyles, namely food habits and physical activity levels (Hernández-Vásquez et al., 2016).

We also observed sex differences in the prevalence of childhood/adolescence overweight, favouring boys. Available systematic review (Kanter & Caballero, 2012) revealed similar trends within and between countries, emphasizing that in developing countries these sex disparities are more exacerbated and are commonly observed before and during puberty. Several factor may contribute to this sex difference: firstly, boys and girls differ in body composition as well as in weight gain patterns (Wells, 2007); secondly, boys tend to carry out heavy work and physical activities with greater energy expenditure, whereas girls are more responsible for household tasks, involving less energy expenditure (Preston, Ariana, Penny, Frost, & Plugge, 2015).

A major finding of our study was that the main fraction of the total variance in BMI categories (~79%) was explained by child-level characteristics. These results are congruent with those obtained in the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE), where 90% of the variance in obesity was explained at the childhood level among 9-11 yrs old children from 12 countries (P.T. Katzmarzyk et al., 2015). Further, ISCOLE demonstrated that 92% to 94% of the variance in BMI and waist circumference, respectively, was explained at the childhood level, with the remainder being explained at the school and site levels (P. T. Katzmarzyk et al., 2018).

We also showed that younger children were more likely to be overweight, corroborating Cremm et al. (2012) study with Brazilian children linking their results to the fact that younger children were more prone to consume healthier foods less frequently and engage in less moderate-to-vigorous physical activities or sports as compared to older children. Boys tended to be less likely to be overweight than girls as they get older (the age-by-sex interaction was statistically significant). There is a tendency for girls to surpass boys in their overweight trends, which are also linked to the fact that girls exhibit, on average, higher amounts of body fat and boys higher amounts of muscle mass (Wells, 2007). These sex-differences in body composition are evident from fetal life, but emerge primarily during prepubertal and pubertal phases of life. Girls enter puberty earlier – they experience their mid-growth spurt and their adolescent spurt at ealier ages, and undergo a more rapid pubertal transition, whereas boys have a substantially longer growth period (Gasser et al., 1985). Furthermore, the action of sex steroid hormones (estrogen) begins earlier in girls, preparing them for menarche, which results in a greater accumulation of body fat (Riggs, Khosla, & Melton III, 2002), predisposing them to a greater risk of being overweight.

We also showed that children and adolescents ahead in their maturity status were more likely to be overweight, which agrees with (Gomes et al., 2014) data in Portuguese children. This is expected since previous research has shown that the timing of biological maturation further seems to contribute to greater adiposity development and early maturing youths usually are taller, heavier and have higher BMI than their later maturing peers (Ahmed, Ong, & Dunger, 2009). As such, our results were expected since those closer to their PHV had higher BMI values and, consequently, had a greater likelihood of being overweight. However, to the best of our knowledge, we were not able to identify information about biological maturation and its associations with body weight in Peruvian children and adolescents to compare with our results. We were only able to find reports on girls (Gonzales & Villena, 1996) based on their age-at-menarche, showing that those living at sea-level had a higher BMI than those living at high-altitude; their age-at-menarche occurred earlier which may also explain the higher prevalence of overweight previously reported among sea-level girls compared with their peers from the other regions.

Physical fitness is an important health marker (F. Ortega et al., 2018) and there is emerging evidence showing that adequate physical fitness levels are associated with the prevention of overweight during childhood and adolescence, playing an important protective role in its rate of development (Rodrigues, Stodden, & Lopes, 2016). Our results confirmed this link, showing that muscular strength, agility and cardiorespiratory fitness have negative associations with overweight status. This trend was also found by McGavock, Torrance, McGuire, Wozny, and Lewanczuk (2009) in that low cardiorespiratory fitness and reductions in physical fitness over time were positively related to weight gain and increased risk of overweight in children 6–15 yrs old. Similarly, Stodden et al. (2008) showed that the development of adequate levels of motor competence and health-related fitness may be a key component to prevent “unhealthy” weight gain in children and adolescents. Therefore, we emphasize the important role of physical fitness as a protective factor to reduce overweight/obesity when developing efficient interventions programs in children and adolescents.

Contextual information appears to be important in explaining why children vary in their weight status. Living at sea-level, particulary in the region of Barranco, was related to a greater likelihood of being overweight compared with high altitude, which may indicate that overweight is not yet a nationally-distributed problem in this country (Torres-Roman et al., 2018). One possible explanation for this discrepancy may be due to distinct lifestyle patterns in the three geographical areas. Barranco has a high density population of 10.132 inhabitants per km^2, increasing public insecurity and the lack of public recreational infrastructures available to schoolchildren, contributing to the adoption of sedentary lifestyles. In addition, the existence of several fast food restaurants, convenience stores, and marketing of unhealthy food choices increases the likelihood of children acquiring unhealthy eating habits. Conversely, Chanchamayo and Junín have a lower population density (10.08 inhabitants per km^2 and 12.22 inhabitant per km^2, respectively), and the majority of the schoolchildren participate in recreational activities, housework, and in supporting agricultural activities in the field, showing higher levels of physical activity compared with their peers from sea-level. Additionally, the market penetration is less common and the main livelihoods are some tourism, mainly in Amazon region, but predominantely stockbreeding and non-diversified agriculture, which limits the nutritional intake and, consequently, affects children and adolescent's health and weight status (Preston et al., 2015).

On the other hand, it has been suggested that lower obesity rates among highlanders as compared to lowlanders can also be explained by direct effects of living at high-altitude on human physiology (e.g., loss of appetite due to increased leptin concentrations (Riepl et al., 2012), increased thermogenesis due to cold temperatures that increase thyroid hormone (Basu & Samet, 2002) and catecholamine levels (Antezana, Richalet, Noriega, Galarza, & Antezana, 1995)). Thus, it is possible that living at high-altitude has a weight lowering effect *per se*, independent of various confounders factors, including multiple expressions of families´ socioeconomic status as proposed by Woolcott et al. (2016).

Additionally, a lower obesity rates among high-altitude children and adolescents may also be considered in terms of the "reverse causality" theory. It suggests that overweight/obese individuals might tend to migrate to lower altitudes where the natural environment is friendlier in terms of performing their daily tasks/chores and activities and/or because they have easier access to health care services (Woolcott et al., 2014; Woolcott et al., 2016). However, our sample only included native children and adolescents from their respective regions (i.e., no migrants were identified).

It is widely accepted that schools are an important factor in understanding variability in childhood overweight (Procter et al., 2008). Our results confirmed this, given that ~21% of the total variance in BMI categories was attributed to the schools children attended. In previous studies (O'Malley et al., 2007; Pallan et al., 2014), lower values of variance (ranging from 2% to 5%) were found to explain school-level differences in the variability in the odds of a student being overweight. This discrepancy can be due to the higher dissimilarity observed across school environments in developing countries, such as in Peru, when compared to developed countries.

We found that children attending schools with lower number of students were more likely to be overweight, whereas those attending schools with playground areas without obstacles and without multi-sports roofed were less likely to be overweight. Because school size was defined according to the number of enrolled students, schools with more students apparently have more space and facilities for children to play during their recess time, and have greater potential to increase children’s physical activity levels (A. Cradock, S. Melly, J. Allen, J. Morris, & S. Gortmaker, 2007), which could also promote a positive effects in their weight status. Furthermore, it is possible that a playground without obstacles represents a greater free space for children to play, acting as a protective agent of overweight during childhood.

In an effort to fight childhood overweight and obesity, school-based healthy eating and physical activity programs have been implemented across the globe, providing opportunities to enhance children’s future health and well-being (Veugelers & Fitzgerald, 2005). Surprisingly, we found an inverse effect in our results, probably because the effectiveness of these programs is not yet very well established. For example, in a systematic review of intervention studies, Campbell, Waters, O'meara, and Summerbell (2001) only tracked seven studies on prevention of childhood obesity: four revealed effective programs whereas three did not. In fact, the lack of evidence exploring how policies and practices within the school system are associated with an individual student’s risk of being overweight continues to represent an important gap in the available literature (Veugelers & Fitzgerald, 2005). Finally, Peruvian students from schools with two Physical Education classes per week, with a maximum of 90 minutes’ duration, were less likely to be overweight. In Peru, physical education classes are mandatory by government authorities, and all students are engaged in at least 1 class per week. As such, it is of no surprise that students who have 2 classes per week were less likely to be overweight.

This study is not without limitations. Firstly, the cross-sectional nature of the design does not allow a dynamic analysis of intraindividual changes and interindividual differences in overweight/obesity unfolding during childhood and adolescence. Yet, no study is apparently available in South America sampling hundreds/thousands of children and adolescents from different socio-geographic areas. Secondly, notwithstanding the size of our sample, it is not representative of the Peruvian population and care must be taken when trying to generalize our results. Thirdly, we were not able to obtain information about dietary habits and objective measures of physical activity. Fourthly, our results were not adjusted for the putative influence of family income and/or insurance status. Despite these short-comings, the study has several merits: firstly, we sampled children aged 6 to 16 yrs which represents an important growth and developmental time window; secondly, we used standard methods and highly reliable data at the individual and school levels; thirdly, we relied on multilevel modelling to capture the complexity of the nested information – children within their schools; fourthly, the inclusion of three different geographical areas of residence permitted a more comprehensive interpretation of differences in childhood.

CONCLUSIONS

In summary, the present study showed that the prevalence of overweight in Peruvian children and adolescents decreased with age, was higher in girls, and was also higher at sea-level compared to the Amazon region and high-altitude. Child-level variables (age, sex, maturation, PF_z, and geographical area of residence), as well as school-level variables (number of students, policies and practices for physical activity, playground area, multi-sports roofed, frequency and duration of Physical Education classes) played important roles in explaining variation in childhood overweight. This information should be take into account when designing more efficient strategies to combat the overweight and obesity epidemic.

DATA AVAILABILITY

The datasets generated and analysed during the current study are not publicly available due to privacy laws associated with children's data, but are available with a data sharing agreement as approved by the ethics committee of the National University of Education Enrique Guzmán y Valle, Lima, Peru.

CONFLICT OF INTEREST STATEMENT

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

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AUTHOR CONTRIBUTIONS

CS, DH and JM analyzed the data. CS, JM, DH, PTK and AB drafted the manuscript. AB and JM designed the study and directed its implementation. AB and JM provided necessary logistical support. AB, DH, OV, RG and PTK provided extensive critical comments and did the final editing of the manuscript.

SUPPLEMENTARY MATERIALS

We provide the following supplementary information: Supplementary table 1 – Sample size and frequencies [n (%)] for BMI categories (normal weight and overweight) according to IOTF cut-off points, by age, sex and geographical area of residence); Supplementary table 2 – Sample size and frequencies [n (%)] for BMI categories (normal weight and overweight) according to WHO cut-off points, by age, sex and geographical area of residence; and Supplementary table 3 – Multilevel modelling results: odds ratios (OR) and 95% confidence intervals (95%CI) for child- and school-level characteristics. All these supplementary materials were referenced at appropriate sections in the manuscript.

REFERENCES

1. Ng, M., et al., *Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013.* Lancet, 2014. **384**(9945): p. 766-781.

2. Lobstein, T., L. Baur, and R. Uauy, *Obesity in children and young people: a crisis in public health.* Obes Rev, 2004. **5**: p. 4-85.

3. Guh, D., et al., *The incidence of co-morbidities related to obesity and overweight: a systematic review and meta-analysis.* BMC Public Health, 2009. **9**(1): p. 88.

4. Withrow, D. and D. Alter, *The economic burden of obesity worldwide: a systematic review of the direct costs of obesity.* Obes Rev, 2011. **12**(2): p. 131-141.

5. Abarca-Gómez, L., et al., *Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128· 9 million children, adolescents, and adults.* Lancet, 2017. **390**(10113): p. 2627-2642.

6. Yang, L., et al., *Prevalence of underweight and overweight among young adolescents aged 12–15 years in 58 low‐income and middle‐income countries.* Pediatr Obes, 2018.

7. Filozof, C., et al., *Obesity prevalence and trends in Latin‐American countries.* Obes Rev, 2001. **2**(2): p. 99-106.

8. Rivera, J., et al., *Childhood and adolescent overweight and obesity in Latin America: a systematic review.* Lancet Diabetes Endocrinol, 2014. **2**(4): p. 321-332.

9. Pomeroy, E., et al., *Stunting, adiposity, and the individual‐level "dual burden" among urban lowland and rural highland peruvian children.* Am J Hum Biol, 2014. **26**(4): p. 481-490.

10. Pajuelo-Ramírez, J., et al., *Overweight, obesity and chronic mal nutrition in 6 to 9 year-old children in Peru, 2009-2010.* Rev Peru Med Exp Salud Publica, 2013. **30**(4): p. 583-589.

11. Narciso, J., et al., *Behavioral, contextual and biological factors associated with obesity during adolescence: A systematic review.* PLoS One, 2019. **14**(4): p. e0214941.

12. Wells, J., *Sexual dimorphism of body composition.* Best Pract. Res. Clin. Endocrinol. Metab., 2007. **21**(3): p. 415-430.

13. Hanley, A., et al., *Overweight among children and adolescents in a Native Canadian community: prevalence and associated factors.* Am J Clin Nutr, 2000. **71**(3): p. 693-700.

14. Wang, Y., *Is obesity associated with early sexual maturation? A comparison of the association in American boys versus girls.* Pediatrics, 2002. **110**(5): p. 903-910.

15. Kim, J., et al., *Relationship of physical fitness to prevalence and incidence of overweight among schoolchildren.* Obes Res, 2005. **13**(7): p. 1246-1254.

16. Riedel, C., et al., *Interactions of genetic and environmental risk factors with respect to body fat mass in children: results from the ALSPAC study.* Obesity, 2013. **21**(6): p. 1238-1242.

17. Mispireta, M., et al., *Transición nutricional en el Perú, 1991-2005.* Rev Peru Med Exp Salud Publica, 2007. **24**(2): p. 129-135.

18. Huynen, M., et al., *The epidemiologic transition in Peru.* Rev Panam Salud Publica, 2005. **17**: p. 51-59.

19. Torres-Roman, J., et al., *Geographic differences in overweight and obesity prevalence in Peruvian children, 2010–2015.* BMC public health, 2018. **18**(1): p. 353.

20. Tarqui-Mamani, C., D. Alvarez-Dongo, and P. Espinoza-Oriundo, *Prevalence and factors associated with overweight and obesity in Peruvian primary school children.* Rev Salud Publica, 2018. **20**(2): p. 171-176.

21. Álvarez-Dongo, D., et al., *Sobrepeso y obesidad: prevalencia y determinantes sociales del exceso de peso en la población peruana (2009-2010).* Rev Peru Med Exp Salud Publica, 2012. **29**: p. 303-313.

22. Procter, K.L., et al., *Measuring the school impact on child obesity.* Soc Sci Med, 2008. **67**(2): p. 341-349.

23. O’Malley, P., et al., *Variation in obesity among American secondary school students by school and school characteristics.* Am J Prev Med, 2007. **33**(4): p. S187-S194.

24. Pallan, M., et al., *Are school physical activity characteristics associated with weight status in primary school children? A multilevel cross-sectional analysis of routine surveillance data.* Arch. Dis. Child., 2014. **99**(2): p. 135-141.

25. INEI. *Perfil Sociodemográfico del Perú. Informe nacional*. 2017 [cited 2019 18 February]; Available from:

https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1539/index.html.

26. Bustamante, A., G. Beunen, and J. Maia, *Como crecen y se desarrollan los niños y adolescentes en La Merced y San Ramón.* Alcances para la Educación Física, el Deporte y la Salud. Lima: Universidad Nacional de Educación, 2011: p. 174.

27. ESCALE. 2010 [cited 2019 18 February]; Available from: http://escale.minedu.gob.pe/magnitudes.

28. Cole, T., et al., *Establishing a standard definition for child overweight and obesity worldwide: International survey.* BMJ, 2000. **320**: p. 1240-1243.

29. Onis, M., et al., *Development of a WHO growth reference for school-aged children and adolescents.* Bull. World Health Organ., 2007. **85**: p. 660-667.

30. Eveleth, P. and J. Tanner, *Worldwide Variation in Human Growth* 2nd ed. 1990, Cambridge: Cambridge University Press.

31. Lohman, T., A. Roche, and R. Martorell, *Anthropometric standarization reference manual.* Champaign, IL: Human Kinetics Books, 1988.

32. Mirwald, R., et al., *An assessment of maturity from anthropometric measurements.* Med Sci Sports Exerc, 2002. **34**(4): p. 689-694.

33. AAHPERD, *Health related physical fitness: Test manual*. 1980, Reston, VA: American Alliance for Health, Physical Education, Recreation and Dance.

34. EUROFIT, *Handbook for the EUROFIT tests of physical fitness*. 2nd ed. 1993, Strasbourg: Committee of Experts on Sports Research.

35. Huang, Y. and R.M. Malina, *BMI and health-related physical fitness in Taiwanese youth 9-18 years.* Med Sci Sports Exerc, 2007. **39**(4): p. 701-708.

36. Joint Consortium for School Health. *Healthy School Planner*. 2012 18 October 2018]; Available from: www.healthyschoolplanner.uwaterloo.ca.

37. Snijders, T.A.B. and R.J. Bosker, *Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling*. 2nd ed. 2012, London: Sage Publishers.

38. Hox, J.J., M. Moerbeek, and R. Van de Schoot, *Multilevel analysis: Techniques and applications* ed. r. ed. 2018, New York, USA: Routledge.

39. Hedeker, D., et al., *Supermix: Mixed effects models*. 2008, Lincolnwood, IL, USA: Scientific Software International, Inc.

40. Hernández-Vásquez, A., et al., *Análisis espacial del sobrepeso y la obesidad infantil en el Perú, 2014.* Rev Peru Med Exp Salud Publica, 2016. **33**: p. 489-497.

41. Kanter, R. and B. Caballero, *Global gender disparities in obesity: a review.* Adv Nutr, 2012. **3**(4): p. 491-498.

42. Preston, E., et al., *Prevalence of childhood overweight and obesity and associated factors in Peru.* Rev Panam Salud Publica, 2015. **38**: p. 472-478.

43. Katzmarzyk, P.T., et al., *Relationship between lifestyle behaviors and obesity in children ages 9–11: Results from a 12-country study.* Obesity, 2015. **23**(8): p. 1696-1702.

44. Katzmarzyk, P.T., et al., *Sources of variability in childhood obesity indicators and related behaviors.* Int J Obes, 2018. **42**(1): p. 108.

45. Cremm, E., et al., *Factors associated with overweight in children living in the neighbourhoods of an urban area of Brazil.* Public Health Nutr, 2012. **15**(6): p. 1056-1064.

46. Gasser, T., et al., *An analysis of the mid-growth and adolescent spurts of height based on acceleration.* Ann. Hum. Biol., 1985. **12**(2): p. 129-148.

47. Riggs, B., S. Khosla, and L. Melton III, *Sex steroids and the construction and conservation of the adult skeleton.* Endocr. Rev., 2002. **23**(3): p. 279-302.

48. Gomes, T.N., et al., *Overweight and obesity in Portuguese children: prevalence and correlates.* Int J Environ Res Public Health, 2014. **11**(11): p. 11398-11417.

49. Ahmed, M., K. Ong, and D. Dunger, *Childhood obesity and the timing of puberty.* Trends Endocrinol. Metab., 2009. **20**(5): p. 237-242.

50. Gonzales, G. and A. Villena, *Body mass index and age at menarche in Peruvian children living at high altitude and at sea level.* Human biology, 1996: p. 265-275.

51. Ortega, F., et al., *Fitness and Fatness as Health Markers through the Lifespan: An Overview of Current Knowledge.* Adv Prev Med., 2018. **3**(2): p. e0013.

52. Rodrigues, L., D. Stodden, and V. Lopes, *Developmental pathways of change in fitness and motor competence are related to overweight and obesity status at the end of primary school.* J Sci Med Sport, 2016. **19**(1): p. 87-92.

53. McGavock, J., et al., *Cardiorespiratory fitness and the risk of overweight in youth: the Healthy Hearts Longitudinal Study of Cardiometabolic Health.* Obesity, 2009. **17**(9): p. 1802-1807.

54. Stodden, D., et al., *A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship.* Quest, 2008. **60**(2): p. 290-306.

55. Riepl, R.L., et al., *Influence of acute exposure to high altitude on basal and postprandial plasma levels of gastroenteropancreatic peptides.* PLoS One, 2012. **7**(9): p. e44445.

56. Basu, R. and J.M. Samet, *Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence.* Epidemiol Rev, 2002. **24**(2): p. 190-202.

57. Antezana, A.M., et al., *Hormonal changes in normal and polycythemic high-altitude natives.* J Appl Physiol (1985), 1995. **79**(3): p. 795-800.

58. Woolcott, O.O., et al., *Inverse association between altitude and obesity: A prevalence study among andean and low-altitude adult individuals of Peru.* Obesity (Silver Spring), 2016. **24**(4): p. 929-37.

59. Woolcott, O.O., et al., *Inverse association between diabetes and altitude: a cross-sectional study in the adult population of the United States.* Obesity (Silver Spring), 2014. **22**(9): p. 2080-90.

60. Cradock, A., et al., *Characteristics of school campuses and physical activity among youth.* Am J Prev Med, 2007. **33**(2): p. 106-113. e1.

61. Veugelers, P. and A. Fitzgerald, *Effectiveness of school programs in preventing childhood obesity: a multilevel comparison.* Am J Public Health, 2005. **95**(3): p. 432-435.

62. Campbell, K., et al., *Interventions for preventing obesity in childhood. A systematic review.* Obes Rev, 2001. **2**(3): p. 149-157.

Supplementary Table 1. Sample size and frequencies [n (%)] for BMI categories (normal weight and overweight) according to IOTF cut-off points, by age, sex and geographical area of residence.

	Sea-level (Barranco)				**Amazon region** (La Merced and San Ramon)				**High-altitude** (Junín)				**All areas**			
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
Age (yrs)	Normalweight		Overweight		Normalweight		Overweight		Normalweight		Overweight		Normalweight		Overweight	
6	62 (60.2)	28 (62.2)	41 (39.8)	17 (37.8)	118 (67.0)	109 (72.2)	58 (33.0)	42 (27.8)	46 (93.9)	53 (94.6)	3 (6.1)	3 (5.4)	226 (68.9)	190 (75.4)	102 (31.1)	62 (24.6)
7	37 (47.4)	13 (33.3)	41 (52.6)	26 (66.7)	127 (80.4)	185 (79.4)	31 (19.6)	48 (20.6)	69 (89.6)	53 (93.0)	8 (10.4)	4 (7.0)	233 (74.4)	251 (76.3)	80 (25.6)	78 (23.7)
8	52 (55.3)	30 (43.5)	42 (44.7)	39 (56.5)	191 (82.7)	166 (79.8)	40 (17.3)	42 (20.2)	59 (100)	57 (83.8)	0 (0.0)	11 (16.2)	302 (78.6)	253 (73.3)	82 (21.4)	92 (26.7)
9	66 (47.5)	28 (43.8)	73 (52.5)	36 (56.3)	169 (80.9)	188 (78.7)	40 (19.1)	51 (21.3)	74 (91.4)	92 (87.6)	7 (8.6)	13 (12.4)	309 (72.0)	308 (75.5)	120 (28.0)	100 (24.5)
10	61 (60.4)	44 (62.0)	40 (39.6)	27 (38.0)	227 (83.5)	198 (80.2)	45 (16.5)	49 (19.8)	85 (100)	100 (98.0)	0 (0.0)	2 (2.0)	373 (81.4)	342 (81.4)	85 (18.6)	78 (18.6)
11	76 (55.9)	54 (49.1)	60 (44.1)	56 (50.9)	176 (76.2)	178 (76.1)	55 (23.8)	56 (23.9)	94 (87.9)	80 (100)	13 (12.1)	0 (0.0)	346 (73.0)	312 (73.6)	128 (27.0)	112 (26.4)
12	56 (49.1)	46 (43.8)	58 (50.9)	59 (56.2)	247 (82.3)	168 (88.0)	53 (17.7)	23 (12.0)	174 (95.6)	119 (95.2)	8 (4.4)	6 (4.8)	477 (80.0)	333 (79.1)	119 (20.0)	88 (20.9)
13	49 (57.6)	21 (67.7)	36 (42.4)	10 (32.3)	224 (82.4)	140 (83.3)	48 (17.6)	28 (16.7)	91 (89.2)	127 (96.2)	11 (10.8)	5 (3.8)	364 (79.3)	288 (87.0)	95 (20.7)	43 (13.0)
14	106 (71.1)	46 (62.2)	43 (28.9)	28 (37.8)	188 (82.5)	145 (91.2)	40 (17.5)	14 (8.8)	137 (95.1)	134 (95.0)	7 (4.9)	7 (5.0)	431 (82.7)	325 (86.9)	90 (17.3)	49 (13.1)
15	100 (83.3)	87 (73.1)	20 (16.7)	32 (26.9)	159 (83.7)	171 (89.1)	31 (16.3)	21 (10.9)	122 (88.4)	112 (100)	16 (11.6)	0 (0.0)	381 (85.0)	370 (87.5)	67 (15.0)	53 (12.5)
16	64 (79.0)	27 (75.0)	17 (21.0)	9 (25.0)	75 (85.2)	79 (88.8)	13 (14.8)	10 (11.2)	64 (85.3)	62 (100)	11 (14.7)	0 (0.0)	203 (83.2)	168 (89.8)	41 (16.8)	19 (10.2)
Total	**729**	**424**	**471**	**339**	**1901**	**1727**	**454**	**384**	**1015**	**989**	**84**	**51**	**3645**	**3140**	**1009**	**774**

Supplementary Table 2. Sample size and frequencies [n (%)] for BMI categories (normal weight and overweight) according to WHO cut-off points, by age, sex and geographical area of residence.

	Sea-level (Barranco)				**Amazon region** (La Merced and San Ramon)				**High-altitude** (Junín)				**All areas**			
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
Age (yrs)	Normalweight		Overweight		Normalweight		Overweight		Normalweight		Overweight		Normalweight		Overweight	
6	60 (58.3)	21 (46.7)	43 (41.7)	24 (53.3)	113 (64.2)	94 (62.3)	63 (35.8)	57 (37.7)	44 (89.8)	49 (87.5)	5 (10.2)	7 (12.5)	217 (66.2)	164 (65.1)	111 (33.8)	88 (34.9)
7	34 (43.6)	12 (30.8)	44 (56.4)	27 (69.2)	122 (77.2)	162 (69.5)	36 (22.8)	71 (30.5)	68 (88.3)	48 (84.2)	9 (11.7)	9 (15.8)	224 (71.6)	222 (67.5)	89 (28.4)	107 (32.5)
8	46 (48.9)	24 (34.8)	48 (51.1)	45 (65.2)	190 (82.3)	140 (67.3)	41 (17.7)	68 (32.7)	59 (100)	55 (80.9)	0 (0.0)	13 (19.1)	295 (76.8)	219 (63.5)	89 (23.2)	126 (36.5)
9	64 (46.0)	23 (35.9)	75 (54.0)	41 (64.1)	161 (77.0)	167 (69.9)	48 (23.0)	72 (30.1)	74 (91.4)	81 (77.1)	7 (8.6)	24 (22.9)	299 (69.7)	271 (66.4)	130 (30.3)	137 (33.6)
10	56 (55.4)	36 (50.7)	45 (44.6)	35 (49.3)	224 (82.4)	185 (74.9)	48 (17.6)	62 (25.1)	79 (92.9)	94 (92.2)	6 (7.1)	8 (7.8)	359 (78.4)	315 (75.0)	99 (21.6)	105 (25.0)
11	70 (51.5)	47 (42.7)	66 (48.5)	63 (57.3)	172 (74.5)	164 (70.1)	59 (25.5)	70 (29.9)	94 (87.9)	76 (95.0)	13 (12.1)	4 (5.0)	336 (70.9)	287 (67.7)	138 (29.1)	137 (32.3)
12	52 (45.6)	36 (34.3)	62 (54.4)	69 (65.7)	235 (78.2)	155 (81.2)	65 (21.7)	36 (18.8)	170 (93.4)	117 (93.6)	12 (6.6)	8 (6.4)	457 (76.7)	308 (73.2)	139 (23.3)	113 (26.8)
13	49 (57.6)	16 (51.6)	36 (42.4)	15 (48.4)	219 (80.5)	130 (77.4)	53 (19.5)	38 (22.6)	91 (89.2)	123 (93.2)	11 (10.8)	9 (6.8)	359 (78.2)	269 (81.3)	100 (21.8)	62 (18.7)
14	103 (69.1)	45 (60.8)	46 (30.9)	29 (39.2)	184 (80.7)	145 (91.2)	44 (19.3)	14 (8.8)	137 (95.1)	132 (93.6)	7 (4.9)	9 (6.4)	424 (81.4)	322 (86.1)	97 (18.6)	52 (13.9)
15	99 (82.5)	87 (73.1)	21 (17.5)	32 (26.9)	159 (83.7)	166 (86.5)	31 (16.3)	26 (13.5)	121 (87.7)	112 (100)	17 (12.3)	0 (0.0)	379 (84.6)	365 (86.3)	69 (15.4)	58 (13.7)
16	62 (76.5)	27 (75.0)	19 (23.5)	9 (25.0)	75 (85.2)	79 (88.8)	13 (14.8)	10 (11.2)	63 (84.0)	62 (100)	12 (16.0)	0 (0.0)	200 (82.0)	168 (89.8)	44 (18.0)	19 (10.2)
Total	**695**	**374**	**505**	**389**	**1854**	**1587**	**501**	**524**	**1000**	**949**	**99**	**91**	**3549**	**2910**	**1105**	**1004**

Supplementary Table 3. Multilevel modelling results: odds ratios (OR) and 95% confidence intervals (95%CI) for child- and school-level characteristics

	WHO			
Parameters	Null model (M$_0$)	Model 1 (M$_1$)	Model 2 (M$_2$)	Model 3 (M$_3$)
Regression coefficients (fixed effects)				
Level-1 child-level				
Intercept	0.23 (0.15-0.35)*	4.52 (2.77-7.39)*	0.95 (0.35-2.61)^{ns}	22.61 (8.44-60.57)*
Age		0.19 (0.17-0.22)*	0.19 (0.17-0.21)*	0.19 (0.17-0.21)*
Sex (boys)*		3.31 (2.80-3.92)*	3.31 (2.81-3.89)*	3.51 (3.01-4.09)*
Interaction (age-by-sex)		0.74 (0.71-0.78)*	0.74 (0.71-0.78)*	0.75 (0.72-0.79)*
Maturity offset (yrs to PHV)		10.29 (8.85-11.97)*	10.44 (8.97-12.14)*	10.38 (8.92-12.08)*
PF$_z$		0.83 (0.79-0.86)*	0.83 (0.79-0.86)*	0.82 (0.79-0.86)*
Geographical area of residence (High-altitude)$^{¤}$				0.09 (0.04-0.18)*
Geographical area of residence (Amazon region)				1.09 (0.70-1.69)^{ns}
Level-2 school-level				
Number of students†			1.02 (1.01-1.02)*	0.98 (0.97-0.99)*
School setting (urban)$^{\Theta}$			0.70(0.41-1.20)^{ns}	1.27 (0.90-1.81)^{ns}
Existence policies or/and practices for physical activity (policies)$^{\infty}$			4.32 (2.35-7.93)*	3.64 (2.24-5.93)*
Existence policies or/and practices for physical activity (practices)			2.45 (1.65-3.64)*	1.22 (1.01-1.64)*
Playground area (without obstacles)$^{£}$			1.68 (0.68-4.16)^{ns}	0.15 (0.06-0.36)*
Multi-sports roofed (no)$^{¥}$			2.22 (1.46-3.36)*	0.43 (0.27-0.68)*
Frequency of physical education classes (two)$^{\alpha}$			1.94 (0.51-7.42)^{ns}	0.07 (0.02-0.25)*
Duration of physical education classes (>90 min)§			2.98 (1.89-4.69)*	3.60 (2.67-4.84)*
Extracurricular activities (no)$^{\Delta}$			0.61 (0.40-0.92)*	0.89 (0.67-1.19)^{ns}
Variance components (random effects)				
Intercept	0.80±0.28	0.90±0.32	0.05±0.03	0.00±0.00
Model summary				
Deviance	8686.31	7385.03	7341.06	7314.74
Number of estimated parameters	2	7	16	18

*p<0.001; ^{ns}= non-significant; *Girls are the reference; $^{¤}$Sea-level is the reference; †Divided by 10; $^{\Theta}$Mixed is the reference; $^{\infty}$No policies and practices is the reference; $^{£}$with obstacles is the reference; $^{¥}$Yes is the reference; $^{\alpha}$One is the reference; §90 min is the reference; $^{\Delta}$Yes is the reference; PF$_z$ = total physical fitness score

Paper IV

A multilevel analysis of gross motor coordination of children and adolescents living at different altitudes: the Peruvian Health and Optimist Growth Study

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ABSTRACT

Background: Gross motor coordination (GMC) is a potential correlate of lifestyle behaviours and health outcomes in childhood and adolescence. Aims: The aim of this study was to examine how sex, age, biological maturation, overweight, stunting, and physical fitness are associated with GMC in children and adolescents from Peru, and to examine associations between geographical area of residence, school-level characteristics, and GMC.

Subjects and methods: The sample included 7408 subjects, aged 6–14 years, from sea level, Amazon and high-altitude regions of Peru. A composite marker of total coordination was derived by the sum of scores from each test (GMC_T). Overweight was identified using BMI, and biological maturation, physical fitness, and stunting were assessed. School characteristics were obtained via an objective audit.

Results: Boys (β=12.23±0.90) and older children (β=13.37±0.64) had higher GMC_T than girls and younger, respectively. Overweight was associated with lower GMC_T (β=-5.23±0.80), whereas fitness was positively associated with GMC_T (β=6.30±0.25). Biological maturation was not a predictor; however, stunting was negatively associated with GMC_T (β=-3.71±1.56). Subjects living in the Amazon had higher GMC_T than those at sea-level (β=16.57±4.73). Five out of nine school-level predictors (number of students, playground area with obstacles, multi-sports roofed, frequency and duration of Physical Education classes) were significant predictors of GMC_T.

Conclusions: Child- and school-level variables were significantly associated with GMC_T in this sample. These findings are important for the Peruvian community, especially school principals, councils and physical education teachers, helping them to define more efficient strategies and action plans to increase motor coordination in children.

Keywords: children and adolescents; gross motor coordination; school context; environment; multilevel modelling

INTRODUCTION

Gross motor coordination (GMC) has been defined as the harmonious and economic interactions of the muscular, skeletal, nervous and sensorial systems aiming to produce precise and balanced motor actions, as well as adapted reactions to varied situations (Kiphart & Schilling, 1974). Further, cross-sectional (Chaves et al., 2015; Luz et al., 2018) and longitudinal studies (Deus et al., 2010; Willimczik, 1980), as well as systematic reviews (Barnett et al., 2016; Maria Teresa Cattuzzo et al., 2016), have provided evidence of a positive association between GMC and several health-related factors such as cardiorespiratory fitness and weight status. Additionally, motor skill efficiency, i.e., the mature display of fundamental and combined motor skills (Ré et al., 2018), cognition, and intelligence (van der Fels et al., 2015) have been associated with GMC in children and adolescents. The same pattern seems to occur with health-related physical fitness (Vandendriessche et al., 2011), cardiometabolic health (Wahi et al., 2011), and health-related habits like moderate-to-vigorous physical activity, healthy eating habits, and screen time (David R Lubans, Morgan, Cliff, Barnett, & Okely, 2010).

Levels of GMC are potentially influenced by a plethora of biological and environmental factors (Claude Bouchard, Malina, & Pérusse, 1997; Chaves et al., 2015). For example, a gradual and steady increase in GMC is expected to occur with increasing age, from 5 to 15 years of age (Kiphard & Schilling, 1974), and more mature subjects have, on average, higher levels of GMC (Freitas et al., 2016). Sex-specific differences have also been reported, mostly favouring boys (Barnett et al., 2016), although some studies have reported a different trend, with girls outperforming boys (M. A. M. Dos Santos et al., 2018; A. C. Reyes et al., 2019). On the other hand, more physically fit children and adolescents tend to be more coordinated (Chaves et al., 2016), while those with overweight or obesity were more prone to display lower GMC levels (Vítor P Lopes, David F Stodden, Mafalda M Bianchi, Jose AR Maia, & Luis P Rodrigues, 2012).

Variation in GMC levels of children and adolescents is also associated with the natural (ex: weather severe conditions, exposure to altitude) and built (ex:

public recreational infrastructures) environments. In Peru, three natural areas (sea-level, Amazon region and high-altitude) exist, which mirrors the country's diversity of geographic, demographic, socioeconomic and education features (INEI, 2018). However, it appears that information regarding GMC levels and developmental patterns is scarce in Peru as we were only able to identify two studies (de Chaves et al, 2016; Valdivia et al, 2018). Chaves et al. (2016) reported that sea-level and high-altitude children were more likely to suffer from GMC problems than their peers from the Amazon region, and Valdívia et al. (2018) found that sibling pairs from the Amazon region had higher GMC levels than those from the other areas.

It has consistently been reported that living in adverse conditions such as at high altitudes, might be associated with short stature (stunting) (Frisancho, 1978; Frisancho & Baker, 1970), which has also been related to maturation delay (Cossio-Bolaños et al., 2015), and overweight and/or obesity (Emma Pomeroy et al., 2014; Urke, Mittelmark, & Valdivia, 2014). Thus, it would be of interest to investigate putative links between stunting and GMC in Peruvian youth living at different altitudes.

Since children and adolescents spend a great part of their daily life at school, it is of interest to understand whether features of the school environment are associated with GMC (Morgan et al., 2013). Schools are highly organized and structured institutions offering children and adolescents a wide range of spaces, infrastructure, equipment, as well as other resources, in order to provide enriching opportunities for motor learning and development. For example, Chaves et al. (2015) reported that the school context explained 10% of the total GMC variation among Portuguese children, although Ana Carolina Reyes et al. (2019) found no apparent link.

We contend that a more extensive and integrative examination highlighting the combined effects of individual characteristics and environmental factors (geographical area of residence as well as the school context), is of great importance to better understand why Peruvian children and adolescents living at different altitudes differ in their GMC. Hence, based on a multilevel modelling approach, we aim to examine how sex, age, biological maturation, overweight, stunting, and physical fitness are associated with GMC in children and adolescents from Peru, and to examine associations between geographical area of residence, school-level characteristics, and GMC. The following hypotheses were tested: (1) older children are more coordinated than younger ones, and boys outperform girls; (2) biological maturation, overweight, stunting and physical fitness are associated with GMC; (3) geographical area of residence and school-level characteristics are associated with GMC.

MATERIALS AND METHODS

Study participants

The sample is from the *Peruvian Health and Optimist Growth Study*. Very briefly, this cross-sectional research project examines the complex network of relationships between physical growth, motor development, and markers of health in Peruvian children and adolescents living at different altitudes (Bustamante et al., 2011). Data were collected between November and December (2009) and April and July (2010) in Barranco, May and August (2010) in La Merced and San Ramon, and September and October (2009) in Junín.

In this report we used a sample of 7408 children and adolescents (3283 boys, aged 6-14 yrs), from 18 random public schools located in the three geographical areas of the central region of Peru: (1) sea-level: in the coast, Barranco (58 m) is one of the 43 districts of Lima Province, and is located on the shore of the Pacific Ocean; (2) Amazon region: in the jungle area La Merced and San Ramon (751 m) are districts with geographical continuity and integrate the Chanchamayo province; (3) in high-altitude, Junín is located on a plateau at 4107 m in the central Andes mountains. The sample was selected according to the following criteria: (1) all children were native from their respective regions (i.e., no migrants were included, regardless of whether their parents or grandparents were migrants). We gathered information about their birth place and current place of residence or address and cross-checked this information with participants' identity cards; and (2) all children had complete data on GMC and all covariates. Additionally, the percentage of missing data varied from 4% to 10% in physical fitness tests and from 5% to 6% in GMC tests, and do not significantly differ (p>0.05) from those considered in our parental data set.

Formal permission from schools´ governmental bodies and written informed consent from parents/legal guardians was obtained. The Ethics Committee of the National University of Education Enrique Guzmán y Valle (UNE EGyV), as well as all school directors approved the project. Information about sample size by age, sex and geographical area of residence are presented in Table 1.

Table 1. Sample size by sex, age and geographical area of residence

Age (yrs)†	**Sea-level** (Barranco)		**Amazon region** (La Merced and San Ramon)		**High-altitude** (Junín)		**All areas**	
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
6	104	45	179	154	50	60	333	259
7	74	28	162	241	82	60	318	329
8	87	36	238	219	70	84	395	339
9	126	43	216	247	92	110	434	400
10	99	42	288	249	94	105	481	396
11	143	82	242	249	112	80	497	411
12	115	102	320	192	191	129	626	423
13	89	32	291	177	112	136	492	345
14	149	73	249	162	151	146	549	381
Total	986	483	2185	1890	954	910	4125	3283

†Age was used as decimals of a yr and children aged 5.5 to 6.49 yrs were designated as 6, children aged 6.50 to 7.49 yrs as 7, and so on (Eveleth & Tanner, 1990).

Child-level correlates

Groos motor coordination

The *KöperkoordinationsTest für Kinder* battery (KTK) developed in German by Kiphard and Schilling (1974) was used to assess GMC. It has been reported as a valid and reliable measure (Iivonen, Sääkslahti, & Laukkanen, 2015), and is consistently used in several countries (Moreira et al., 2019; A. C.

Reyes et al., 2019), including Peru (Chaves et al., 2016; Valdívia et al., 2018). All four tests were performed according to their standardized protocols: (1) walking backwards on balance beams: each subject walked three times along each of three balance beams, each with a different width. For each balance beam, a maximum of 24 steps (eight per trial, and 3 trials) were counted, with maximum of 72 steps (24 steps in 3 beams) for this test; (2) moving sideways: each subject moved across the floor for 20 s (two trials) by stepping from one plate to the next, transferring to the first plate, stepping on it. The number of relocations was counted and summed over trials; (3) hopping for height on one foot: each subject jumped from one leg over an increasing pile of pillows after a short run-up. The successful performance on the first trial corresponds to 3 points, on the second to 2 points and on the third trial to 1 point. A maximum of 39 points (maximum of 12 pillows) could be scored for each leg, yielding a possible maximum score of 78 points; (4) jumping sideways: each subject jumped laterally as many times as possible over a wooden slat in 15 s, in two trials. The number of jumps over the two trials was summed. The sum of scores from each test was used as a measure of total GMC (GMC_T) as advocated (Kiphard & Schilling, 1974).

Anthropometry

The standardized procedures of T. Lohman et al. (1988) were used to measure height and sitting height with the head positioned in the Frankfurt plane to the nearest 0.1 cm with a portable stadiometer (Sanny, Model ES-2060), and body weight was measured to the nearest 0.1 kg using a digital scale (Pesacon, Model IP68). Body mass index (BMI) was computed using the standard formula [weight (kg)/height $(m)^2$], and subjects were classified in two groups [normal weight, and overweight (including obesity)] according to World Health Organization (WHO) (Onis et al., 2007) criteria. BMI z-scores (normal weight: <1SD; overweight: ≥1SD) were computed. A dummy coding was created, with normal-weight coded as 0 (reference category), and overweight (including obesity) coded as 1.

Biological maturation

Biological maturation was assessed with the maturity offset (Mirwald et al., 2002), which estimates time before or after age-at-peak height velocity (aPHV). Formulas are sex-specific and use chronological age, height, sitting height, and leg length. A positive (+) maturity offset indicates the number of estimated yrs a child is beyond aPHV; a negative (-) maturity offset is the number of estimated yrs a child is before the aPHV, whereas a zero value indicates that a child is experiencing his/her aPHV.

Physical fitness

Three components of performance-related physical fitness were assessed using three tests from AAHPERD (1980) and EUROFIT (1993) batteries: muscular strength (standing long jump), agility (shuttle-run), and cardiorespiratory fitness (12 minute run). All tests were performed according to their standardized protocols: (1) standing long jump (SLJ; cm): each subject stood with feet apart behind the take-off line and, without a preparatory run, were instructed to jump as far as possible. The maximum jumping distance was recorded. Two trials were given and the best score was recorded as the maximum jumping distance in centimetres; (2) shuttle-run test (SR; s): each subject performed five cycles (round-trip) at maximum speed between two lines separated by five meters; and (3) 12 minute run test (m): in a previously delimited field, schoolchildren ran/walked the maximum possible distance in 12 minutes. All physical fitness test results were converted to z-scores using a grand-mean centering, and a total physical fitness score (PF_Z) was obtained by summing all individual z-scores as suggested (Y. Huang & R. M. Malina, 2007).

Stunting

Stunting was defined according to the World Health Organization (WHO) (Onis et al., 2007) cut-off points. Stunting z-scores (height-for-age <2SD) were computed using the syntax file provided by World Health Organization (2006). A dummy coding was created, with no stunting coded as 0 (reference category), and stunting coded as 1.

Socio-geographic context

Geographical areas of residence were located at different altitudes: sea-level (58 m), Amazon region (751 m) and high-altitude (4107 m). A coding scheme was generated with two dummies: sea-level, the reference category, was coded as 0 0, high-altitude was 1 0 and Amazon region was 0 1.

School-level correlates

Information about school characteristics was obtained via an objective school audit, using a modified and locally adapted version of the Healthy Eating and Physical Activity modules of the Healthy School Planner designed by the Joint Consortium for School Health (Joint Consortium for School Health, 2012). This audit was led by the experienced research team members and includes information on the following domains: (1) school characterization (school size – number of students were divided by 10 as to have more interpretable parameter estimates; and school setting – mixed is the reference category, and urban); (2) physical structure of the school (playground area – without obstacles was the reference category; playground equipment – no was the reference category; multipurpose hall – no was the reference category; and multi-sports roofed – no was the reference category); (3) physical education classes (frequency – one was the reference category; and duration – 90 min was the reference category); and (4) extracurricular activities (no was the reference category).

Data quality control

Quality control was assured in four steps: (1) training and careful supervision of all team members concerning technical procedures of body measurements, physical fitness and GMC test protocols (2) conducting a pilot study to assess the quality of data collection that took place at the UNE EGyV in March 2009 with all team members; (3) retesting of a random sample of 29 children and adolescents; and (4) estimating the inter-observer technical error of the measurement for anthropometric data (height TEM=0.2 cm; sitting height

TEM=0.1 cm; body mass TEM=0.1 kg) and ANOVA-based intraclass correlation coefficient (ICC) for GMC and physical fitness tests. The ICC values ranged from 0.78 (moving sideways) to 0.91 (walking backwards), and from 0.79 (12 minute run) to 0.85 (standing long jump).

Statistical Analysis

Exploratory data analysis was done to identify errors in data entry and outliers, to verify the normality assumption, and to obtain descriptive statistics (means, standard deviations and percentages) in SPSS v 24.0. Analysis of variance (ANOVA) and χ^2 tests were used to estimate differences in means and frequencies in child-level variables among the three geographical areas of residence, respectively. Additionally, Tukey HSD test for multiple comparisons was used.

Since the data were structurally dependent, i.e., children nested within schools, a sequence of hierarchical nested models was fitted to explain variation in GMC_T. A three-level structure was initially considered – subjects nested within schools which are nested within regions. However, with only three regions, it is not recommended to treat region as a level in a multilevel analysis (Snijders & Bosker, 2012). Instead, dummy variables for region were included as predictors of GMC_T and were included in the fixed part of the model.

A series of sequential models was tested as advocated (Snijders & Bosker, 2012). Firstly, a null model (M_0) was used to compute the intraclass correlation coefficient and to estimate the variance accounted for by the random school effects on GMC_T. Secondly, Model 1 (M_1) included child-level GMC_T predictors (age, sex, age-by-sex interaction, maturity offset, BMI category and PF_Z); thirdly, in Model 2 (M_2), stunting, stunting-by-age interaction, stunting-by-sex interaction, and geographical area of residence were added. Lastly, in Model 3 (M_3), school-level covariates were added (number of students, school setting, playground area, playground equipment, multipurpose hall, multi-sports roofed, frequency and duration of Physical Education classes, and extracurricular activities). These computations were done in SuperMix (D. Hedeker et al., 2008), allowing a simultaneous estimation of all model parameters using maximum likelihood procedures. The Deviance statistic was used as a measurement of relative fit (Hox et al., 2018); differences in Deviances follow a χ^2 distribution with degrees of freedom equal to the difference in the number of estimated parameters from both models. Statistical significance was set at 5%.

RESULTS

Descriptive statistics for child-level variables are presented in Table 2, and significant differences ($p<0.05$) were found in all variables among subjects living at different altitudes. On average, high-altitude subjects were relatively older than their peers from the other areas ($F=36.38$, $p<0.05$), whereas sea-level subjects were further ahead in their maturity status ($F=55.06$, $p<0.05$). In addition, high-altitude subjects were less physically fit as compared to their peers ($F=1184.44$, $p<0.05$), but they outperformed their peers in GMC_T ($F=52.13$, $p<0.05$). In all geographical areas, girls were similarly represented as boys, except at sea-level (Amazon region: 53.6% girls; high-altitude: 51.2% girls; sea-level: 67.1% girls). Overweight was more prevalent at sea-level (53.9%), and the highest prevalences of stunting occurred simultaneously in the Amazon (12.4%) as well as at high-altitude (12.5%) regions.

Table 2. Descriptive statistics for child-level variables

Child-level variables	**Sea-level (S)** (n=1469)	**Amazon region (A)** (n=4075)	**High-altitude (H)** (n=1864)	***F***	***Post hoc* among areas**
	Mean±SD	Mean±SD	Mean±SD		
Biological characteristics					
Age (yrs)	10.40±2.54	10.16±2.45	10.74±2.46	36.38*	H>S>A
Maturity offset (yrs-to-aPHV)	-1.81±2.00	-2.39±1.97	-2.01±1.94	55.06*	S>H>A
SLJ (cm)	118.33±28.03	117.95±25.19	116.62±19.22	2.53	
SR (s)	24.15±3.36	22.81±2.36	27.60±2.28	2219.35*	H>S>A
12 minute run (m)	1276.58±293.45	1418.61±448.04	1573.67±334.59	236.31*	H>A>S
PF_z	0.33±1.59	0.38±1.47	-1.45±1.03	1184.44*	H<S; H<A
WB (points)	45.17±14.19	53.70±12.48	50.62±11.80	247.67*	A>H>S
MS (points)	52.69±15.24	50.02±13.59	51.30±14.06	20.58*	S>H>A
HH (points)	46.94±17.41	52.27±16.52	47.30±18.05	82.74*	A>S;A>H
JS (points)	40.71±9.79	42.42±9.89	43.16±9.91	26.26*	H>A>S
GMC_T (sum of points)	185.51±44.34	192.38±44.06	198.42±41.31	52.13*	H>A>S
		Frequencies n (%)		χ^2	
Sex					
Girls	986 (67.1)	2185 (53.6)	954 (51.2)	100.22*	
Boys	483 (32.9)	1890 (46.4)	910 (48.8)		
BMI Category					
Normal weight	677 (46.1)	2965 (72.8)	1629 (87.4)	694.35*	
Overweight (including obesity)	792 (53.9)	1110 (27.2)	235 (12.6)		
Stunting					
Stunting	45 (3.1)	504 (12.4)	233 (12.5)	108.98*	
No stunting	1424 (96.9)	3571 (87.6)	1631 (87.5)		

$^*p<0.05$; PF_z = total physical fitness score; GMC_T = total gross motor coordination; BMI = body mass index; SLJ = standing long jump; SR = shuttle-run; WB = walking backwards on balance beams; MS = moving sideways; HH = hopping for height on one foot; JS = jumping sideways

Descriptive statistics for school-level variables are presented in Table 3 (for school-level variables' results according to geographical area of residence please see Supplementary Table 1). The number of students in schools ranged from 96 to 1200, and 83.3% of the schools were located in urban regions. Further, 83.3% and 77.8% of schools had a recreation space without obstacles and without available equipment, respectively. Likewise, 55.6% of schools had multipurpose hall, whereas 66.7% did not have multi-sports roofed complexes. In 94.4% of schools, physical education classes were conducted once per week and 55.6% of them lasted >90 min. Lastly, 77.8% of schools provided extracurricular activities for schoolchildren.

Table 3. Descriptive statistics for school-level variables

School-level variables	Mean±SD	Range
School characterization		
School size		
Number of students	453±263	96-1200
	Frequencies n (%)	
School setting		
Mixed	3 (16.7)	
Urban	15 (83.3)	
Physical structure of the school		
Playground area		
With obstacles	3 (16.7)	
Without obstacles	15 (83.3)	
Playground equipment		
Yes	4 (22.2)	
No	14 (77.8)	
Multipurpose hall		
Yes	10 (55.6)	
No	8 (44.4)	
Multi-sports roofed		
Yes	6 (33.3)	
No	12 (66.7)	
Physical Education classes		
Physical Education class frequency		
1 per week	17 (94.4)	
2 per week	1 (5.6)	
Physical Education class duration		
90 minutes	8 (44.4)	
>90 minutes	10 (55.6)	
Extracurricular activities		
Yes	14 (77.8)	
No	4 (22.2)	

The results of the multilevel models are presented in Table 4. The null model (M_0) indicated that school-level variables matter in explaining children's GMC_T differences since the intraclass coefficient correlation was 0.31 [595.95/(595.95+1317.75)], leaving 69% of the total variance as explained by child-level characteristics.

Results from M_1 indicated that the GMC_T of a 10 y old average girl was 189.18 points, and that boys outperformed girls (β=12.93±0.85). Further, older children and adolescents were more coordinated (β=11.81±0.57), and since the age-by-sex interaction was statistically significant (β=2.29±0.28), boys and girls differ in their GMC_T across age. Further, biological maturation did not significantly affect GMC_T (β=0.35±0.76), but overweight subjects were less coordinated (β=-5.90±0.79), whereas those with high PF_z were more coordinated (β=6.40±0.25). There was a significant decrease in Deviance favoring M_1 relative to M_0 (from 74330.68 to 69452.98; $\chi^2_{(6)}$=4877.7, p<0.001) indicating a better fit.

In M_2, stunting, stunting-by-age interaction, stunting-by-sex interaction, and geographical area of residence were added. Previous estimates remain similar, but those ahead in maturation were less coordinated (β=-1.69±0.84). Further, stunting negatively affects GMC_T (β=-3.67±1.56) in a similar manner across age (the interaction stunting-by-age was not significant), but girls were more affected (the interaction stunting-by-sex is significant). Additionally, children and adolescents living at high-altitude (β=13.22±4.35), as well as in the Amazon region (β=16.80±4.07) were more coordinated than those living at sea-level. There was a reduction in Deviance from M_1 to M_2 (from 69452.98 to 69405.24; $\chi^2_{(5)}$= 47.74, p<0.001), showing that M_2 fits the data better.

Finally, M_3 included school-level predictors. In this model, child-level estimates remain similar in their interpretation, but biological maturation is no longer significant, and high-altitude subjects do not differ in their GMC_T from those living at sea-level. Five out of nine school-predictors were statistically significant (p<0.001). Children and adolescents from schools with lower number of students (β=-0.37±0.14) tend to be less coordinated, whereas those from schools with playground with obstacles (β=25.03±10.24) and with multi-sports roofed (β=14.67±7.07) showed higher GMC_T. Additionally, those from schools with Physical Education classes with greater duration than 90 minutes (β=14.25±3.56) were more coordinated, although, those with a higher Physical Education classes frequency (β=-37.97±15.30) were apparently less coordinated. This last model fit the data better than M_2 [$\chi^2_{(9)}$=16.94, p<0.001].

Table 4. Multilevel modelling results: parameter estimates (standard-errors) and variance components for total gross motor coordination (GMC_T)

Parameters	Null model (M_0)	Model 1 (M_1)	Model 2 (M_2)	Model 3 (M_3)
Regression coefficients (fixed effects)				
Level-1 child-level				
Intercept	197.21 (5.78)*	189.18 (2.71)*	173.77 (3.70)*	161.04 (8.16)*
Age (yrs)		11.81 (0.57)*	13.36 (0.64)*	13.37 (0.64)*
Sex (boys)		12.93 (0.85)*	12.29 (0.91)*	12.23 (0.90)*
Interaction (age-by-sex)		2.29 (0.28)*	2.46 (0.28)*	2.44 (0.28)*
Maturity offset (yrs-to-aPHV)		0.35 (0.76)^{ns}	-1.69 (0.84)*	-1.50 (0.84)^{ns}
Overweight$^{¤}$		-5.90 (0.79)*	-5.13 (0.80)*	-5.23 (0.80)*
PF_z		6.40 (0.25)*	6.34 (0.25)*	6.30 (0.25)*
Stunting (yes)			-3.67 (1.56)*	-3.71 (1.56)*
Interaction (stunting-by-age)			-0.61 (0.42)^{ns}	-0.61 (0.42)^{ns}
Interaction (stunting-by-sex)			-4.31 (2.02)*	-4.08 (2.02)*
Geographical area of residence (High-altitude)			13.22 (4.35)*	-5.83 (8.35)^{ns}
Geographical area of residence (Amazon region)			16.80 (4.07)*	16.57 (4.73)*
Level-2 school-level				
Number of students				-0.37 (0.14)*
School setting (urban)				6.41 (4.93)^{ns}
Playground area (with obstacles)				25.03 (10.24)*
Playground equipment (yes)				-1.50 (3.11)^{ns}
Multipurpose hall (yes)				-3.22 (4.06)^{ns}
Multi-sports roofed (yes)				14.67 (7.07)*
Frequency of physical education classes (two)				-37.97 (15.30)*
Duration of physical education classes (>90 min)				14.25 (3.56)*
Extracurricular activities (yes)				-3.31 (3.75)^{ns}
Variance components (random effects)				
School-level	595.95 (200.18)*	84.45 (28.93)*	41.89 (14.73)*	14.99 (5.74)*
Child-level	1317.75 (21.68)*	684.27 (11.26)*	680.98 (11.20)*	680.97 (11.20)*
Model summary				
Deviance	74330.68	69452.98	69405.24	69388.30
Number of estimated parameters	3	9	14	23

$^{*}p<0.001$; ns= non-significant

DISCUSSION

In this study we modelled GMC_T of Peruvian children and adolescents living in three geographical regions and probed into associations with different individual- and school-level sets of covariates. Model 1 showed that, on average, older Peruvian children were systematically more coordinated. As children become older, taller, heavier, stronger and more proficient in their motor skills, their GMC_T will also increase and this tendency has previously been reported in different countries using cross-sectional (Chaves, Tani, Souza, Baxter-Jones, & Maia, 2013; Kiphard & Schilling, 1974) and longitudinal data (de Souza et al., 2014; Deus et al., 2010; Willimczik, 1980). However, such age trends are apparently different when controlled for distinct sets of covariates. For example, Chaves et al. (2016) showed that with increasing age there was also a significant increase in the probability of children exhibiting low motor coordination levels because the age effect was confounded by other covariates that conjointly change as children grow, namely their body fat and physical fitness.

Peruvian boys outperformed girls in their GMC_T levels, and this is an apparent finding in previous studies (Antunes et al., 2016; Chaves et al., 2016), which is also supported when crude data are reported (Barnett et al. 2016), although recent investigations showed a different trend with girls outperforming boys (M. A. M. Dos Santos et al., 2018; A. C. Reyes et al., 2019). Yet, Peruvian boys´ higher GMC_T levels are likely explained by the additive effects of their greater body size and adequate body shape (Marcos André M Dos Santos et al., 2018)Dos Santos M. A. M. et al. 2018), higher motor skill proficiency (Ré et al., 2018) and their participation in more intense and varied non-organized play activities, as well as sport participation (Valdívia et al., 2018). Although this sex difference may also be altered when mean differences are adjusted for covariates (A. C. Reyes et al., 2019) no such trend was found in the Peruvian data even when adjusted for biological maturation, overweight, stunting, physical fitness, geographical area of residence, as well as school-level variables.

Our second hypothesis (biological maturation, overweight, stunting and physical fitness are associated with GMC_T) was partially confirmed. In results not shown using a crude analysis, i.e., without adjustments for any covariate, children and adolescents ahead in their maturity status were more coordinated. However, when additional covariates were included in the model, this positive link disappeared, probably confounded by physical fitness levels. In any case, it was recently reported that biological maturation had small positive effects (Freitas et al., 2016; Luz et al., 2016) or no influence on GMC_T levels (Vandendriessche et al., 2012). We also found that BMI emerged as a significant predictor, where children with overweight (including obesity) were less coordinated than their normal-weight peers. Since motor coordination tasks, like moving sideways on boxes, jumping sideways or hopping for height on one foot require children and adolescents to rapidly change their center of mass vertically and/or horizontally, it is expected that children with overweight and/or obesity are usually less capable to do so effectively, and the net result is lower performance. Our results are relatively similar to other Peruvian reports (Chaves et al., 2016; Valdivia et al., 2008). Further, an analogous trend was found in Belgium (D'Hondt et al., 2010), Canada (Cairney, Hay, Faught, & Hawes, 2005), Taiwan (Y.-C. Zhu, Wu, & Cairney, 2011) and Portugal (Chaves et al., 2015).

It has been described that the Peruvian population has, on average, short stature (Bustamante, Freitas, Pan, Katzmarzyk, & Maia, 2015), and that living at high-altitude makes them prone to stunting (Frisancho & Baker, 1970). Our results showed that stunting is negatively associated with GMC_T, with girls being more “affected” than boys. This is a novel result showing the disadvantages of stunted children when performing motor coordination tasks. In KTK tests like moving sideways on boxes or jumping sideways have relatively complex task structures requiring body displacements in different planes, axis, and directions and children/adolescents with shorter limbs may perform worse. Further, since girls exhibit, on average, higher amounts of body fat (Santos et al., 2019), it is expected that they are still more affected than boys in their motor performance across age groups.

Another important finding was the positive association of the overall physical fitness measure and GMC_T which backs previous reports that children and adolescents with higher cardiorespiratory endurance and muscular strength were also more coordinated (Cairney, Hay, Wade, Faught, & Flouris, 2006; Maria Teresa Cattuzzo et al., 2016). A similar trend was found by Chaves et al. (2016), showing that Peruvian children with lower physical fitness levels were also less likely to be more coordinated. On the other hand, it may well be possible that Peruvian children/adolescents may find KTK motor tasks challenging and unusual within the schemes of their daily chores and activities. Further, it is also possible that physical fitness behaves as a mediator between biological maturation and GMC, or that GMC_T and physical fitness are truly interconnected and it is rather difficult to disentangle this link.

Our last hypothesis (geographical area of residence and school-level characteristics are associated with GMC_T) were fully supported by our data. In fact, children and adolescents living at sea-level were less coordinated than those living in the Amazon region, but more coordinated than their high-altitude peers, although this last difference was not statistically significant when school characteristics entered in the last model. A possible explanation for our results may be due to distinct environmental conditions of each region, as previously suggested by Chaves et al. (2016) and Valdívia et al. (2018). Barranco, located at sea-level, has a high population density (~10.132 inhabitants per km^2) (INEI, 2018) and residents deal with serious problems associated their built environment (e.g., traffic congestion, public insecurity, as well as the lack of public recreational infrastructures available to schoolchildren), which limits the range of opportunities for physical activities and may favour more sedentary lifestyles. In turn, high-altitude residents suffer from the permanent exposure to severe constraints of their natural environment (e.g., severe mountain climate, ranging from 7ºC to 12ºC, as well as fewer hours of sunlight and twilight) (INEI, 2018), making it more difficult to participate in outdoor physical and sports activities. Conversely, Chanchamayo city, located in the Amazon region, is favoured by a tropical climate with a large extension of rainforest with ample natural green space allowing children from an early age to diversify and maximize their motor skills associated to traditional games, unstructured play, and house chores that might enhance the development of their motor coordination levels.

Schools matter in terms of GMC_T levels among Peruvian children since 31% of the total variance in GMC_T was attributed to schools´ characteristics. In fact, the school environment is a potentially significant venue for opportunities that can be conducive to stimulating motor development. For example, some aspects of the school's built environment such as school size and setting, and playground area, as well as aspects of the school curriculum, such as frequency and duration of physical education classes may offer the child opportunities for activity. Despite its importance, little research exists examining the relationship between the school context and the child GMC development. We were not able to find any report linking childrens/adolescents GMC with their school contexts in South American countries, but we were able to identify two studies with Portuguese children/adolescents. The first one was a cross-sectional study (Chaves et al., 2015) that reported an explained variance of 10% and the second study, a longitudinal investigation by Reyes et al. (2019), reported no significant variance attributable to school settings.

Peruvian children and adolescents from schools with lower numbers of students tended to be less coordinated, whereas those from schools with playgrounds with obstacles and with multi-sports roofed facilities showed higher GMC_T. It is expected that schools with a higher number of students, commonly associated with a larger campus size or playground areas, are prone to provide more opportunities for their students to engage in physical activities during recess (A. L. Cradock, S. J. Melly, J. G. Allen, J. S. Morris, & S. L. Gortmaker, 2007). Further, a playground with multiple obstacles and physical structures, as well as multicolour markings, can also a suitable stimulus for increasing children's school recess physical activity levels (Ridgers, Stratton, Fairclough, & Twisk, 2007), potentially improving their motor skills as well as their motor coordination levels.

Surprisingly, we also found that Peruvians with two physical education classes per week were apparently less coordinated, although the duration of classes seems to be an important correlate. In fact, the issue does not apparently seem to be the total number of lessons per week, but specific characteristics of the class contents, as well as teacher behavior, namely their teaching methods and strategies used to develop children's motor skills/coordination (McKenzie, Marshall, Sallis, & Conway, 2000). For example, Hastie and Saunders (1991) suggested that a large number of students per class interfere with students being physically active, which, in turn, may have a negative effect on motor skill learning. This is apparently also evident in Peru, since physical education classes have, on average, a total of 30 students per class, as approved by the Peruvian Ministry of Education (Gobierno del Perú, 2018). On the other hand, McKenzie et al. (2000) reported that, in Southern of California, a substantial amount of physical education class time (27%) is often spent on management tasks, and student activity levels can be reduced during these periods. Meanwhile, considerable amounts of time were allocated to fitness (25%) and game play (29%) and little time was directed for motor skill drills (5%). Although there are no similar studies in Peru, the lack of qualified teachers is a well-known problem (Hernani, 2017), which may limit the achievement of educational goals established in the Physical Education curriculum for children's motor development.

It would be of interest to investigate the impact of policies and practices issued by the Ministry of Education and/or other government agencies as well as school boards to promote physical activity in Peruvian students, and consequently, their motor skills/gross motor coordination development. The Active Healthy Kids Global Alliance recently issued a series of national Report Cards on physical activity for children and youth to advocate for the systematic promotion of physical activity (Salomé Aubert et al., 2019; Galaviz et al., 2016; González et al., 2016). However, this information is not available in Peru. We anticipate that with this useful data it would probably be easier to be more effective in providing active environments, promoting active lives and active systems, as well as to encourage the development of GMC among Peruvian youth.

This study is not without limitations. Firstly, the sample is not representative of the Peruvian population and care must be taken when trying to generalize the present results. However, it is large enough and covers a wide age range, which are also important issues when using multilevel models to minimize bias, as well as the preciseness of the regression coefficients estimates, variance components, and standard errors (Maas and Hox 2005; Snijders and Bosker

(2012). Secondly, we were not able to obtain objective physical activity measurements. Yet, given the large study sample size (7408 subjects), the geographical locations and financial costs to run the study, this option was unknot feasible. Thirdly, our results were not adjusted for any putative influence of family income or socioeconomic status. This study has also several important strengths: firstly, the reliance on standardized measurement methods and highly reliable data; secondly, the inclusion of three different geographical areas of residence; and thirdly the use of multilevel modelling to capture the complexity of the nested information. Indeed, multilevel modelling analysis has a wide range of advantages: (i) it allows for the simultaneous examination of the effects of school- and individual-level predictors; (ii) it accounts for the non-independence of observations within schools; (iii) it does not treat subjects and school environment as unrelated, but they are seen as coming from a larger population, and (iv) it examines both inter-individual and inter-school variation as well as the contributions of school- and individual-level covariates (Snijders & Bosker, 2012). Further, the multilevel modelling approach provides an important framework to consider the complex relationships between subjects and their contexts in a holistic manner (Courgeau, 2003).

In conclusion, boys and older children had higher GMC_T than girls and younger children, respectively. Overweight was negatively associated with lower GMC_T, whereas physical fitness was positively associated with GMC_T. Biological maturation was not a significant predictor; however, stunting was negatively associated with GMC_T. Subjects living in the Amazon region had higher GMC_T than those at sea-level. Finally, five out of nine school-level predictors (number of students, playground area with obstacles, multi-sports roofed, frequency and duration of Physical Education classes) were significant predictors of GMC_T.

Our results provide valuable information that should be considered by school principals, councils and Physical Education teachers when designing and implementing their annual plans, as well as intervention programs to increase children's motor coordination. For example, schools' infrastructures (playground area and multi-sports roofed) play important roles as affordances contributing to improvement in children's GMC levels. As such, policy makers should consider this information when planning rehabilitation procedures in old schools as well as when designing new schools. Further, since the duration of physical education classes was also an important predictor, Peruvian physical education teachers should plan their daily classes towards the reduction of management tasks and spending more time in promoting diverse and rich motor skill experiences, culturally significant, based on structured and/or non-structured play.

Moreover, longitudinal research is needed and could connect, in a multivariate approach, children’s and adolescents´ GMC with more individual-level information (e.g., physical activity levels, sedentariness and various health outcomes), as well as the family environment, to better understand children's GMC dynamic changes.

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AUTHOR CONTRIBUTIONS

CS, DH, PTK and JM analyzed the data. CS, JM, AB, DH and PTK drafted the manuscript. AB and JM designed the study and directed its implementation. AB and JM provided necessary logistical support. AB, DH, OV, RG and PTK provided extensive critical comments and did the final editing of the manuscript.

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CONFLICT OF INTEREST STATEMENT

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

REFERENCES

AAHPERD. 1980. Health related physical fitness: Test manual. Reston, VA: American Alliance for Health, Physical Education, Recreation and Dance.

Antunes AM, Maia JA, Gouveia ÉR, Thomis MA, Lefevre JA, Teixeira AQ, Freitas DL. 2016. Change, stability and prediction of gross motor co-ordination in Portuguese children. Annals of human biology. 43(3):201-211.

Aubert S, Barnes JD, Forse ML, Turner E, González SA, Kalinowski J, Katzmarzyk PT, Lee E-Y, Ocansey R, Reilly JJ. 2019. The International Impact of the Active Healthy Kids Global Alliance Physical Activity Report Cards for Children and Youth. Journal of Physical Activity and Health. 1(aop):1-19.

Barnett LM, Lai SK, Veldman SL, Hardy LL, Cliff DP, Morgan PJ, Zask A, Lubans DR, Shultz SP, Ridgers ND. 2016. Correlates of gross motor competence in children and adolescents: a systematic review and meta-analysis. Sports medicine. 46(11):1663-1688.

Bouchard C, Malina RM, Pérusse L. 1997. Genetics of fitness and physical performance. USA: Human Kinetics.

Bustamante A, Beunen G, Maia J. 2011. Como crecen y se desarrollan los niños y adolescentes en La Merced y San Ramón. Alcances para la Educación Física, el Deporte y la Salud. Lima: Universidad Nacional de Educación. Lima, Perú: Universidad Nacional de Educación Enrique Guzmán y Valle, La Cantuta.

Bustamante A, Freitas D, Pan H, Katzmarzyk PT, Maia J. 2015. Centile curves and reference values for height, body mass, body mass index and waist circumference of Peruvian children and adolescents. Int J Environ Res Public Health. 12(3):2905-2922. eng.

Cairney J, Hay J, Faught B, Hawes R. 2005. Developmental coordination disorder and overweight and obesity in children aged 9–14 y. International journal of obesity. 29(4):369.

Cairney J, Hay JA, Wade TJ, Faught BE, Flouris A. 2006. Developmental coordination disorder and aerobic fitness: is it all in their heads or is measurement still the problem? American Journal of Human Biology. 18(1):66-70.

Cattuzzo MT, dos Santos Henrique R, Ré AHN, de Oliveira IS, Melo BM, de Sousa Moura M, de Araújo RC, Stodden D. 2016. Motor competence and health related physical fitness in youth: A systematic review. Journal of Science and Medicine in Sport. 19(2):123-129.

Chaves R, Baxter-Jones A, Gomes T, Souza M, Pereira S, Maia J. 2015. Effects of individual and school-level characteristics on a child's gross motor coordination development. International journal of environmental research and public health. 12(8):8883-8896.

Chaves R, Bustamante A, Nevill AM, Freitas D, Tani G, Katzmarzyk PT, Maia J. 2016. Developmental and physical-fitness associations with gross motor coordination problems in Peruvian children. Research in developmental disabilities. 53:107-114.

Chaves R, Tani G, Souza M, Baxter-Jones A, Maia J. 2013. Desempenho coordenativo de crianças: construção de cartas percentílicas baseadas no método LMS de Cole e Green. Revista Brasileira de Educação Física e Esporte. 27(1):25-42.

Cossio-Bolaños M, Campos R, Andruske C, Flores A, Luarte-Rocha C, Olivares P, Garcia-Rubio J, de Arruda M. 2015. Physical growth, biological age, and nutritional transitions of adolescents living at moderate altitudes in Peru. International journal of environmental research and public health. 12(10):12082-12094.

Courgeau D. 2003. Methodology and epistemology of multilevel analysis: approaches from different social sciences. Vol. 2. Springer Science & Business Media.

Cradock AL, Melly SJ, Allen JG, Morris JS, Gortmaker SL. 2007. Characteristics of school campuses and physical activity among youth. Am J Prev Med. 33(2):106-113. eng.

D'Hondt E, Deforche B, Vaeyens R, Vandorpe B, Vandendriessche J, Pion J, Philippaerts R, Bourdeaudhuij I, Lenoir M. 2010. Gross motor coordination in relation to weight status and age in 5- to 12-year-old boys and girls: A cross-sectional study. International journal of pediatric obesity : IJPO : an official journal of the International Association for the Study of Obesity. 6:e556-564.

de Souza MC, de Chaves RN, Lopes VP, Malina RM, Garganta R, Seabra A, Maia J. 2014. Motor coordination, activity, and fitness at 6 years of age relative to activity and fitness at 10 years of age. Journal of Physical Activity and Health. 11(6):1239-1247.

Deus R, Bustamante A, Lopes V, Seabra A, Silva R, Maia J. 2010. Modelação longitudinal dos níveis de coordenação motora de crianças dos seis aos 10 anos de idade da Região Autônoma dos Açores, Portugal. Revista Brasileira De Educação Física E Esporte. 24(2):259-273.

Dos Santos MAM, Nevill AM, Buranarugsa R, Pereira S, Gomes T, Reyes A, Barnett LM, Maia JAR. 2018. Modeling children's development in gross motor coordination reveals key modifiable determinants. An allometric approach. Scandinavian journal of medicine & science in sports. 28(5):1594-1603.

Dos Santos MAM, Nevill AM, Buranarugsa R, Pereira S, Gomes T, Reyes A, Barnett LM, Maia JAR. 2018. Modeling children's development in gross motor coordination reveals key modifiable determinants. An allometric approach. Scand J Med Sci Sports. 28(5):1594-1603. eng.

EUROFIT. 1993. Handbook for the EUROFIT tests of physical fitness. 2nd ed. Strasbourg: Committee of Experts on Sports Research.

Freitas DL, Lausen B, Maia JA, Gouveia ÉR, Thomis M, Lefevre J, Silva RD, Malina RM. 2016. Skeletal Maturation, Body Size, and Motor Coordination in Youth 11-14 Years. Medicine and science in sports and exercise. 48(6):1129-1135.

Frisancho AR. 1978. Human growth and development among high-altitude populations. In: Baker PT, editor. The biology of high altitude peoples. New York, USA: Cambridge University Press; p. 117-171.

Frisancho AR, Baker PT. 1970. Altitude and growth: a study of the patterns of physical growth of a high altitude Peruvian Quechua population. American journal of physical Anthropology. 32(2):279-292.

Galaviz KI, Arroyo MA, González-Casanova I, Villalobos MFG, Jáuregui A, Ulloa EJ, Miranda SP, Rodríguez MP, Pelayo RAR, López-Taylor JR. 2016. Results from Mexico’s 2016 report card on physical activity for children and youth. Journal of physical activity and health. 13(s2):S206-S212.

Gobierno del Perú. 2018. Resolución Ministerial N° 721-2018-MINEDU. Perú: Ministerio de Educación; [accessed 2019 17 July]. https://www.gob.pe/institucion/minedu/normas-legales/235757-721-2018-minedu.

González SA, Castiblanco MA, Arias-Gómez LF, Martinez-Ospina A, Cohen DD, Holguin GA, Almanza A, Lemos DMC, Correa-Bautista JE, Escobar ID. 2016. Results from Colombia’s 2016 report card on physical activity for children and youth. Journal of physical activity and health. 13(s2):S129-S136.

Hastie PA, Saunders JE. 1991. Effects of class size and equipment availability on student involvement in physical education. The Journal of Experimental Education. 59(3):212-224.

Hedeker D, Gibbons R, Toit MD, Cheng Y. 2008. Supermix: Mixed effects models. Lincolnwood, IL, USA: Scientific Software International, Inc.

Hernani M. 2017. A formação inicial de professores: um estudo comparativo entre Peru e Brasil Rio Grande: Universidade Federal do Rio Grande - Furg.

Hox JJ, Moerbeek M, Van de Schoot R. 2018. Multilevel analysis: Techniques and applications New York, USA: Routledge.

Huang Y, Malina RM. 2007. BMI and health-related physical fitness in Taiwanese youth 9-18 years. Med Sci Sports Exerc. 39(4):701-708.

Iivonen S, Sääkslahti A, Laukkanen A. 2016. A review of studies using the Körperkoordinationstest für Kinder (KTK). European Journal of Adapted Physical Activity. 8:18-36.

INEI. 2017. Perfil Sociodemográfico del Perú. Informe nacional. Lima: Instituto Nacional de Estadística e Informática; [accessed 2019 18 February]. https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1539/index.html.

Joint Consortium for School Health. 2012. Healthy School Planner. [accessed 18 October 2018]. www.healthyschoolplanner.uwaterloo.ca.

Kiphard EJ, Schilling F. 1974. Körperkoordinationstest für Kinder. Weinheim: Beltz Test GmbH.

Lohman T, Roche A, Martorell R. 1988. Anthropometric standarization reference manual. Champaign, IL: Human Kinetics Books.

Lopes VP, Stodden DF, Bianchi MM, Maia JA, Rodrigues LP. 2012. Correlation between BMI and motor coordination in children. Journal of Science and Medicine in Sport. 15(1):38-43.

Lubans DR, Morgan PJ, Cliff DP, Barnett LM, Okely AD. 2010. Fundamental movement skills in children and adolescents. Sports medicine. 40(12):1019-1035.

Luz LG, Cumming SP, Duarte JP, Valente-dos-Santos J, Almeida MJ, Machado-Rodrigues A, Padez C, Carmo BCM, Santos R, Seabra A. 2016. Independent and combined effects of sex and biological maturation on motor coordination and performance in prepubertal children. Perceptual and motor skills. 122(2):610-635.

Luz LG, Valente-dos-Santos J, Luz TD, Sousa-e-Silva P, Duarte JP, Machado-Rodrigues A, Seabra A, Santos R, Cumming SP, Coelho-e-Silva MJ. 2018. Biocultural Predictors of Motor Coordination Among Prepubertal Boys and Girls. Perceptual and motor skills. 125(1):21-39.

McKenzie TL, Marshall SJ, Sallis JF, Conway TL. 2000. Student activity levels, lesson context, and teacher behavior during middle school physical education. Research Quarterly for Exercise and Sport. 71(3):249-259.

Mirwald R, Baxter-Jones A, Bailey D, Beunen G. 2002. An assessment of maturity from anthropometric measurements. Med Sci Sports Exerc. 34(4):689-694.

Moreira JPA, Lopes MC, Miranda-Júnior MV, Valentini NC, Lage GM, Albuquerque MR. 2019. Körperkoordinationstest Für Kinder (KTK) for Brazilian children and adolescents: Factor score, factor analysis, and invariance. Frontiers in psychology. 10:2524.

Morgan PJ, Barnett LM, Cliff DP, Okely AD, Scott HA, Cohen KE, Lubans DR. 2013. Fundamental movement skill interventions in youth: a systematic review and meta-analysis. Pediatrics. 132(5):e1361-e1383.

Onis M, Onyango A, Borghi E, Siyam A, Nishida C, Siekmann J. 2007. Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ. 85:660-667.

Pomeroy E, Stock JT, Stanojevic S, Miranda JJ, Cole TJ, Wells JC. 2014. Stunting, adiposity, and the individual-level “dual burden” among urban lowland and rural highland peruvian children. American journal of human biology. 26(4):481-490.

Ré AH, Logan SW, Cattuzzo MT, Henrique RS, Tudela MC, Stodden DF. 2018. Comparison of motor competence levels on two assessments across childhood. Journal of sports sciences. 36(1):1-6.

Reyes AC, Chaves R, Baxter-Jones AD, Vasconcelos O, Barnett LM, Tani G, Hedeker D, Maia J. 2019. Modelling the dynamics of children’s gross motor coordination. Journal of sports sciences.1-10.

Reyes AC, Chaves R, Baxter-Jones ADG, Vasconcelos O, Barnett LM, Tani G, Hedeker D, Maia J. 2019. Modelling the dynamics of children's gross motor coordination. J Sports Sci.1-10. eng.

Ridgers ND, Stratton G, Fairclough SJ, Twisk JW. 2007. Long-term effects of a playground markings and physical structures on children's recess physical activity levels. Preventive medicine. 44(5):393-397.

Santos C, Bustamante A, Hedeker D, Vasconcelos O, Garganta R, Katzmarzyk PT, Maia J. 2019. Correlates of Overweight in Children and Adolescents Living at Different Altitudes: The Peruvian Health and Optimist Growth Study. Journal of Obesity. (In press).

Snijders TAB, Bosker RJ. 2012. Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling. 2nd ed. London: Sage Publishers.

Urke HB, Mittelmark MB, Valdivia M. 2014. Trends in stunting and overweight in Peruvian pre-schoolers from 1991 to 2011: findings from the Demographic and Health Surveys. Public health nutrition. 17(11):2407-2418.

Valdivia AB, Cartagena LC, Sarria NE, Távara IS, Seabra AFT, Silva RMGd, Maia JAR. 2008. Coordinación motora: influencia de la edad, sexo, estatus socio-económico y niveles de adiposidad en niños peruanos. Rev Bras Cineantropom Desempenho Hum. 10(1):25-34.

Valdívia AB, Henrique RS, Pereira S, Chaves RN, Tani G, Freitas D, Prista A, Stodden DF, Katzmarzyk PT, Hedeker D. 2018. Familial resemblance in gross motor coordination. The Peruvian Sibling Study on Growth and Health. Annals of human biology. 45(6-8):463-469.

van der Fels IM, te Wierike SC, Hartman E, Elferink-Gemser MT, Smith J, Visscher C. 2015. The relationship between motor skills and cognitive skills in 4–16 year old typically developing children: A systematic review. Journal of science and medicine in sport. 18(6):697-703.

Vandendriessche JB, Vaeyens R, Vandorpe B, Lenoir M, Lefevre J, Philippaerts RM. 2012. Biological maturation, morphology, fitness, and motor coordination as part of a selection strategy in the search for international youth soccer players (age 15–16 years). Journal of sports sciences. 30(15):1695-1703.

Vandendriessche JB, Vandorpe B, Coelho-e-Silva MJ, Vaeyens R, Lenoir M, Lefevre J, Philippaerts RM. 2011. Multivariate association among morphology, fitness, and motor coordination characteristics in boys age 7 to 11. Pediatric Exercise Science. 23(4):504-520.

Wahi G, LeBlanc PJ, Hay JA, Faught BE, O'Leary D, Cairney J. 2011. Metabolic syndrome in children with and without developmental coordination disorder. Research in developmental disabilities. 32(6):2785-2789.

Willimczik K. 1980. Development of motor control capability (body coordination) of 6-to 10-year-old children: Results of a Longitudinal Study. Baltimore: University Park Press.

World Health Organization. 2006. A Macro/Programme for Calculating the Z-scores and Prevalences for DHS Individual Flat Files. In: Development DoNfHa, editor. Geneva.

Zhu Y-C, Wu SK, Cairney J. 2011. Obesity and motor coordination ability in Taiwanese children with and without developmental coordination disorder. Research in developmental disabilities. 32(2):801-807.

SUPPLEMENTARY MATERIALS

Supplementary Table 1. Descriptive statistics for school-level variables by geographical area of residence.

	Sea-level		Amazon region		High-altitude	
School-level variables	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
School characterization						
School size						
Number of students	439±85.1	322-521	582.5±326.9	180-1200	290.7±150.2	96-539
			Frequencies n (%)			
School setting						
Mixed	0 (0.0)		3 (37.5)		0 (0.0)	
Urban	4 (100)		5 (62.5)		6 (100)	
Physical structure of the school						
Playground area						
With obstacles	0 (0.0)		2 (25.0)		1 (16.7)	
Without obstacles	4 (100)		6 (75.0)		5 (83.3)	
Playground equipment						
Yes	0 (0.0)		1 (12.5)		3 (50.0)	
No	4 (100)		7 (87.5)		3 (50.0)	
Multipurpose hall						
Yes	2 (50.0)		3 (37.5)		5 (83.3)	
No	2 (50.0)		5 (62.5)		1 (16.7)	
Multi-sports roofed						
Yes	0 (0.0)		2 (25.0)		4 (66.7)	
No	4 (100)		6 (75.0)		2 (33.3)	
Physical Education classes						
Physical Education class frequency						
1 per week	4 (100)		7 (87.5)		6 (100)	
2 per week	0 (0.0)		1 (12.5)		0 (0.0)	
Physical Education class duration						
90 minutes	2 (50.0)		3 (37.5)		3 (50.0)	
>90 minutes	2 (50.0)		5 (62.5)		3 (50.0)	
Extracurricular activities						
Yes	4 (100)		6 (75.0)		4 (66.7)	
No	0 (0.0)		2 (25.0)		2 (33.3)	

Paper V

A multivariate multilevel analysis of youth motor competence. The Peruvian Health and Optimist Growth Study

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ABSTRACT

We use a multivariate multilevel model to study the links between physical fitness (PF) and gross motor coordination (GMC) and investigate the influence of predictors affecting their levels across age. We sampled 7918 Peruvians, aged 6-15 yrs, from sea-level, Amazon region and high-altitude. Composite markers of GMC and PF were derived (GMC_z and PF_z, respectively). BMI, biological maturation and stunting were assessed. School characteristics were obtained via an objective audit. School contexts explained 35% of the associations between PF_z and GMC_z, whereas children's characteristics explained 65% of the total variation. On average, with increasing age, there was a greater increase in GMC_z (β=0.79±0.04, p<0.001) than in PF_z (β=0.15±0.03, p<0.001); boys outperformed girls (PF_z, β=3.25±0.08, p<0.001; GMC_z, β=1.58±0.09, p<0.001); those with lower BMI and ahead in their maturation had higher PF_z (β=-0.13±0.01, p<0.001; β=1.09±0.05, p<0.001, respectively) and GMC_z (β=-0.18±0.01, p<0.001; β=0.39±0.06, p<0.001, respectively) levels. Stunting was negatively related to PF_z (β=-0.30±0.07; p<0.001) and GMC_z (β=-0.30±0.08, p<0.001) and High-altitude Peruvians had significantly lower GMC_z (β=-0.93±0.33, p<0.001), and those living in the Amazon region had significantly higher PF_z (β=1.21±0.58, p<0.001) compared to those living at sea-level. A higher number of students was negatively related to PF_z (β=-0.016±0.006, p<0.001) and positively with GMC_z (β=0.005±0.003, p<0.001); the duration of physical education classes was positively associated to PF_z (β=0.70±0.32, p<0.001) and GMC_z (β=0.46±0.15, p<0.001); and the existence of policies for physical activity was only negatively associated with GMC_z (β=-1.17±0.34, p<0.001). In conclusion, PF_z and GMC_z were positively correlated, and child- and school-level traits predicted their levels.

Keywords: youth; motor competence; physical fitness; gross motor coordination; school context; environment; multivariate multilevel modelling

INTRODUCTION

Physical fitness (PF) and gross motor coordination (GMC) are known to be associated with positive lifestyle behaviors and health in childhood and adolescence (M. T. Cattuzzo et al., 2016; Ruiz et al., 2009), and their levels depend on the combined influence of genetic and environmental factors (Okuda, Horii, & Kano, 2005). Further, it is acknowledged that PF and GMC tend to increase with increasing age (Kiphard & Schilling, 1974; R.M. Malina et al., 2004), boys outperform girls (Barnett et al., 2016; R.M. Malina et al., 2004) and youth ahead in their biological maturation (Freitas et al., 2016; P. Katzmarzyk, Malina, & Beunen, 1997), and with lower body mass index (BMI) (Y. C. Huang & R. M. Malina, 2007; V. P. Lopes, D. F. Stodden, M. M. Bianchi, J. A. Maia, & L. P. Rodrigues, 2012) have higher PF and GMC.

A relatively similar trend is observed in children and adolescents living in emerging countries. For example, Chaves et al. (2016) reported that Peruvian children with greater BMI and those who were delayed in their biological maturation were more likely to suffer from GMC problems; however, they also found that older children had lower GMC. M. Armstrong, M. Lambert, and E. Lambert (2017) reported that South-African children with linear growth retardation and subsequent low height-for-age (i.e. stunted) tend to be less fit in some, but not all, health-related fitness tests. The same trend was found by R. M. Malina, Pena Reyes, Tan, and Little (2011) among Mexican youth. Surprisingly, no information is apparently available linking stunting with GMC.

Physical fitness and GMC are both associated with the natural and built environment. In Peru, children and adolescents living in different geographical regions (sea-level, Amazon region, and high-altitude) are exposed to distinct environmental stressors and daily life conditions are marked by economic, educational, nutritional, and health resource disparities (INEI, 2018). These affect not only their physical growth (Cossio-Bolanos et al., 2015) but may also impact their PF and GMC (Chaves et al., 2016). Yet, to our knowledge, no study has investigated how children and adolescents´ motor competence, jointly marked by their PF and GMC, expresses itself within the complexity of their living conditions.

Children and adolescents spend a large part of their daily life at school, and this exposure has the potential to afford unique opportunities to develop their motor competence (M. T. Cattuzzo et al., 2016). For example, W. Zhu, Boiarskaia, Welk, and Meredith (2010) reported that school physical education programs and policy factors were significantly associated with PF. Similarly, Chaves et al. (2015) showed that the school context was important in predicting GMC in Portuguese children, although A. C. Reyes et al. (2019) found no such linkage. We were unable to identify any published studies that examined the relationships between the school environment and both PF and GMC in emerging countries, while accounting for disparities in geographical living conditions.

Motor competence during childhood and adolescence is in itself multivariate, and PF and GMC are two of its important facets. Further, their putative joint predictors may affect them differently, i.e., with distinct effect sizes which are apparently not clearly recognized. Therefore, in this paper we will use a multivariate multilevel analytical framework to investigate two dependent variables (PF and GMC) simultaneously, as well as to identify the influence of a set of predictor variables. Hence, the present study aims to: (1) investigate the relationship between PF and GMC in Peruvian youth; (2) determine the effects of age, sex, BMI, biological maturation and stunting condition on PF and GMC; (3) examine the effects of geographical area of residence on PF and GMC, and (4) probe the influence of school-level characteristics on PF and GMC.

MATERIALS AND METHODS

Sample

The sample comes from *The Peruvian Health and Optimist Growth Study* (Bustamante et al., 2011), carried out between 2009 and 2010, comprising 7918 children and adolescents (4388 girls, aged 6-15 yrs), from 18 randomly selected public schools located in three geographical areas located at different altitudes: sea-level (Barranco – 58 m), Amazon region (La Merced and San Ramon – 751 m), and (3) high-altitude (Junín – 4107 m). Geographic, demographic, socioeconomic and educational characteristics of these areas (INEI, 2018) are presented in Table 1.

Table 1. Geographic, demographic, socioeconomic and educational characteristics of the three geographical areas located in the central region of Peru.

Characteristics	**Sea-level** (Barranco)	**Amazon region** (La Merced and San Ramon)	**High-altitude** (Junín)
Geographic			
Area (km^2)	3.33	5 315.07	883.80
Altitude (m)	58	751	4107
Demographic			
Total population	34378	53590	10796
Population density ($people/km^2$)	10.13	10.08	12.22
Official language	Spanish	Spanish/Quechua	Spanish/Quechua
Climate	Arid; semi-warm	Rainy; warm	Rainy; cold
Average annual temperature	18°C	24°C	7°C-12°C
Socioeconomic			
Human Development Index (HDI)	0.72	0.52	0.44
Life expectancy at birth (y)	79.08	65.49	69.14
Education (%)[1]	86.94	86.61	76.56
Literacy (%)[2]	99.35	90.97	89.84
Per capita family income (dollars)	1440.6	785.1	512.7
Primary production	Trade/Tourism	Agriculture/Tourism	Stockbreeding/Agriculture
Educational			
School age children	15.829	13.960	2.703
Boys	7.118 (45.0%)	7.172 (51.4%)	1.359 (50.3%)
Girls	8.711 (55.0%)	6.788 (48.6%)	1.344 (49.7%)
Public	8.881 (56.1%)	11.126 (79.7%)	2.601 (96.2%)
Private	6.948 (43.9%)	2.834 (20.3)	102 (3.8%)
Urban	15.829 (100%)	12.927 (92.6%)	2.678 (99.1%)
Rural	0 (0%)	1.033 (7.4%)	25 (0.9%)

[1] School age population; [2] Children and adults 15 years of age or more who know how to read and write

Based on information obtained from the Ministry of Education (ESCALE, 2010) on the distribution of students enrolled in the 2009-10 academic year (date of data collection), it was decided to intentionally select 31 public education institutions located in urban areas, of which 13 belonged to kindergarten, 10 at the primary-school and 8 at the secondary-school levels. A total of 38% of the total number of students enrolled in the study, that is, 4 out of every 10 students who regularly attended school. The sample only included children and adolescents from primary and secondary-school levels, as well as who were native to their respective regions (i.e., no immigrants were identified). We gathered information about the participants birth place and current place of residence or address and cross-checked this information with their identity cards. Further, only subjects with complete data on PF, GMC and all covariates were included. The percentage of missing data varied from 4% to 7% in PF tests and from 4% to 5% in GMC tests, and do not significantly differ (p>0.05) from those considered in the present analysis. Formal permissions from school governmental bodies and written informed consent from parents/legal guardians were obtained. The project was approved by the Ethics Committee of the National University of Education Enrique Guzmán y Valle (UNE EGyV). Information about sample size by age, sex and geographical area of residence is presented in Table 2.

Table 2. Sample size by sex, age and geographical area of residence

Age (y)[†]	**Sea-level** (Barranco)		**Amazon region** (La Merced and San Ramon)		**High-altitude** (Junín)		**All areas**	
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
6	104	44	177	154	50	60	331	258
7	74	28	160	241	82	60	316	329
8	87	36	238	219	70	84	395	339
9	126	43	216	247	92	110	434	400
10	99	42	288	247	94	105	481	394
11	143	82	242	249	112	80	497	411
12	115	102	320	192	191	129	626	423
13	89	32	291	177	112	136	492	345
14	149	73	249	162	151	146	549	381
15	91	85	93	96	83	69	267	250
Total	1077	567	2274	1984	1037	979	4388	3530

[†] Age was used as decimals of a year and children aged 5.5 to 6.49 years were designated as 6, children aged 6.50 to 7.49 years as 7, and so on (Eveleth & Tanner, 1990).

Dependent variables

PF was assessed using four tests from AAHPERD (1980) and EUROFIT (EUROFIT, 1993) batteries: (1) handgrip strength (kg^f – marker of static strength) was measured using a hand dynamometer (Takei Hand Grip Dynamometer®, Takei Scientific Instruments Co., Ltd, Nigata, Japan) – all participants gripped the dynamometer with maximum force for 5 to 10 s and the best score was recorded from two trials.; (2) standing long jump (SLJ; cm – marker of muscular power) – each subject was instructed to jump as far as possible and the maximum jumping distance was recorded from two trials; (3) shuttle-run test (SR; seconds and the sign was reverted – marker of agility) – each subject performed five cycles (round-trip) at maximum speed between two lines separated by five meters; and (4) 12 minute run test (m – marker of cardiorespiratory fitness) – in a previously delimited field, schoolchildren ran/ walked the maximum possible distance in 12 minutes. All individual PF test results were converted to z-scores using grand-mean centering, and a total physical fitness score (PF_z) was derived by summing all individual z-scores as suggested (Y. C. Huang & R. M. Malina, 2007).

GMC was assessed using the *KöperkoordinationsTest für Kinder* test battery (Kiphard & Schilling, 1974), comprising four tests: (i) walking backwards on balance beams; (ii) moving sideways; (iii) hopping for height on one foot; and (iv) jumping sideways. This test battery has been extensively used in Portuguese speaking countries (Chaves et al., 2015; M. A. M. Dos Santos et al., 2018) and detailed information about the protocol can be obtained in A. C. Reyes et al. (2019). All individual GMC test results were converted to z-scores using grand-mean centering, and a total GMC score (GMC_z) was obtained by summing all individual z-scores.

Predictor Variables

Child-level

Height (cm) and sitting height (cm) were measured to the nearest 0.1 cm according to standardized procedures (T. G. Lohman, A. F. Roche, & R. Martorell, 1988) using a portable stadiometer (Sanny, Model ES-2060) holding the child´s head in the Frankfurt plane. Body weight was measured to the nearest 0.1 kg with a digital scale (Pesacon, Model IP68). Body mass index (BMI) was calculated using the standard formula [$BMI=weight(kg)/height(m)^2$].

Biological maturation was assessed with the maturity offset (Mirwald et al., 2002). This method uses sex-specific formulas and information about chronological age, height, sitting height, and leg length to estimate time before or after age-at-peak height velocity (aPHV). A positive (+) maturity offset indicates the number of years the participant is beyond aPHV, whereas a negative (-) maturity offset represents the number of years the participant is before aPHV.

Stunting (height-for-age) was calculated with age- and sex-specific *WHO Child Growth Standards* references for 5-19 years of age (Onis et al., 2007), according to the STATA software syntax provided by the WHO (World Health Organization, 2007). Within the stunting sample, two groups were formed: normal growth [height-for-age Z score ≥ -2 standard deviation (SD)], and stunted growth (height-for-age Z score < -2 SD). A dummy coding was created, with normal growth coded as 0 (reference category), and stunting coded as 1.

Geographical areas of residence were located at different altitudes: sea-level (58 m), Amazon region (751 m) and high-altitude (4107 m). A coding scheme generated two dummy variables: sea-level, the reference category, was coded as 0 0, high-altitude was 1 0 and Amazon region was 0 1.

School-level

Information about school characteristics was obtained via an objective school audit, using modified and locally adapted versions of the Healthy Eating and Physical Activity modules of the Healthy School Planner designed by the Joint Consortium for School Health (Joint Consortium for School Health, 2012). For the present study, the following domains were considered: (1) school characterization (school size – number of students were divided by 10 as to have more interpretable parameter estimates); (2) policies and practices for physical activity (specifically, the existence of policies and practices issued by the state, school board, or any other government agency to promote physical activity, health and well-being of students and are organized by the school). No policies and practices was the reference category; (3) physical structure of the school (playground area – without obstacles was the reference category; and multi-sports roofed – no was the reference category); (4) physical education classes (duration – 90 min/week was the reference category).

Data quality control

To ensure data quality, the following procedures were used: (1) all team members were trained concerning the technical procedures of body measurements, PF and GMC test protocols; (2) a pilot study was conducted to assess the quality of data collection; and (3) a random sample was retested. The inter-observer technical errors of the measurement were 0.2 cm for height, 0.1 cm for sitting height, and 0.1 kg for body mass. ANOVA-based intraclass correlation coefficient for GMC and PF tests ranged from 0.78 (moving sideways) to 0.91 (walking backwards), and from 0.79 (12 minute run) to 0.85 (standing long jump), respectively.

Statistical Analysis

Descriptive statistics (means, standard deviations and percentages) were obtained using SPSS 24. ANOVA and χ^2 tests were used to estimate differences in means and frequencies in child-level variables among the three geographical areas of residence, respectively. Additionally, Tukey HSD tests for multiple comparisons were also used.

Since the data were structurally dependent, i.e., variables (GMC_z and PF_z) nested within children which were nested within schools, a multilevel analysis was used. Also, given our interest in jointly analyzing two dependent variables (PF_z and GMC_z), a multivariate approach was used as advocated (Snijders & Bosker, 2012) and displayed in Figure 1.

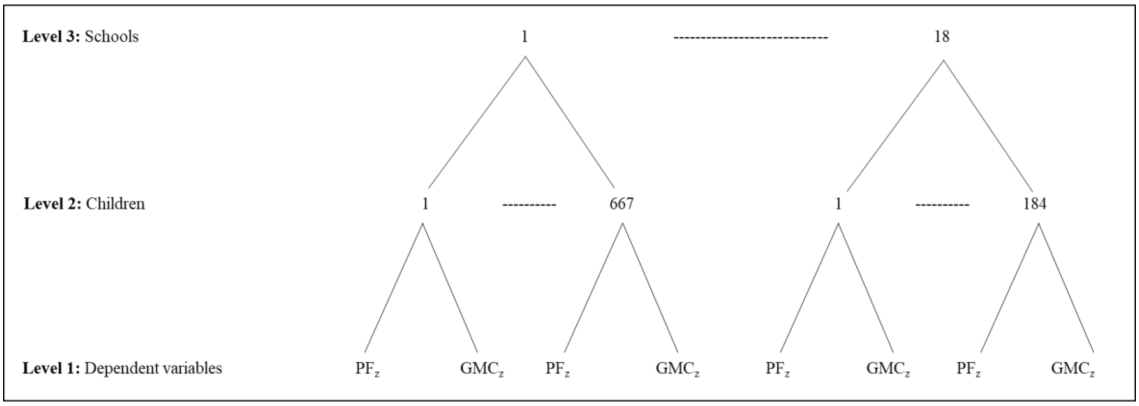

Figure 1. Multivariate multilevel structure of variables: total physical fitness score (PF_z) and total gross motor coordination score (GMC_z) are at level 1, nested within children at level 2, nested within schools at level 3.

A series of three-level sequential models were tested following our aims. The first model – the null model (M_0), with no predictors, allowed the joint estimation of variances and covariances for PF_z and GMC_z. These estimates permitted the calculation of two important pieces of information: (i) how much of the total variation and covariation is explained at the child and school levels; and (ii) what is the size and direction of the correlations between PF_z and GMC_z for children within schools, and between schools. The second model (M_1) included child-level predictors as well as location, and in the last model (M_2) we added school contextual variables. Because we have only three regions (sea-level, Amazon region and high-altitude), it is not recommended to treat it as a level in a multilevel analysis (Snijders & Bosker, 2012). Therefore, dummy variables for region were included in the fixed part of the second model (M_1). Covariates (age and BMI) were centered at their grand mean when necessary as is common in multilevel analysis (Snijders & Bosker, 2012). All analyses were done using the SuperMix software program (D. Hedeker et al., 2008) which provided simultaneous estimation of all model parameters using maximum likelihood procedures. The Deviance statistic was used as a measurement of relative fit of the multivariate model to the data (Snijders & Bosker, 2012); differences in Deviances (from M_0 to M_1 and from M_1 to M_2) follow a χ^2 distribution with degrees of freedom equal to the difference in the number of estimated parameters from models M_0 to M_1, and from M_1 to M_2. Statistical significance was set at 5%.

RESULTS

Descriptive statistics for child and school-level variables are provided in Table 3. On average, high-altitude subjects are relatively older than their peers from the Amazon region ($F=54.94$, $p<0.05$), whereas sea-level subjects have a higher BMI ($F=420.49$, $p<0.05$), and are further ahead in their maturity status ($F=91.87$, $p<0.05$). In addition, subjects living in the Amazon region have higher PF_z ($F=103.94$, $p<0.05$) and GMC_z ($F=34.41$, $p<0.05$) compared to their peers. Lastly, the highest prevalences of stunting occur simultaneously in the Amazon (12.5%) and high-altitude (12.1%) regions.

The average number of students per school is 453±263, ranging from 96 to 1200; 16.7% of the schools have policies, and 38.9% have practices for physical activity. Furthermore, 83.3% have recreation spaces without obstacles, whereas 66.7% do not have multi-sports roofed complexes. Lastly, 55.6% of the schools have physical education classes lasting >90 min. Information about descriptive statistics for school-level variables by geographical area of residence can be found in Supplementary Table 1.

Table 3. Descriptive statistics for variables at the child and school-levels

Child-level variables

	Sea-level (S) (n=1644)	Amazon region (A) (n=4258)	High-altitude (H) (n=2016)	*F*	*Post hoc* among areas
		Mean±SD			
Age (y)	10.90±2.79	10.38±2.59	11.07±2.62	54.94*	S>A; H>A
BMI (kg/m^2)	20.42±3.55	18.40±2.93	17.71±2.33	420.49*	S>A>H
Maturity offset (y-to-PHV)	-1.21±2.16	-2.01±2.14	-1.57±2.10	91.87*	S>H>A
Handgrip (kg^f)	15.81±7.25	15.05±6.66	15.13±6.73	7.64*	S>A; S>H
SLJ (cm)	121.73±30.24	118.96±25.65	117.65±19.90	12.09*	S>A; S>H
SR (s)	24.07±3.53	22.76±2.32	27.48±2.31	2229.56*	H>S>A
12 minute run (m)	1300.23±313.86	1426.55±449.61	1601.39±350.20	265.64*	H>A>S
PF$_z$	-0.12±3.08	0.37±2.66	-0.69±2.62	103.94*	A>H>S
WB (points)	45.60±13.97	54.05±12.40	50.82±11.71	271.20*	A>H>S
MS (points)	54.01±15.48	50.57±13.66	52.05±14.11	36.14*	S>H>A
HH (points)	48.87±17.68	52.87±16.44	48.28±18.05	63.23*	A>S;A>H
JS (points)	41.88±10.40	42.91±10.07	43.74±10.00	15.25*	H>A>S
GMC$_z$	-0.50±3.29	0.24±3.03	-0.09±3.18	34.41*	A>S>H
		Frequencies n (%)		χ^2	
Sex					
Girls	1077 (65.5)	2274 (53.4)	1037 (51.4)	87.69*	
Boys	567 (34.5)	1984 (46.6)	979 (48.6)		
Stunting condition					
Stunting	66 (4.0)	534 (12.5)	244 (12.1)	96.47*	
Normal growth	1578 (96.0)	3724 (87.5)	1772 (87.9)		

School-level variables

School characterization	Mean±SD	Range	Frequencies n (%)
School size			
Number of students	453±263	96-1200	
Policies and practices for PA			
Policies and practices			
Only policies			3 (16.7)
Only practices			7 (38.9)
None			8 (44.4)
Physical structure of the school			
Playground area			
With obstacles			3 (16.7)
Without obstacles			15 (83.3)
Multi-sports roofed			
Yes			6 (33.3)
No			12 (66.7)
Physical Education (PE) classes			
PE class duration			
90 minutes p/week			8 (44.4)
>90 minutes p/week			10 (55.6)

$^*p<0.05$; PF$_z$ = total physical fitness score; GMC$_z$ = total gross motor coordination score; BMI = body mass index; SLJ = standing long jump; SR = shuttle-run; WB = walking backwards on balance beams; MS = moving sideways; HH = hopping for height on one foot; JS = jumping sideways

Results of the multivariate multilevel model are provided in Table 4. The null model (M_0) indicated that school-level characteristics jointly explain 35% of the variance in PF_z and GMC_z, since the intraclass coefficient correlation was obtained by the following formula: ICC = [school variance/(school and child variance)], and the variance of the average of these two variables, which is done at both the school and child level, is [0.5 x [variance (PF_z) + variance (GMC_z) + 2 x covariance (PF_z, GMC_z)]]. The major portion of the variance in PF_z and GMC_z (65%) was at the child level. Further, at the child level (within-schools), the covariance (σ) between PF_z and GMC_z was significant ($\sigma=3.76\pm0.08$, $p<0.05$), which translates to a positive correlation coefficient within schools ($\rho=0.63$). PF_z and GMC_z intercepts were not significantly different from their z-score means ($\beta=0.26\pm0.42$, $p>0.05$; $\beta=0.10\pm0.43$, $p>0.05$, respectively) suggesting that, on average, 10.66 year-old Peruvians had similar levels of PF_z and GMC_z.

Model 1 included age (centered at 10.66 yrs), sex, BMI (centered at 18.64 kg/m^2), maturity offset, stunting and geographical area of residence. On average, with increasing age, there was a greater increase in GMC_z ($\beta=0.78\pm0.04$, $p<0.001$) than in PF_z ($\beta=0.14\pm0.03$, $p<0.001$), and boys significantly outperformed girls (PF_z, $\beta=3.24\pm0.08$, $p<0.001$; GMC_z, $\beta=1.56\pm0.09$, $p<0.001$). Further, boys and girls with lower BMI and who were ahead in their maturation had also higher PF_z ($\beta=-0.13\pm0.01$, $p<0.001$; $\beta=1.08\pm0.05$, $p<0.001$, respectively) and GMC_z ($\beta=-0.18\pm0.01$, $p<0.001$; $\beta=0.39\pm0.06$, $p<0.001$, respectively) levels. Stunting was negatively related to both PF_z ($\beta=-0.30\pm0.07$, $p<0.001$) and GMC_z ($\beta=-0.30$; $p=0.08$). Children living in the Amazon region had higher PF_z ($\beta=1.01\pm0.44$, $p<0.001$) and GMC_z ($\beta=1.01\pm0.26$, $p<0.001$) than their peers from the sea-level. There was a significant decrease in Deviance favoring M_1 relative to M_0 (Δ in Deviance=7131.2, $\chi^2_{(22)}= 7131.2$, $p<0.001$) indicating a better fit.

In the final model (M_2), school-level predictors were added. Here, child-level estimates remain relatively similar in their magnitude and interpretation, but now high-altitude Peruvians significantly differ in their GMC_z ($\beta=-0.93\pm0.33$, $p<0.001$) and those living in the Amazon region only significantly differ in their PF_z ($\beta=1.21\pm0.58$, $p<0.001$) from their sea-level peers. Further, on average, children and adolescents from schools with a higher number of students had lower PF_z (β=-0.016±0.006, $p<0.001$) and have higher GMC_z (β=0.005±0.003, $p<0.001$), whereas having physical education classes with greater duration than 90 minutes was associated with higher PF_z (β=0.70±0.32, $p<0.001$) and GMC_z (β=0.46±0.15, $p<0.001$). Surprisingly, students from schools where policies for physical activity were implemented tend to have lower GMC_z (β=-1.17±0.34, $p<0.001$), but no significant association was observed for PF_z (β=0.18±0.79, $p>0.05$). Additionally, no significant relationships were seen for playground areas as well as multi-sports roofed equipment. This model fitted the data better than the previous one (Δ in Deviance=46.84, $\chi^2_{(34)}$=46.84, $p<0.001$).

Table 4. Multivariate multilevel modelling results: parameter estimates (standard-errors) and variance components for both total physical fitness score (PF$_z$) and total gross motor coordination score (GMC$_z$)

	Null Model (M$_0$)		**Model 1 (M$_1$)**		**Model 2 (M$_2$)**	
Parameters	PF$_z$	GMC$_z$	PF$_z$	GMC$_z$	PF$_z$	GMC$_z$
Regression coefficients (fixed effects)						
Child-level						
Intercept	0.26 (0.42)^{ns}	0.10 (0.43)^{ns}	0.21 (0.37)^{ns}	-0.61 (0.22)*	-0.54 (0.80)^{ns}	0.06 (0.35)^{ns}
Age (y)			0.14 (0.03)*	0.78 (0.04)*	0.15 (0.03)*	0.79 (0.04)*
Sex (boys)			3.24 (0.08)*	1.56 (0.09)*	3.25 (0.08)*	1.58 (0.09)*
BMI (kg/m^2)			-0.13 (0.01)*	-0.18 (0.01)*	-0.13 (0.01)*	-0.18 (0.01)*
Maturity offset (y-to-aPHV)			1.08 (0.05)*	0.39 (0.06)*	1.09 (0.05)*	0.39 (0.06)*
Stunting growth (yes)			-0.30 (0.07)*	-0.30 (0.08)*	-0.30 (0.07)*	-0.30 (0.08)*
Geographical area of residence (High-altitude)			-0.72 (0.47)^{ns}	-0.12 (0.28)^{ns}	-0.88 (0.75)^{ns}	-0.93 (0.33)*
Geographical area of residence (Amazon region)			1.01 (0.44)*	1.01 (0.26)*	1.21 (0.58)*	0.03 (0.25)^{ns}
School-level						
Number of students					-0.016 (0.006)*	0.005 (0.003)*
Existence policies or/and practices for physical activity (policies)					0.18 (0.79)^{ns}	-1.17 (0.34)*
Existence policies or/and practices for physical activity (practices)					0.24 (0.42)^{ns}	0.05 (0.18)^{ns}
Playground area (with obstacles)					0.08 (0.45)^{ns}	-0.21 (0.20)^{ns}
Multi-sports roofed (yes)					0.03 (0.38)^{ns}	0.11 (0.17)^{ns}
Duration of physical education classes (>90 min)					0.70 (0.32)*	0.46 (0.15)*
Variance components (random effects)						
Between-schools (school-level)						
Variance	3.18 (1.06)*	3.39 (1.14)*	0.52 (0.17)*	0.17 (0.06)*	0.22 (0.08)*	0.03 (0.01)*
Covariance	2.93 (1.04)*		0.15 (0.08)*		0.07 (0.04)*	
Correlation	0.89		0.50		0.77	
Within schools (child-level)						
Variance	5.19 (0.08)*	6.80 (0.11)*	2.54 (0.04)*	3.92 (0.06)*	2.54 (0.04)*	3.92 (0.06)*
Covariance	3.76 (0.08)*		1.16 (0.04)*		1.16 (0.03)*	
Correlation	0.63		0.37		0.37	
Deviance	69265.94		62134.74		62087.90	

$^{*}p$<0.001; ^{ns}= non-significant

DISCUSSION

The novelty of this study rests not only in its multilevel approach to analyze the multivariate expression of motor competence marked by PF$_z$ and GMC$_z$, but also by identifying its links to individual, natural (distinct geographical locations), and built environments (school contexts).

The first relevant finding was that the school context explained 35% of the joint associations between PF$_z$ and GMC$_z$, whereas children's characteristics explained 65% of the total variation. Further, children with higher PF$_z$ also tend to express higher GMC$_z$ levels (□=0.63), and this correlation declines to 0.37 after adjusting for a set of covariates at the child and school levels. Children's systematic engagement in a variety of organized and non-organized physical activities, as well as in they daily chores, serve to concomitantly enhance their PF and GMC levels. For example, ballistic skills (throwing, jumping, running and hopping) performed in organized sport activities demand high levels of physical effort, neuromuscular coordination and control favoring both PF and GMC development (Vandorpe et al., 2012). Further, locomotor and object control skills highly stimulated during physical education classes and leisure games also tend to promote increases in PF and GMC levels (M. T. Cattuzzo et al., 2016). Although available reports based on cross-sectional (Haga, 2008; Vandendriessche et al., 2011) and longitudinal data (Hands, 2008; A. C. Reyes et al., 2019) suggest that PF is moderately associated with GMC, there are no multivariate studies available reporting on their joint links whose variance is explained by school contexts and individual characteristics.

PF$_z$ and GMC$_z$ levels depend upon the influence of individual predictors as shown in Model 1. With increasing age, children express their PF$_z$ and GMC$_z$ development in higher levels of mature performance, which may be explained by increases in their body size, and changes in body composition and neuromuscular maturation (R.M. Malina et al., 2004), as well as by expected increases in motor skill proficiency (Branta, Haubenstricker, & Seefeldt, 1984). These findings are consistent with other reports considering PF and GMC in a univariate fashion (Chaves et al., 2013; Latorre Román et al., 2017). The novel finding was that this increase was greater in GMC_z than in PF_z, which may reflect a non-synchronicity in their developmental timing and tempo across age.

Sex-differences in both PF_z and GMC_z were also confirmed by our results, even after adjusting for other covariates, with boys outperforming girls. A novel finding was that the sex differences were more pronounced in PF_z, than in GMC_z, probably due to the fact that PF testing is more demanding in terms of cardiorespiratory capacity and muscular strength, than are GMC tasks. This trend is consistent with previous research when analyzing PF and GMC separately (Chaves et al., 2016; M. A. M. Dos Santos et al., 2018), and may be explained by differences in body size and composition favouring boys (R.M. Malina et al., 2004). It is also possible that boys´ engagement in more intense non-organized play activities, as well as sports and competitive games, may exert greater influences on PF (Valdívia et al., 2018).

Peruvian children and adolescents with greater BMI tend to be less physically fit, as well as less coordinated, which can be partially explained by increases in fat mass with its detrimental effects in motor performance when tasks require the body mass to be projected (Lopes, Maia, Rodrigues, & Malina, 2012). For example, GMC tests like moving sideways on boxes or jumping sideways, and PF tests like shuttle-run and standing long jump require children to rapidly change their center of mass vertically and/or horizontally, and so it is expected that those with higher BMI are usually less capable to do so effectively, and the net result is their lower performance. A similar trend was evident not only in previous Peruvian reports (Bustamante Valdivia, Maia, & Nevill, 2015; Chaves et al., 2016) but also in studies conducted in other countries (Y. C. Huang & R. M. Malina, 2007; V. P. Lopes et al., 2012).

It has been suggested that individual differences in maturation may affect motor performance. Our results showed a positive relationship, with Peruvian youth ahead in their maturity status, exhibiting simultaneously, higher PF_z and GMC_z levels. On the one hand this is expected since early maturation reflects, to some extent, a greater neuromuscular maturation which contributes to the development of motor performance (P. Katzmarzyk et al., 1997). Further, higher

PF and GMC levels in early maturing children seems to be linked to a higher rate of sports participation (Vandorpe et al., 2012), even accounting for their increased size and mass (R.M. Malina et al., 2004). On the other hand, maturity-related changes in both size and body composition could negatively affect motor performance, particularly on tasks requiring body displacement, especially in girls experiencing greater pubertal gains in fat mass (Luz et al., 2016).

Another important finding is that stunted Peruvian children tend to have lower levels of PF_z and GMC_z. Since KTK and PF tasks, like hopping for height on one foot, moving sideways on boxes, standing long jump or shuttle-run, require body displacements in different planes, axes, and directions, it is expected that children with shorter limbs perform worse. These findings were partially corroborate by R. M. Malina et al. (2011), showing that stunted Mexican youth significantly differ from their normal peers in grip strength and standing long jump tests. Additionally, M. Armstrong et al. (2017) reported that stunted South-African children performed poorer in standing long jump, sit-up and cricket ball throw tests. However, there are no available studies linking stunting with GMC to compare with our results.

Natural and built environmental differences within Peru also seem to play important roles in shaping motor competence in children and youth, given that our results showed that those living at high-altitude significantly differ in their GMC_z, as well as those living in the Amazon region significantly differ in their PF_z from their sea-level peers. These results can be explained by the different environmental conditions affecting their daily life routines as well as their motor development as previously suggested (Chaves et al., 2016; Valdívia et al., 2018). In the city of Junín, located at 4,107 m of altitude, residents deal with severe environmental stressors (hypoxic stress, low temperatures and relative humidity, high cosmic radiation, and fewer hours of sunlight and twilight) (INEI, 2018) that are not expressed at sea-level, making it difficult for them to participate in outdoor physical activities and sports, which may probably negatively influence their motor skills development. Further, since children spend a lot of time helping their parents with household chores and supporting them in agricultural activities in the field, they have less opportunities to engage in structured and non-structured play, suffering a possible delay in motor skill development. On the other hand, at sea-level, particularly in the region of Barranco, the natural environment does not seem to be problematic as occurs at high-altitude, but the characteristics of the built environment may generate a diversified set of constraints, such as high population density, traffic congestion, public insecurity, as well as the lack of multisport outdoor and public recreational infrastructures available to schoolchildren, which may probably restrict their opportunities to engage in a wide range of motor tasks. In turn, the city of Chanchamayo, located in the Amazon region, is friendlier in terms of natural and built environment, since it has a favourable climate conditions, with a large extension of rainforest with its ample green spaces where children can enjoy carefree play; further, it is also propitious for them to diversify their play activities, which can gradually improve their PF levels.

During childhood and adolescence, students spend many hours at school making it a privileged context to learn, participate and interact with peers in a wide range of activities like sports, physical exercises and leisure-time activities, improving their motor competence since an early age (M. T. Cattuzzo et al., 2016). Although we were not able to locate a study using a multivariate framework linking the school context to both PF and GMC, we found a few reports based on a univariate approach. For example, W. Zhu et al. (2010) showed that school physical education programs and policy factors were significantly related to PF. Similarly, Chaves et al. (2015) showed that the school context was important in predicting GMC in Portuguese children, while A. C. Reyes et al. (2019) found no such relationship. In our study, the school context explained 35% of the joint associations between PF_z and GMC_z, with school size, defined according to the number of enrolled students, as well as the duration of physical education classes emerging as a significant predictors that differently influence the dependent variables.

Peruvian children from schools with higher numbers of students are less physically fit, but have higher GMC_z levels. On the one hand, schools with more students apparently have more space and facilities for children to play during their recess time, which may represent a greater potential to increase their motor skill efficiency, and, consequently, to promote positive effects in their GMC levels. On the other hand, schools with more students usually have larger class sizes which may offer fewer opportunities for youth to participate in meaningful class activities, as well as to create highly efficient class environments for the teaching-learning process, and this may help explaining the negative effect in their PF. This is apparently evident in Peru, since physical education classes have, on average, a total of 30 students per class, as approved by the Peruvian Ministry of Education. In this sense, it is expected that a greater duration of physical education classes per week (more than 90 minutes) may be connected with higher gains of GMC_z and PF_z, providing more class time for students to exercise physically and, consequently, develop their motor skills and physical capacities over time.

Surprisingly, students from schools where policies for physical activity were implemented by the Peruvian Ministry of Education, seems to negatively influence the development of children's GMC_z levels. It is possible that the effectiveness of these policies is not yet very well established, so urgent action is needed to prevent or counter this trend. For example, we can anticipate that information regarding report cards on physical activity for children, developed by the Active Healthy Kids Global Alliance youth (Salomé Aubert et al., 2019), and widely used in several countries, can help Peruvian political leaders or government officials promote more active lives and active systems, as well as encourage the development of GMC among Peruvian schoolchildren.

This study has limitations. First, the sample is not representative of the Peruvian population, which restricts the generalization of the results. However, we have a fairly large sample (7918 subjects) aged 6-15 yrs within an important time window in their growth and development. Second, no systematic information was collected about objectively measured physical activity since it would probably be a daunting task given the sample size; further, no funding was available to buy accelerometers. Third, we did not consider information about the putative influence of family income and/or socioeconomic status. Yet, the financial costs associated with collecting data on 8000 families made this option unfeasible. This study has also several strengths: (1) the use of multivariate multilevel analysis to identify relationships between PF_z and GMC_z, as well as capturing the complexity of the nested information at child and school levels; (2) the use of objective and standardized measurement methods for data collection; and (3) the inclusion of three different geographical locations.

In summary, we showed that the school context explained 35% of the joint associations between PF_z and GMC_z, and children's characteristics explained 65% of the total variation. On average, with increasing age, there was a greater increase in GMC_z than in PF_z, with boys outperforming girls. Further, those with lower BMI and who were ahead in their maturation also had higher PF_z and GMC_z levels. On the other hand, stunted Peruvian children tend to be less physically fit, as well as less coordinated. Youth living at high-altitude tend to be less coordinated than their sea-level peers, while Amazon region children are more physically fit than those living at sea-level. Finally, youth from schools with higher number of students are less physically fit, but have higher GMC_z levels; further, those whose physical education classes have more than 90 minutes tend to exhibit higher PF_z and GMC_z levels. The existence of policies for physical activity was only negatively associated with GMC_z.

PERSPECTIVES

Using a multivariate modelling approach to best understand the relationships between PF_z and GMC_z, as well as to identify the influence of individual, natural, and built environments, enabled us to enhance our understanding on the links between these two important facets of motor competence. Even though children's characteristics explain the greatest fraction of the joint variation in PF_z and GMC_z, there is no doubt that the school has a wide range of possibilities to play a key role in sustainable motor development given that youth spend a large amount of their awake time at school. This is relevant information and should to be taken into consideration by Peruvian school authorities, school councils and physical education teachers, when designing and implementing diversified strategies to improve children's PF and GMC levels from an early age, helping them reach their full potential.

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AUTHOR CONTRIBUTIONS

CS, DH, PTK and JM analyzed the data. CS, JM, AB, DH, GT and PTK drafted the manuscript. AB and JM designed the study and directed its implementation. AB and JM provided necessary logistical support. AB, DH, OV, RG, GT and PTK provided extensive critical comments and did the final editing of the manuscript.

CONFLICT OF INTEREST STATEMENT

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

REFERENCES

1. Ruiz JR, Castro-Pinero J, Artero EG, et al. Predictive validity of health-related fitness in youth: a systematic review. *Br J Sports Med.* 2009;43(12):909-923.

2. Cattuzzo MT, Dos Santos Henrique R, Re AH, et al. Motor competence and health related physical fitness in youth: A systematic review. *J Sci Med Sport.* 2016;19(2):123-129.

3. Okuda E, Horii D, Kano T. Genetic and environmental effects on physical fitness and motor performance. *International Journal of Sport and Health Science.* 2005;3:1-9.

4. Kiphard EJ, Schilling F. *Körperkoordinationstest für Kinder.* Weinheim: Beltz Test GmbH; 1974.

5. Malina RM, Bouchard C, Bar-Or O. *Growth, maturation and physical activity.* Champaign, IL: Human Kinetics; 2004.

6. Barnett LM, Lai SK, Veldman SL, et al. Correlates of gross motor competence in children and adolescents: a systematic review and meta-analysis. *Sports medicine.* 2016;46(11):1663-1688.

7. Freitas DL, Lausen B, Maia JA, et al. Skeletal Maturation, Body Size, and Motor Coordination in Youth 11-14 Years. *Medicine and science in sports and exercise.* 2016;48(6):1129-1135.

8. Katzmarzyk P, Malina R, Beunen G. The contribution of biological maturation to the strength and motor fitness of children. *Annals of human biology.* 1997;24(6):493-505.

9. Huang YC, Malina RM. BMI and health-related physical fitness in Taiwanese youth 9-18 years. *Med Sci Sports Exerc.* 2007;39(4):701-708.

10. Lopes VP, Stodden DF, Bianchi MM, Maia JA, Rodrigues LP. Correlation between BMI and motor coordination in children. *J Sci Med Sport.* 2012;15(1):38-43.

11. Chaves R, Bustamante A, Nevill AM, et al. Developmental and physical-fitness associations with gross motor coordination problems in Peruvian children. *Res Dev Disabil.* 2016;53:107-114.

12. Armstrong M, Lambert M, Lambert E. Relationships between different nutritional anthropometric statuses and health-related fitness of South African primary school children. *Annals of human biology.* 2017;44(3):208-213.

13. Malina RM, Pena Reyes ME, Tan SK, Little BB. Physical fitness of normal, stunted and overweight children 6-13 years in Oaxaca, Mexico. *Eur J Clin Nutr.* 2011;65(7):826-834.

14. INEI. Perfil Sociodemográfico del Perú. Informe nacional. Instituto Nacional de Estadística e Informática. https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1539/index.html. Published 2017. Accessed 18 February, 2019.

15. Cossio-Bolanos M, Campos RG, Andruske CL, et al. Physical Growth, Biological Age, and Nutritional Transitions of Adolescents Living at Moderate Altitudes in Peru. *Int J Environ Res Public Health.* 2015;12(10):12082-12094.

16. Zhu W, Boiarskaia EA, Welk GJ, Meredith MD. Physical education and school contextual factors relating to students' achievement and cross-grade differences in aerobic fitness and obesity. *Research quarterly for exercise and sport.* 2010;81(sup3):S53-S64.

17. Chaves R, Baxter-Jones A, Gomes T, Souza M, Pereira S, Maia J. Effects of individual and school-level characteristics on a child’s gross motor coordination development. *International journal of environmental research and public health.* 2015;12(8):8883-8896.

18. Reyes AC, Chaves R, Baxter-Jones ADG, et al. Modelling the dynamics of children's gross motor coordination. *J Sports Sci.* 2019:1-10.

19. Bustamante A, Beunen G, Maia J. *Como crecen y se desarrollan los niños y adolescentes en La Merced y San Ramón. Alcances para la Educación Física, el Deporte y la Salud.* Lima, Perú: Universidad Nacional de Educación Enrique Guzmán y Valle, La Cantuta; 2011.

20. ESCALE. Magnitudes de la Educación. http://escale.minedu.gob.pe/magnitudes. Published 2010. Accessed 18 February, 2019.

21. AAHPERD. *Health related physical fitness: Test manual.* Reston, VA: American Alliance for Health, Physical Education, Recreation and Dance; 1980.

22. EUROFIT. *Handbook for the EUROFIT tests of physical fitness.* 2nd ed. Strasbourg: Committee of Experts on Sports Research; 1993.

23. Dos Santos MAM, Nevill AM, Buranarugsa R, et al. Modeling children's development in gross motor coordination reveals key modifiable determinants. An allometric approach. *Scand J Med Sci Sports.* 2018;28(5):1594-1603.

24. Lohman TG, Roche AF, Martorell R. *Anthropometric standardization reference manual.* Vol 177: Human kinetics books Champaign, IL; 1988.

25. Mirwald R, Baxter-Jones A, Bailey D, Beunen G. An assessment of maturity from anthropometric measurements. *Med Sci Sports Exerc.* 2002;34(4):689-694.

26. Onis M, Onyango A, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ.* 2007;85:660-667.

27. World Health Organization. WHO Reference 2007 STATA macro package https://www.who.int/childgrowth/software/readme_stata.pdf. Published 2007. Accessed 27th, November, 2019.

28. Joint Consortium for School Health. Healthy School Planner. www.healthyschoolplanner.uwaterloo.ca. Published 2012. Accessed 18 October 2019.

29. Snijders TAB, Bosker RJ. *Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling.* 2nd ed. London: Sage Publishers; 2012.

30. Hedeker D, Gibbons R, Toit MD, Cheng Y. *Supermix: Mixed effects models.* Lincolnwood, IL, USA: Scientific Software International, Inc.; 2008.

31. Vandorpe B, Vandendriessche J, Vaeyens R, et al. Relationship between sports participation and the level of motor coordination in childhood: a longitudinal approach. *Journal of Science and Medicine in Sport.* 2012;15(3):220-225.

32. Vandendriessche JB, Vandorpe B, Coelho-e-Silva MJ, et al. Multivariate association among morphology, fitness, and motor coordination characteristics in boys age 7 to 11. *Pediatric Exercise Science.* 2011;23(4):504-520.

33. Haga M. The relationship between physical fitness and motor competence in children. *Child: care, health and development.* 2008;34(3):329-334.

34. Hands B. Changes in motor skill and fitness measures among children with high and low motor competence: a five-year longitudinal study. *J Sci Med Sport.* 2008;11(2):155-162.

35. Branta C, Haubenstricker J, Seefeldt V. Age changes in motor skills during childhood and adolescence. *Exerc Sport Sci Rev.* 1984;12:467-520.

36. Latorre Román P, Moreno del Castillo R, Lucena Zurita M, Salas Sánchez J, García-Pinillos F, Mora López D. Physical fitness in preschool children: association with sex, age and weight status. *Child: care, health and development.* 2017;43(2):267-273.

37. Chaves R, Tani G, Souza M, Baxter-Jones A, Maia J. Desempenho coordenativo de crianças: construção de cartas percentílicas baseadas no método LMS de Cole e Green. *Revista Brasileira de Educação Física e Esporte.* 2013;27(1):25-42.

38. Valdívia AB, Henrique RS, Pereira S, et al. Familial resemblance in gross motor coordination. The Peruvian Sibling Study on Growth and Health. *Annals of human biology.* 2018;45(6-8):463-469.

39. Lopes VP, Maia JA, Rodrigues LP, Malina R. Motor coordination, physical activity and fitness as predictors of longitudinal change in adiposity during childhood. *European journal of sport science.* 2012;12(4):384-391.

40. Bustamante Valdivia A, Maia J, Nevill A. Identifying the ideal body size and shape characteristics associated with children's physical performance tests in Peru. *Scand J Med Sci Sports.* 2015;25(2):e155-165.

41. Luz LG, Cumming SP, Duarte JP, et al. Independent and combined effects of sex and biological maturation on motor coordination and performance in prepubertal children. *Perceptual and motor skills.* 2016;122(2):610-635.

42. Aubert S, Barnes JD, Forse ML, et al. The International Impact of the Active Healthy Kids Global Alliance Physical Activity Report Cards for Children and Youth. *Journal of Physical Activity and Health.* 2019;1(aop):1-19.

SUPPLEMENTARY MATERIALS

Supplementary Table 1. Descriptive statistics for school-level variables by geographical area of residence.

	Sea-level		Amazon region		High-altitude	
School-level variables	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
School characterization						
School size						
Number of students	439±85.1	322-521	582.5±326.9	180-1200	290.7±150.2	96-539
	Frequencies n (%)					
Policies and practices for PA						
Only policies	3 (75.0)		0 (0.0)		0 (0.0)	
Only practices	1 (25.0)		4 (50.0)		2 (33.3)	
None	0 (0.0)		4 (50.0)		4 (66.7)	
Physical structure of the school						
Playground area						
With obstacles	0 (0.0)		2 (25.0)		1 (16.7)	
Without obstacles	4 (100)		6 (75.0)		5 (83.3)	
Multi-sports roofed						
Yes	0 (0.0)		2 (25.0)		4 (66.7)	
No	4 (100)		6 (75.0)		2 (33.3)	
Physical Education (PE) classes						
PE class duration						
90 minutes p/week	2 (50.0)		3 (37.5)		3 (50.0)	
>90 minutes p/week	2 (50.0)		5 (62.5)		3 (50.0)	

CHAPTER IV

Research Articles Based on Peruvian Sibling Data

Paper VI

Sibling resemblance in physical fitness components. The Peruvian Sibling Study on Growth and Health

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Behavior Genetics (under review)

ABSTRACT

Our purpose was to estimate sibling resemblance in health-related physical fitness components, and to examine how individual characteristics and shared natural environment explained sibling similarities in each physical fitness component. The sample comprised 656 sibling pairs and 102 triplets (6-15 years), from three geographical areas of Peru. Physical fitness components included morphological (waist circumference, sum of skinfolds), muscular (handgrip strength, standing long jump), and motor (shuttle-run). Body mass index (BMI), biological maturation and stunting were also assessed. A series of multilevel models were used, and sibling resemblance was estimated using intraclass correlations. When adjusted for covariates, only in some cases sibling resemblance was higher in same-sex sibs than in opposite sex siblings, depending upon the fitness component considered. Further, older siblings were better performers in all fitness components, BMI was negatively associated with standing long jump and shuttle-run, biological maturation was positively associated with skinfolds and handgrip, and stunting was negatively associated with muscular and motor components. Sister-sister pairs from high-altitude and Amazon regions were more agile than brother-brother pairs. In conclusion, individual characteristics and shared natural environment jointly influenced the expression of physical fitness in Peruvian siblings, revealing the importance of these features when designing individualized programs promoting fitness.

Keywords: physical fitness; youth; siblings; familial resemblance; shared environment; multilevel modelling.

INTRODUCTION

In very general terms, physical fitness can be defined as an individual trait expressing the efficiency of a varied set of bodily systems and functions in a wide-ranging set of contexts (Bouchard and Shephard 1994). Youngsters' physical fitness is now acknowledged to be a powerful marker of their health and well-being (Ortega et al. 2008), and the maintenance of adequate levels of physical fitness is expected to reduce a variety of health problems later in their lives (Ruiz et al. 2009). Further, physical fitness has also been positively linked to cognitive function and academic achievements during childhood and adolescence (Donnelly et al. 2016). It is also well acknowledged that physical fitness levels tend to increase in a non-linear fashion with increasing age, with boys outperforming girls (Malina et al. 2004). Moreover, youth ahead in their biological maturation (Katzmarzyk et al. 1997) and with lower body mass index (BMI) (Huang and Malina 2007) are more likely to be physically fit, but stunted children are less likely to be physically fit (Malina et al. 2011).

It has been reported that differences in children's physical fitness components are governed by the intertwined effects of genetic and environmental factors (Bouchard et al. 1997; Cheah et al. 2012), with an undeniable influence from the family context. Available data from twins and/or siblings have revealed the existence of significant familial resemblance expressed by intraclass correlations (ρ), regardless of the relationship degree in physical fitness indicators. For example, Schutte et al. (2016) described higher correlations in monozygotic twins (ρ=0.34-0.79) than dizygotic twins (ρ=0.28-0.54) in a total physical fitness score (vertical jump, handgrip strength, balance and flexibility). On the other hand, Malina and Mueller (1981), using US siblings, reported that brother-brother pairs (ρ=0.46) were more similar than brother-sister (ρ=0.24) and sister-sister pairs (ρ=0.19) in their muscular strength. Differently, Pereira et al. (2017) using Portuguese sibling data, showed greater resemblance for morphological, muscular and motor fitness components among sister-sister (0.35≤ρ≤0.55) and brother-brother (0.25≤ρ≤0.60) than brother-sister pairs

($0 \leq \rho \leq 0.15$), except for the cardiorespiratory component (1-mile run test: $\rho SS > \rho BS > \rho BB$).

It is well-known that biological siblings share on average 50% of their genes and also share common family contexts as well as natural and built environments. However, they differ in their chronological age, sex and health behaviours, as well as in their physical growth, biological maturation, and motor development trajectories (Keyes et al. 2013). Particularly in Peru, it is expected that different trends in similarity between brother-brother (BB), sister-sister (SS), and brother-sister (BS) pairs may be found because boys and girls face distinct regional cultural customs and traditions. For example, in Peruvian families, boys tend to have more freedom in their daily lives, e.g., to participate in outdoor activities. On the contrary, girls are expected to attend the nearest schools to home, and help their mothers with daily household chores which probably generate different life paths within sib-ships. Further, Peruvian siblings also distinctively share the circumstance of living in three distinct geographical areas (sea-level, Amazon region and high-altitude), characterized by their specific geographic, demographic, socioeconomic, health care and cultural characteristics (see Table 1). As such, Peruvians are exposed to different natural stressors daily (e.g., altitude, temperature regimes, and pollutants), as well as social and economic inequalities (e.g., access to health care, quality of nutrition, access to public recreational infrastructure) (Gallup et al. 2003). These different natural stressors allow the investigation of adaptive mechanisms expressed by human phenotypic plasticity in response to diverse environmental conditions (Frisancho 1978). Together, these factors can influence the intrapair similarities/dissimilarities in each physical fitness component. However, to date, there has been no study of variation of physical fitness levels among Peruvian siblings considering the diversity of the three geographical regions (sea-level, Amazon region and high-altitude). Hence, using sibling pairs (sib-ships), in conjunction with the multilevel statistical model (Hedeker et al. 2012) to analyze clustered data (individuals nested within their sib-ships), allows us to unravel the joint influence of individual and common shared environmental characteristics in Peruvian siblings physical fitness components. Therefore, the present study aimed to test the following hypotheses: (1) sibling resemblance was higher in same-sex sibs than in opposite sex siblings for all physical fitness components; and (2) individual characteristics and shared natural environment were significantly associated with siblings' health-related physical fitness components.

MATERIALS AND METHODS

Study participants

Study participants

Participants came from The Peruvian Sibling Study on Growth and Health (Bustamante et al. 2011), which investigated the association between several correlates and Peruvian siblings’ resemblance in body composition, physical activity, different facets of their motor development as well as gross motor coordination. The present sample consists of 1618 biological siblings (897 females and 721 males), aged 6-15 years from 758 nuclear families (656 pairs and 102 triplets) from 18 schools located in three geographical areas in the central region of Peru: sea-level (Barranco – 58 m; n=210), Amazon region (La Merced and San Ramon – 751 m; n=514) and (3) high-altitude (Junín – 4107 m; n=894). All data were collected between 2009 and 2010. Further, we only included siblings with complete data on all study variables, as well as being native to their respective regions (i.e., no migrants were included, regardless of whether their parents or grandparents were migrants). For this, we gathered information about their birth place and current place of residence or address and cross-checked this information with participants’ identity cards. Additionally, we did not find statistically significant mean differences ($p<0.05$) between included and excluded siblings with respect to physical fitness (the percentage of missing data was only 1% in handgrip, standing long jump and shuttle-run). Parents provided written consent, and siblings provided assent to freely participate in the study. The project was approved by the Ethics Committee of the National University of Education Enrique Guzmán y Valle (UNE EGyV).

Dependent variable

Physical fitness

Based on the health-related physical fitness model of Bouchard and Shephard (1994), all sibling pairs were assessed in three physical fitness components:

1. Morphological component: waist circumference was measured, in cm, with a non-stretchable fibreglass tape (Sanny, model 4010) at the midpoint between the edge of the lowest rib and the superior iliac crest during shallow apnea. Skinfold thickness (biceps, triceps, subscapular, abdominal, suprailiac, calf and thigh) was measured using a Holtain skinfold caliper (Crosswell, Crymych, UK) and recorded to the nearest 0.2 mm following the ISAK protocol (Norton 1996);

2. Muscular component: muscular strength (static strength) was assessed with the handgrip strength test using a hand held dynamometer (Takei Hand Grip Dynamometer®, Takei Scientific Instruments Co., Ltd, Nigata, Japan), and the result was recorded in kg^f. The participants gripped the dynamometer with maximum force for 5 to 10 seconds and the best score was recorded from two trials. Muscular power was obtained with the standing long jump test and the results were recorded in centimetres (cm). Each subject was instructed to jump as far as possible and the maximum jumping distance was recorded from two trials;

3. Motor component: agility was assessed with the shuttle-run test, and the time was recorded in seconds (s). Each subject performed five cycles (round-trip) at maximum speed between two lines separated by five meters.

Covariates

Individual characteristics

Anthropometry

Anthropometric measures [height (cm) and sitting height (cm)] were assessed using standardized protocols established by Lohman et al. (1988). Height as well as sitting height were measured with a portable stadiometer (Sanny, Model ES-2060) holding the child's head in the Frankfurt plane. Body weight was measured with a digital scale (Pesacon, Model IP68), and BMI was computed using the standard formula [weight(kg)/height(m)^2].

Biological maturation

Biological maturation was estimated via the maturity offset procedure proposed by Mirwald et al. (2002). This method uses sex-specific formulas and estimates the distance, in decimal years, each subject is from age at peak height velocity (aPHV). A positive (+) maturity offset represents the number of years the participant is beyond aPHV, whereas a negative (−) maturity offset represents the number of years the participant is before aPHV. This procedure has already been used in previous Peruvian studies (Bustamante Valdivia et al. 2015; Cossio-Bolanos et al. 2015; Valdívia et al. 2018).

Stunting

Stunting condition (height-for-age) was computed using the age- and sex-specific *WHO Child Growth Standards* for children and adolescents 5 to 19 years of age as advocated by Onis et al. (2007). Two groups were formed: normal growth [height-for-age Z score ≥ -2 standard deviation (SD)], and stunting (height-for-age Z score < -2 SD), using STATA software syntax provided by the WHO (World Health Organization 2007). Dummy coding was created, with normal growth coded as 0 (reference category), and stunting coded as 1.

Shared environment characteristics

Natural environment (geographical areas of residence)

Peru is characterized by the impressive heterogeneity of its three regions (sea-level, Amazon region, and high-altitude), which are shaped by cultural diversity as well as distinct geographical, demographical, socio-economic, political and educational characteristics (Table 1). On the coast, Barranco (58 m) is one of the 43 districts of Lima Province, located on the shore of the Pacific Ocean. In turn, the Amazon region is the largest of the Peruvian territory and occupies ~60% of its surface, and we sampled from La Merced and San Ramon (751 m) districts that have a geographical continuity and integrate the Chanchamayo province. Lastly, at high-altitude, the Andean region is located in the central part of the Andes Mountains and comprises 28.0% of the national territory. Junín was the chosen site (4107m), is the capital of the Junín province, and is located on the southern shore of Lake Junín or Chinchaycocha. We used a coding scheme with two dummies: sea-level, the reference category, was coded as 0 0, high-altitude was 1 0 and Amazon region was 0 1.

Table I. Geographic, demographic, socioeconomic, health care and cultural characteristics of the three geographical areas located in the central region of Peru

Characteristics	**Sea-level** (Barranco)	**Amazon region** (Chanchamayo)	**High-altitude** (Junín)
Geographic			
Altitude (m)	58	751	4107
Climate	Arid; semi-warm	Rainy; warm	Rainy; cold
Average annual temperature	18°C	24°C	12°C
Demographic			
Total population	8.564.867	411.011	1.272.890
Population density (people/km^2)	236.6	10.2	27.7
Socioeconomic			
Human Development Index	0.72	0.52	0.44
Per capita family income	1440.6	785.1	512.7
Primary production	Trade/Tourism	Agriculture/Tourism	Stockbreeding/Agriculture
Basic access to health care			
Health center	Yes	No	No
Public hospital	No	Yes	Yes
Private clinic	Yes	No	No
Infrastructure for physical activity and sports available			
Parks	Yes	Yes	Yes

Playground	Yes	Yes	Yes
Pool	Yes	Yes	Yes
Multisport indoor	Yes	Yes	Yes
Multisport outdoor	No	Yes	Yes
Gymnastics complex	No	No	No

Data quality control

Data quality control was assured using several procedures. Firstly, all research team members were certified in all methodological procedures and protocols by the lead researchers of the project. Secondly, a pilot study was conducted at the UNE EGyV. Thirdly, a reliability-in-field procedure was used, such that three to five students were randomly selected on alternating assessment days and re-tested. Technical errors of measurement (TEM) for height, body mass, sitting height and skinfolds were 0.2 cm, 0.1 kg, 0.1 cm and 0.2 mm, respectively. Reliability intraclass correlation coefficients (R) for skinfolds and physical fitness tests were calculated and ranged from 0.81 (shuttle-run) to 0.85 (standing long jump). Finally, systematic checks of all data entry, as well as identification/correction of putative input errors was done in SPSS v26.

Statistical Analysis

Descriptive statistics (means, standard deviations and frequencies) and standard statistical methods [analysis of variance (ANOVA), chi squared (χ^2), and Tukey HSD] were computed to test for mean differences between sib-ship pairs [brother-brother (BB), sister-sister (SS) and brother-sister (BS)], using SPSS v26 software. Skinfold thickness was normalized with a log transformation due to its skewness, and a sum of log-scores was used.

Given that individuals were nested within sib-ships, i.e. data were clustered, we used a multilevel model developed by Hedeker et al. (Hedeker et al. 2012). To address the first aim,we estimated separate within- and between-sib-ship variances, and different intraclass correlation coefficients (ICC) (ρ), with corresponding 95% confidence intervals for each physical fitness test. Moreover, based on the likelihood-ratio test, we compared a model that constrained ρ to be equal across sib-ship pairs (Null model) to a model that freely estimated ρ across sib-ship pairs (Model 1). The following models were henceforth estimated with the same or different ICC, depending on the result attained.

For the second aim, a more complex model (Model 2) was considered with adjustments for individual characteristics such as age, BMI, maturity offset and stunting; and ρ was estimated for each sib type. Finally, a full model (Model 3) was estimated by including the geographical area of residence as well as the interactions between the three regions with each sib-type (BB, SS and BS). In this model, ρ's were calculated considering geographical area and sibtype. Model comparisons were made with the likelihood ratio test. Importantly, because we have only three regions (sea-level, Amazon region and high-altitude), it was not recommended to treat them as a level in a multilevel analysis (Snijders and Bosker 2012). Therefore, dummy variables for each region were added in the fixed part of Model 3. When needed, covariates were centered around their respective means, and sea-level BB pairs were the reference category. All analyses were done in STATA 14, and the alpha level was set at 0.05.

RESULTS

Descriptive statistics for anthropometry, maturity off-set, all physical fitness components, and stunting are presented in Table 2. On average, high-altitude siblings were relatively older than their peers from the other regions ($F=9.24$ $p<0.05$). In turn, sea-level siblings had higher body weight ($F=17.60$ $p<0.05$) and had a higher BMI ($F=46.29$, $p<0.05$), waist circumference ($F=10.20$, $p<0.05$) and skinfold thickness score ($F=96.54$, $p<0.05$), whereas those living in the Amazon region were shorter ($F=6.45$, $p<0.05$), lagged behind their peers in biological maturation ($F=6.64$, $p<0.05$), and performed better in the shuttle-run test ($F=692.54$, $p<0.05$). Lastly, the highest prevalences of stunting occur simultaneously in the Amazon (14.3%) and high-altitude (12.5%) regions.

Table II. Descriptive statistics [means and standard deviations (SD); frequencies (%)], F tests, post-hoc comparisons, and χ^2 by each geographical region

	Sea-level (S) (n=210)	Amazon region (A) (n=514)	High-altitude (H) (n=894)	*F*	*Post hoc* among areas
		Mean±SD			
Age (yrs)	10.5±2.7	10.5±2.7	11.1±2.6	9.24*	H>S; H>A
Height (cm)	138.4±15.1	135.0±15.1	137.1±13.9	6.45*	A<S; A<H
Weight (kg)	38.9±12.3	34.1±11.0	34.2±10.0	17.60*	S>A, S>H
BMI (kg/m^2)	19.8±3.4	18.2±2.6	17.7±2.3	46.29*	S>A>H
Maturity offset (aPHV)	-1.9±1.2	-2.2±1.5	-2.0±1.4	6.64*	A<S; A<H
Physical fitness					
Morphological component					
Waist circumference (cm)	63.2±8.4	61.3±6.7	60.7±6.8	10.20*	S>A>H
Sum of skinfolds (log transformed)	17.6±2.8	15.8±2.5	14.8±2.2	96.54*	S>A>H
Muscular component					
Handgrip strength (kg^f)	14.3±6.3	15.3±6.9	14.9±6.6	1.76^{ns}	
Standing long jump (cm)	120.6±26.3	119.3±25.0	116.6±19.6	2.89^{ns}	
Motor component					
Shuttle-run (s)	24.2±3.0	22.6±2.2	27.5±2.3	692.54*	A>S; A>H
		Frequencies n (%)		χ^2	
Stunting					
Stunting	8 (3.8)	128 (14.3)	64 (12.5)	17.3*	
Normal growth	202 (96.2)	766 (85.7)	450 (87.5)		

*p<0.05; ^{ns} = non-significant

Intraclass correlations for physical fitness components adjusted and unadjusted for individual characteristics are presented in Table 3. Model-based results showed that model 1 (with different variance components among sib-types and consequently different intraclass correlation coefficients) fit the data significantly better than the null model (with equal intraclass correlation coefficient) for handgrip strength and waist circumference, whereas for standing long jump, shuttle-run and sum of skinfolds, model 1 did not fit the data significantly better than the null model, i.e., the three different sib pairs (BB, SS and BS) have the same intraclass correlation coefficient.

In general, the inclusion of individual characteristics (model 2) influenced the size of the intraclass correlations. For example, the BB unadjusted correlation for handgrip strength was 0.32 and dropped to 0.21 after the inclusion of individual characteristics; in addition, SS and BS pairs did not change substantially. For standing long jump the unadjusted correlation for all sib-types was 0.08 and only substantially increased to 0.16 after the inclusion of all covariates. For the shuttle-run, the unadjusted correlation for all sib-types was 0.50, but with the inclusion of individual covariates the value changed to 0.55. For waist circumference, the unadjusted correlation for BB was 0.30 and for SS was 0.13 and decreased to 0.19 and 0.11, respectively. On the contrary, the BS correlation increased after the inclusion of all covariates (from 0.11 to 0.17). Lastly, for sum of skinfolds, the unadjusted correlation for all sib-types was 0.23, but with the inclusion of individual covariates the value changed to 0.22. In general, a pattern was observed in ρ values, with same-sex siblings revealing greater resemblance for most physical fitness components, regardless of the inclusion of additional covariates.

Table III. Intraclass correlation coefficients (ρ) and their 95% confidence intervals for each test in each physical fitness component: unadjusted and adjusted for individual characteristics values

		BB (95%CI)	SS (95%CI)	BS (95%CI)	Log likelihood (LL)	Δ LL(χ^2)	*p-value*
Morphological component							
Waist circumference (cm)	Null model equal ρ	0.15 (0.09-0.23)	0.15 (0.09-0.23)	0.15 (0.09-0.23)	-5439.57	4.89 (9.77)	0.04
	Model 1 (without covariates and different ρ)	0.30 (0.17-0.45)	0.13 (0.05-0.30)	0.11 (0.05-0.24)	-5434.68		
	Model 2 (individual characteristics)	0.19 (0.08-0.38)	0.11 (0.03-0.30)	0.17 (0.09-0.28)	-4300.30	1134.38 (2269.20)	0.01
Sum of skinfolds (log transformed)	Null model equal ρ	0.23 (0.17-0.30)	0.23 (0.17-0.30)	0.23 (0.17-0.30)	-3814.57	2.87 (5.75)	0.22
	Model 1 (without covariates and different ρ)	0.20 (0.09-0.39)	0.30 (0.20-0.42)	0.18 (0.11-0.29)	-3811.70		
	Model 2 (individual characteristics)	0.22 (0.16-0.29)	0.22 (0.16-0.29)	0.22 (0.16-0.29)	-3802.73	11.84 (23.68)	<0.001
Muscular component							
Handgrip strength (kg^f)	Null model equal ρ	0.15 (0.09-0.22)	0.15 (0.09-0.22)	0.15 (0.09-0.22)	-5358.81	26.63 (53.26)	<0.001
	Model 1 (without covariates and different ρ)	0.32 (0.20-0.47)	0.13 (0.05-0.31)	0.08 (0.02-0.22)	-5332.18		
	Model 2 (individual characteristics)	0.21 (0.10-0.39)	0.19 (0.09-0.34)	0	-4258.73	1073.45 (2145.95)	<0.001
Standing long jump (cm)	Null model equal ρ	0.08 (0.03-0.17)	0.08 (0.03-0.17)	0.08 (0.03-0.17)	-7396.78	3.27 (6.55)	0.16
	Model 1 (without covariates and different ρ)	0.17 (0.07-0.37)	0.04 (0.00-0.42)	0.06 (0.01-0.23)	-7393.51		
	Model 2 (individual characteristics)	0.16 (0.10-0.23)	0.16 (0.10-0.23)	0.16 (0.10-0.23)	-7086.16	310.62 (620.88)	<0.001
Motor component							
Shuttle-run (s)	Null model equal ρ	0.50 (0.45-0.55)	0.50 (0.45-0.55)	0.50 (0.45-0.55)	-4021.84	2.65 (5.31)	0.26
	Model 1 (without covariates and different ρ)	0.51 (0.39-0.60)	0.46 (0.36-0.55)	0.51 (0.44-0.58)	-4019.19		
	Model 2 (individual characteristics)	0.55 (0.50-0.60)	0.55 (0.50-0.60)	0.55 (0.50-0.60)	-3953.69	68.15 (136.30)*	<0.001

Individual characteristics = age, BMI, maturity offset (aPHV) and stunting

Intraclass correlation coefficients for each physical fitness test in interaction with geographical area of residence are presented in Table 4. Model based results showed that for handgrip strength and waist circumference, the intraclass correlations were different among sib-types living at different altitudes, whereas for standing long jump, shuttle-run and sum of skinfolds the variance components were not significantly different. For handgrip strength, adjusted correlations tended to be higher among BB pairs living at sea-level (0.22), followed by Amazon region (0.17) and high-altitude (0.07); in addition, SS and BS pairs did not vary substantially. For waist circumference, the adjusted correlations also tended to be higher among BB living at sea-level (0.24), followed by Amazon region (0.23) and high-altitude (0.01). However, the results were inverted for SS and BS pairs with the highest correlation arising between those living in Amazon region (SS=0.19; BS=0.20), followed by high-altitude (SS=0.11; BS=0.14) and sea-level (SS=0; BS=0.08). Lastly, for shuttle-run and sum of skinfolds, the adjusted correlation for all sib-types tended to be higher at sea-level (0.22; 0.19), whereas in standing long jump was higher in Amazon region (0.20).

Table IV. Intraclass correlation coefficients (ρ) and their 95% confidence intervals for each test in each physical fitness component: interacting with geographical area of residence values (full model)

		Sea-level (95%CI)	High-altitude (95%CI)	Amazon region (95%CI)	Log likelihood (LL)	Δ LL(χ^2)$^{\infty}$	*p-value*
Morphological component							
Waist circumference (cm)	BB	0.24 (0.04-0.71)	0.01 (0.00-1.00)	0.23 (0.09-0.46)	-4265.44	34.86 (69.73)	<0.001
	SS	0	0.11 (0.01-0.60)	0.19 (0.07-0.42)			
	BS	0.08 (0.00-0.95)	0.14 (0.05-0.35)	0.20 (0.10-0.35)			
Sum of skinfolds (log transformed)	All sibtype	0.19 (0.07-0.44)	0.14 (0.06-0.29)	0.12 (0.05-0.24)	-3723.40	79.33 (158.66)	<0.001
Muscular component							
Handgrip strength (kg^f)	BB	0.22 (0.03-0.73)	0.07 (0.00-0.77)	0.17 (0.04-0.46)	-4214.09	44.64 (89.28)	<0.001
	SS	0.16 (0.03-0.54)	0.14 (0.02-0.58)	0.16 (0.05-0.41)			
	BS	0	0	0			
Standing long jump (cm)	All sibtype	0	0.05 (0.00-0.36)	0.20 (0.13-0.31)	-7035.74	50.42 (721.73)	<0.001
Motor component							
Shuttle-run (s)	All sibtype	0.22 (0.09-0.45)	0	0	-3461.00	492.69 (985.39)	<0.001

$^{\infty}$Comparison values between model 2 with model 3

Multilevel analysis results are provided in Table 5. Model 3 fit the data significantly better than model 2 for all physical fitness tests, meaning that geographical area and respective interactions with sib-type were important in explaining sibling resemblance.

For the morphological component, BB pairs average is 63.1±0.9 (waist circumference) and 18.4±0.5 (sum of skinfolds). Older siblings with higher BMI had higher waist circumference, and those ahead in their biological maturation had higher skinfold thickness score. Surprisingly, stunted children had lower waist circumference, but higher skinfolds score. Further, SS and BS pairs living at high-altitude and Amazon region do not significantly differ from sea-level BB pairs in both tests ($p > 0.05$).

In the muscular component, the mean performance of BB pairs was 17.88±0.71 for hangrip strength and 135.61±3.09 for standing long jump. SS had lower values than BB pairs on both tests, and BS only significantly differed in hangrip strength. Older siblings were stronger in both tests and youth ahead in their biological maturation performed better only in hangrip strength. Higher BMI was linked with poorer performance in standing long jump, but not in hangrip strength, whereas stunted children tended to exhibit less muscular performance in both tests. Further, SS and BS pairs living at high-altitude and Amazon region did not significantly differ from sea-level BB pairs in both tests ($p > 0.05$).

Finally, the motor component average for BB pairs was β=21.71±0.44 (shuttle-run). SS and BS required more time to cover the distance of five cycles (round-trip) than BB pairs. Older siblings performed better, whereas those with higher BMI and early growth "retardation" tended to perform worse. Biological maturation did not significantly associate with the motor component ($p > 0.05$). Lastly, SS pairs living at high-altitude and Amazon region showed a greater agility than BB pairs, while there were no statistically significant differences between BS and BB pairs ($p > 0.05$). Information regarding estimates of the variance components (σ^2) and standard errors (SE) for each physical fitness test can be found in Supplementary Table 1.

Table V. Parameter estimates, standard errors (SE) and variance components for each test in each physical fitness component

	Full model (Model 3)				
	Morphological component		**Muscular component**		**Motor component**
	Waist circumference (cm)	**Sum of skinfolds (log transformed)**	**Handgrip strength (kg^f)**	**Standing long jump (cm)**	**Shuttle-run (s)**
Fixed effects	Estimate±SE	Estimate±SE	Estimate±SE	Estimate±SE	Estimate±SE
Intercept (BB)	63.11±0.91***	18.41±0.47***	17.88±0.71***	135.61±3.09***	21.71±0.44***
SS	-2.58±0.94**	-0.38±0.52^{ns}	-3.48±0.74***	-11.54±3.31***	2.96±0.48***
BS	-0.85±1.02^{ns}	-0.76±0.69^{ns}	-2.71±0.64**	-6.58±4.35^{ns}	1.96±0.64**
Age	0.74±0.04***	-0.06±0.03^{ns}	1.68±0.04***	5.01±0.24***	-0.36±0.03***
Age^2	-0.07±0.01***	-0.02±0.01**	0.33±0.03***	-0.36±0.06***	0.03±0.01***
BMI	1.76±0.04***	-0.01±0.03^{ns}	0.08±0.02***	-1.00±0.21***	0.08±0.02***
Maturity offset (aPHV)	0.05±0.07^{ns}	0.14±0.05**	0.87±0.07***	0.74±0.41^{ns}	0.02±0.05^{ns}
Stunting	-2.46±0.26***	0.48±0.18**	-2.81±0.25***	-7.86±1.44***	0.35±0.15*
High-altitude	-0.51±0.96^{ns}	-3.51±0.52***	-0.54±0.76**	-8.37±3.35**	4.69±0.48***
Amazon region	0.01±0.92^{ns}	-2.02±0.49***	1.51±0.72^{ns}	-5.27±3.31^{ns}	-0.21±0.44^{ns}
SSxHigh-altitude interaction	2.06±1.07^{ns}	0.68±0.62^{ns}	0.69±0.87^{ns}	-2.72±4.00^{ns}	-1.17±0.57*
SSxAmazon region interaction	1.42±0.99^{ns}	0.11±0.58^{ns}	-0.50±0.80^{ns}	-2.22±3.99^{ns}	-1.35±0.52**
BSxHigh-altitude interaction	0.41±1.11^{ns}	1.24±0.74^{ns}	1.41±0.94^{ns}	-1.57±4.77^{ns}	-0.91±0.69^{ns}
BSxAmazon region interaction	0.26±1.07^{ns}	0.63±0.72^{ns}	0.95±0.90^{ns}	-2.33±4.80^{ns}	-1.25±0.66^{ns}

$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$; ^{ns} = non-significant; BB=brother-brother; SS=sister-sister; BS=brother-sister; BMI= body mass index

DISCUSSION

In this study, we confirmed that individual characteristics and shared natural environment were significantly associated with siblings' health-related physical fitness components, but found that only in some cases sibling resemblance was higher in same-sex sibs than in opposite sex siblings depending upon the physical fitness component considered.

The literature supports our results demonstrating different intra-class correlations among different sib-ship types. For example, available data from Portuguese sib-ships (Pereira et al. 2017) reported low-to-moderate correlations in waist circumference and shuttle-run, with SS resemble more than BB and BS after adjustments for a set of individual, sociodemographic and behavioural covariates. Low correlations of 0.25 for waist circumference and 0.28 for the sum of skinfolds were also reported by Katzmarzyk et al. (2000) in Canadian siblings, although the analysis was not separated by type (BB, SS and BS pairs), and was not adjusted for any covariates. Available data from Mozambican sib-ships (Saranga et al. 2010) reported a greater familiarity in the shuttle-run test among BB pairs than in SS and BS. Conversely, SS pairs resemble more than their sib-ship pairs in handgrip strength and standing long jump. Also, Pawlak (1984) reported the highest resemblance in Polish BB pairs for standing long jump, but similar results in SS pairs and BS pairs, although results were only adjusted for age and sex.

It is worth noting that resemblance discrepancies among the previous studies may be linked to differences in a wide variety of uncontrollable factors such as the ethnic composition of each sample, distinct strategies for covariate adjustments, siblings' unique developmental histories during their physical growth, biological maturation, exercise habits and food consumption, as well as distinct socio-geographic and demographic living conditions.

Shared environmental factors also seem to play important roles in the expression of physical fitness phenotypes, and differences in resemblance reflect distinct daily lifestyles and routine activities, as well as the dynamics of the traditional structure of Peruvian families, given the need to adapt to environmental and natural particularities of each geographical region. For example, at sea-level, the main livelihood is trade/tourism, with families having greater food resources with ample access to marketing of unhealthy food choices, which increases sibling pairs' likelihood of acquiring unhealthy eating habits and consequently resembling each other more with higher values in the morphological component. Further, the built environment may generate a diversified set of constraints, such as high population density, traffic congestion, public insecurity, and lack of public recreational infrastructure, which may restrict parents' permission to their sons and daughters to play freely and restricts their motor experiences, resulting in an increased engagment in more sedentary activities and lower levels of physical activity. In fact, Sharma et al. (2018) showed that 78% of Peruvian adolescents living at sea-level do not meet the WHO recommendations for moderate-to-vigorous physical activity, which increases the likelihood of sibling pair's resemblance with lower values in the muscular and motor component.

Conversely, in the Amazon region and at high-altitude, a lower population density is prevalent, and the main livelihood is stockbreeding and non-diversified agriculture. Hence, poverty may result in insufficient access to food at the household level, which increases the likelihood of sibling pairs having lower values in the morphological component. Although families live on scarce resources, children have an extension of the natural environment, where they can enjoy plenty of space to play freely and diversify their play activities. Further, the majority of parents encourage their daughters and sons to participate in recreational activities, housework, and supporting agricultural activities in the field, resulting in higher levels of physical activity compared with their sibling peers at the sea-level, which may help to explain the higher similarity among sibling pairs with higher levels of muscular strength/power and agility.

These examples as well as the remainder of our results, suggest that the individual/environmental contribution to physical fitnes components vary by component and as such, resist easy classification.

Multilevel model results showed that siblings' individual characteristics were differently related to physical fitness components. Chronological age was positively associated with better performance in all physical fitness components during childhood and adolescence, except for sum of skinfolds (not statistically significant). Our findings are consistent with other previous sibling (Pereira et al. 2017) as well as non-sibling (Welk et al. 2015) data, although results vary in terms of effect sizes. For example, Pereira et al. (2017) investigated Portuguese siblings, aged 9 to 20 years, and showed that for each increasing chronological year the expected mean changes in static strength and muscle power were very different, and also had no significant link to the morphological component (% body fat). In a different vein, Guedes et al. (2012), examined children and adolescents, aged 6 to 18 years, and reported that age was negatively related to performance in all physical fitness tests (sit-and-reach, curl-up, trunk-lift, push-up, and progressive endurance run).

Peruvian siblings with higher BMI tended to have higher waist circumference values, were stronger and more agile, but performed worse in the standing long jump test. Since this last test required children to rapidly change their center of mass vertically and/or horizontally, it was expected that those with higher BMI were less capable of doing so effectively, and the net result lowered their performance. A similar trend was evident in previous reports using non-sibling data (Bustamante Valdivia et al. 2015; Huang and Malina 2007). Our results also showed that Peruvian siblings ahead in their biological maturation had higher sums of skinfolds, as well as higher static strength. This was expected since early maturation reflects, to some extent, a greater body size, as well as a greater neuromuscular maturation contributes to an improvement in muscle strength production (Katzmarzyk et al. 1997). Although available reports using sibling data are scarce, we found one study that investigated this association and showed that the maturity offset was negatively associated with siblings' morphological component and positively with muscular component (Pereira et al. 2017).

Another important finding is that stunted Peruvian siblings tend to have lower waist circumference, probably due to their smaller body size; also, their muscular and motor performance is impaired. Since physical fitness tasks, like standing long jump or shuttle-run, require body displacements in different planes, axes, and directions, it is expected that children with shorter limbs perform worse. These findings were partially supported by Malina et al. (2011) showing that stunted Mexican youth significantly differed from their normal peers in grip strength and standing long jump tests. Additionally, Armstrong et al. (2017) reported that stunted South African children performed poorer in the standing long jump, sit-up, and cricket ball throw tests. However, there are no available studies based on sibling's data linking stunting with physical fitness to compare with our results.

Geographical region also had a marked influence on physical fitness in Peruvian siblings, given that our results showed that SS pairs living at high-altitude and Amazon region showed a greater agility than BB pairs, while there were no statistically significant differences between BS and BB pairs. Firstly, as previously specified, sibling pairs living in the Amazon region and at high-altitude are not exposed to the presence of a hostile environment created by traffic congestion and public security as experienced by residents living at sea-level. Conversely, youth can enjoy plenty of space to play freely and diversify their play activities, which may help to explain their greater agility. Secondly, this trend is more pronounced among SS pairs probably due to the fact that in the Amazon region and at high-altitude, daughters tend to participate not only in a wide range of recreational activities, but also help with demanding household chores, which may positively influence their agility capacity. In a previous report (Bustamante Valdivia et al. 2015) using non-sibling data, we showed that Peruvian children from the rainforest had better physical performance in muscular power and flexibility tests, and youth from the high-altitude region had higher cardiorespiratory fitness. However, we could not find a published paper that investigated the links between natural environments (sea-level, Amazon region, or high-altitude) and siblings physical fitness to make suitable comparisons.

Notwithstanding the relevance of these results, our study is not without limitations. First, the sample is not representative of the Peruvian sibling population which restricts the generalizability of our results. Second, no adjustments were made for putative influences of family income and/or socioeconomic status, and this may limit other interpretations of our results. However, because of the study’s strengths - (i) a large sample size of siblings from three different geographical locations; (ii) the examination of important time windows in children's growth and development; (iii) the use of multilevel analysis to capture the complexity of the nested information; (iv) the use of a broad approach of health-related physical fitness with siblings, and (v) the use of objective, standardized and highly reliable methods for data collection, our results make a significant contribution to the literature.

CONCLUSIONS

In overall terms, our findings confirmed that individual characteristics and shared natural environment were significantly associated with siblings' health-related fitness components. Further, only in some cases, sibling resemblance was higher in same-sex sibs than in opposite sex siblings, depending upon the physical fitness component considered. Older siblings were the best physical fitness performers, but those with higher BMI had higher waist circumference performed worse in standing long jump and shuttle-run. More mature subjects had higher skinfold thickness and performed better in handgrip strength, but stunted siblings had lower waist circumference and were worse performers in the muscular and motor components. In turn, SS pairs living at high-altitude and Amazon region were more agile than BB pairs. These results emphasize the idea that physical fitness expression is a constant volley between genetic endowments and environmental exposures. Hence, when developing suitable intervention programs aiming to promote physical fitness, it is crucial to take in account specificities of cultural and social strata of each geographical region, as well as the complex and intertwined relationships of both familial and individual characteristics.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest Statement: Carla Santos, Alcibíades Bustamante, Olga Vasconcelos, Sara Pereira, Rui Garganta, J. Timothy Lightfoot, Go Tani, Donald Hedeker, Peter T. Katzmarzyk, José Maia declare that they have no conflict of interest.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Formal permission was obtained from authorities and written informed consent was obtained from the children, parents or legal guardians. The project was approved by the Ethics Committee of the National University of Education Enrique Guzmán y Valle (UNE EGyV) (Resolution: 2459-R-2008-UNE).

Publication consent: Not applicable

Data Availability: The datasets generated and analyzed during the current study are not publicly available due to privacy laws associated with children's data but are available with a datasharing agreement as approved by the Ethics Committee of the National University of Education Enrique Guzmán y Valle, Lima, Peru.

Code availability: Not applicable

AUTHOR CONTRIBUTIONS

Conceptualization, C.S., A.B.V., and J.M.; methodology, C.S., A.B.V., and J.M.; formal analysis, C.S., D.H., S.P., and J.M.; investigation, C.S., A.B.V., O.V., S.P., R.G., J.T.L., G.T., D.H., P.T.K., and J.M.; resources, C.S., A.B.V., and J.M.; data curation, C.S., A.B.V., and J.M.; writing – original draft preparation, C.S., P.T.K., A.B.V. and J.M.; writing – review and editing, A.B.V., O.V., S.P., R.G., J.T.L., G.T., D.H., P.T.K., and J.M.; visualization, A.B.V., O.V., S.P., R.G, J.T.L., G.T., D.H., P.T.K., and J.M.; supervision, A.B.V., P.T.K., and J.M.; project administration, C.S., A.B.V., P.T.K., and J.M.; funding acquisition, C.S., and J.M.

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REFERENCES

Armstrong MEG, Lambert MI, Lambert EV (2017) Relationships between different nutritional anthropometric statuses and health-related fitness of South African primary school children. Ann Hum Biol 44(3):208-213

Bouchard C, Malina RM, Pérusse L (1997) Genetics of fitness and physical performance. Human Kinetics. Champaign., IL, USA

Bouchard C, Shephard RJ (1994) Physical activity, fitness, and health: The model and key concepts. In: Bouchard C, Shephard RJ, Stephens T (eds) Physical activity, fitness, and health: International proceedings and consensus statement. Human Kinetics Publishers., Champaign, IL, England, pp 77-88

Bustamante A, Beunen G, Maia J (2011) Como crecen y se desarrollan los niños y adolescentes en La Merced y San Ramón. Alcances para la Educación Física, el Deporte y la Salud. Universidad Nacional de Educación Enrique Guzmán y Valle, La Cantuta, Lima, Perú

Bustamante Valdivia A, Maia J, Nevill A (2015) Identifying the ideal body size and shape characteristics associated with children's physical performance tests in Peru. Scand J Med Sci Sports 25(2):e155-165

Cheah WL, Chang CT, Saimon R (2012) Environment factors associated with adolescents' body mass index, physical activity and physical fitness in Kuching South City, Sarawak: a cross-sectional study. Int J Adolesc Med Health 24(4):331-337

Cossio-Bolanos M, Campos RG, Andruske CL, Flores AV, Luarte-Rocha C, Olivares PR, Garcia-Rubio J, de Arruda M (2015) Physical Growth, Biological Age, and Nutritional Transitions of Adolescents Living at Moderate Altitudes in Peru. Int J Environ Res Public Health 12(10):12082-12094

Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, Lambourne K, Szabo-Reed AN (2016) Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. Med Sci Sports Exerc 48(6):1197

Frisancho AR (1978) Human growth and development among high-altitude populations. In: Baker PT (ed) The biology of high altitude peoples. Cambridge University Press, New York, USA, pp 117-171

Gallup JL, Gaviria A, Lora E (2003) Is Geography Destiny?: Lessons from Latin America. Stanford University Press

Guedes DP, Neto JM, Lopes VP, Silva AJ (2012) Health-related physical fitness is associated with selected sociodemographic and behavioral factors in Brazilian school children. J Phys Act Health 9(4):473-480

Hedeker D, Mermelstein RJ, Demirtas H (2012) Modeling between-subject and within-subject variances in ecological momentary assessment data using mixed-effects location scale models. Statistics in medicine 31(27):3328-3336

Huang YC, Malina RM (2007) BMI and health-related physical fitness in Taiwanese youth 9-18 years. Med Sci Sports Exerc 39(4):701-708

INEI (2018) Perfil sociodemográfico del Peru, Informe Nacional. In. Instituto Nacional de Estadística e Informática, Lima, Perú, pp

Katzmarzyk P, Malina R, Beunen G (1997) The contribution of biological maturation to the strength and motor fitness of children. Ann Hum Biol 24(6):493-505

Katzmarzyk PT, Malina RM, Pérusse L, Rice T, Province MA, Rao D, Bouchard C (2000) Familial resemblance in fatness and fat distribution. American Journal of Human Biology: The Official Journal of the Human Biology Association 12(3):395-404

Keyes KM, Smith GD, Susser E (2013) On sibling designs. Epidemiology 24(3):473-474

Lohman TG, Roche AF, Martorell R (1988) Anthropometric standardization reference manual. Human kinetics books Champaign, IL

Malina RM, Bouchard C, Bar-Or O (2004) Growth, maturation and physical activity. Human Kinetics, Champaign III, IL, USA

Malina RM, Mueller WH (1981) Genetic and environmental influences on the strength and motor performance of Philadelphia school children. Human biology 163-179

Malina RM, Pena Reyes ME, Tan SK, Little BB (2011) Physical fitness of normal, stunted and overweight children 6-13 years in Oaxaca, Mexico. Eur J Clin Nutr 65(7):826-834

Mirwald R, Baxter-Jones A, Bailey D, Beunen G (2002) An assessment of maturity from anthropometric measurements. Med Sci Sports Exerc 34(4):689-694

Norton K, Whittingham, N., Carter, L., Kerr, D., Gore, C., Marfell-Jones, M. (1996) Measurement Techniques in Anthropometry. Anthropometrica Sydney: University of New South Wales Press

Onis M, Onyango A, Borghi E, Siyam A, Nishida C, Siekmann J (2007) Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ 85660-667

Ortega FB, Ruiz JR, Castillo MJ, Sjöström M (2008) Physical fitness in childhood and adolescence: a powerful marker of health. Int J Obes (Lond) 32(1):1-11

Pawlak K (1984) Heritability of strength and speed: methods of testing and evaluation. . In: Wolanski N, Sniarski A (eds) Genetics of psychomotor traits in man. College of Physical education., Warsaw, pp

Pereira S, Katzmarzyk PT, Gomes TN, Souza M, Chaves RN, dos Santos FK, Santos D, Hedeker D, Maia J (2017) A multilevel analysis of health-related physical fitness. The Portuguese sibling study on growth, fitness, lifestyle and health. PloS one 12(2):e0172013

Ruiz JR, Castro-Pinero J, Artero EG, Ortega FB, Sjostrom M, Suni J, Castillo MJ (2009) Predictive validity of health-related fitness in youth: a systematic review. Br J Sports Med 43(12):909-923

Saranga S, Nhantumbo L, Fermino RC, Prista A, Seabra A, Maia JAR (2010) Semelhança fraterna nos níveis de aptidão física: um estudo na população rural de Calanga, Moçambique. Revista Brasileira de Educação Física e Esporte 24(3):363-372

Schutte NM, Nederend I, Hudziak JJ, de Geus EJ, Bartels M (2016) Differences in adolescent physical fitness: a multivariate approach and meta-analysis. Behavior genetics 46(2):217-227

Sharma B, Chavez RC, Nam EW (2018) Prevalence and correlates of insufficient physical activity in school adolescents in Peru. Revista de saude publica 5251

Snijders TAB, Bosker RJ (2012) Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling. Sage Publishers, London

Valdívia AB, Henrique RS, Pereira S, Chaves RN, Tani G, Freitas D, Prista A, Stodden DF, Katzmarzyk PT, Hedeker D (2018) Familial resemblance in gross motor coordination. The Peruvian Sibling Study on Growth and Health. Ann Hum Biol 45(6-8):463-469

Welk GJ, Saint-Maurice PF, Csányi T (2015) Health-related physical fitness in Hungarian youth: age, sex, and regional profiles. Res Q Exerc Sport 86(sup1):S45-S57

World Health Organization (2007) WHO Reference 2007 STATA macro package In, pp

SUPPLEMENTARY MATERIALS

Supplementary Table I. Variance components (σ^2) and standard errors (SE) for each physical fitness test

	Full model (Model 3)				
	Morphological component		**Muscular component**		**Motor component**
	Waist circumference (cm)	Sum of skinfolds (log transformed)	Handgrip strength (kg^f)	Standing long jump (cm)	Shuttle-run (s)
Variance components (σ^2)	σ^2±SE	σ^2±SE	σ^2±SE	σ^2±SE	σ^2±SE
Between siblings (σ^2_B)					
BB					
Sea-level	7.06±6.11	1.48±0.77	3.80±3.56	0	1.45±0.65
High-altitude	0.12±1.74	0.66±0.29	0.69±1.23	11.74±13.85	0
Amazon region	2.29±1.02	0.74±0.29	1.70±1.10	89.19±21.45	0
SS					
Sea-level	0	1.48±0.77	1.53±1.23	0	1.45±0.65
High-altitude	1.51±1.74	0.66±0.29	1.40±1.38	11.74±13.85	0
Amazon region	1.78±0.87	0.74±0.29	1.19±0.68	89.19±21.45	0
BS					
Sea-level	0.70±1.81	1.48±0.77	0	0	1.45±0.65
High-altitude	1.96±1.08	0.66±0.29	0	11.74±13.85	0
Amazon region	2.10±0.69	0.74±0.29	0	89.19±21.45	0
Within siblings (σ^2_w)					
BB					
Sea-level	21.91±6.28	6.17±0.85	13.64.67	372.84±36.76	5.05±0.72
High-altitude	11.27±2.46	4.18±0.36	8.43±1.74	229.96±19.41	4.38±0.28
Amazon region	7.67±1.10	5.48±0.36	8.48±1.29	349.11±22.78	3.76±0.18
SS					
Sea-level	13.46±1.69	6.17±0.85	7.90±1.44	372.84±36.76	5.05±0.72
High-altitude	12.14±2.22	4.18±0.36	8.76±1.66	229.96±19.41	4.38±0.28
Amazon region	7.50±0.96	5.48±0.36	6.16±0.80	349.11±22.78	3.76±0.18
BS					
Sea-level	7.82±2.52	6.17±0.85	9.06±2.22	372.84±36.76	5.05±0.72
High-altitude	12.08±1.30	4.18±0.36	12.11±0.96	229.96±19.41	4.38±0.28
Amazon region	8.41±0.76	5.48±0.36	12.96±0.86	349.11±22.78	3.76±0.18
Log likelihood	-4265.44	-3723.40	-4214.09	-7035.74	-3461.00

BB=brother-brother; SS=sister-sister; BS=brother-sister

Paper VII

Sibling resemblance in physical activity levels. The Peruvian Family Study on Growth and Health

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ABSTRACT

Background: Physical activity is associated with a host of positive health outcomes, and shaped by a constellation of genetic and environmental factors.

Aims: To estimate sibling resemblance in two physical activity phenotypes (steps/day and aerobic activity), and to investigate the joint associations of individual characteristics and shared natural environment with intra-pair sibling similarities in each phenotype.

Subjects and Methods: We sampled 247 biological siblings (147 females), aged 6-17 years, from three geographical areas of Peru. Physical activity was measured using pedometers and body mass index (BMI) was calculated.

Results: In general, non-significant variations in the intraclass correlation coefficients were found after adjustment for individual characteristics and geographical area for both phenotypes ($p>0.05$). Further, no significant differences were found between the three sib-ship types. Sister-sister pairs tended to take fewer steps than BB (β=-2908.75±954.31). Older siblings tended to walk fewer steps (β=-81.26±19.83), whereas BMI was not associated with physical activity. Siblings living at high-altitude and in the Amazon had higher steps/day (β=2508.92±737.94; β=2213.11±776.63, respectively) compared with their peers living at sea-level.

Conclusions: Shared factors need to be considered when developing more effective and personalized intervention programs to bring about positive changes in physical activity among Peruvian youth.

Keywords: physical activity; youth; siblings; shared factors; multilevel modelling.

INTRODUCTION

Physical activity (PA) has been associated with a variety of positive health outcomes generating transitional benefits from childhood through adolescence into adulthood (van Sluijs et al. 2021), including decreases in obesity (Hills et al. 2011), cardiovascular disease and diabetes (Wahid et al. 2016), and increases in cognitive function as well as academic achievement (Donnelly et al. 2016). Despite its recognized benefits, updated information on the prevalence and trends of PA (Aubert et al. 2018; Guthold et al. 2020) showed that the majority of children and adolescents worldwide are physically inactive, putting their current and future health at risk, and Peru is no exception (Marques et al. 2020).

It has been suggested that diferences in children's PA levels can be shaped by a constellation of genetic (de Vilhena e Santos et al. 2012; Lin et al. 2017; Lightfoot et al. 2018) and environmental factors (Bray et al. 2011; Sallis et al. 2015), with an unequivocal influence of the family context (Kracht and Sisson 2018; Rhodes et al. 2020). As with most behaviours (Plomin et al. 2008), PA is developed and expressed within the familial orbit, which constitutes an interactive-interdependent linkage and a source of multiple genetic and environmental influences (Jacobi et al. 2011; Maia et al. 2014). For example, Carlsson et al. (2006), using data from The Swedish Twin Registry, reported that the intrapair correlation (ρ) for monozygotic twins (ρ=0.62) was higher for leisure-time PA than for dizygotic twins (ρ=31). On the other hand, Pereira et al. (2018), using questionnaire data in Portuguese sibling pairs, showed that after adjustments for several covariates (biological, behavioural, familial and environmental characteristics), sister-sister pairs demonstrated greater resemblance in their PA (ρ=0.53) than brother-sister (ρ=0.26) or brother-brother pairs (ρ=0.18). Differently, and using PA data collected using pedometers, Jacobi et al. (2011) found no differences in correlations among different sib-types (all ρ=0.28).

Since PA is a complex and multi-faceted trait, it has also been documented that a significant fraction of its variation can be explained by different environmental exposures throughout the lifespan (Wild 2005). Peru is something akin to a natural laboratory that offers an opportunity to assess the impact of geographical variation on PA levels by combining settings on the spectrum of both rural-urban development as well as lowland-highland scenarios. Peruvians are exposed daily to different natural stressors (e.g., altitude, temperature, and pollutants), as well as social and economic inequalities (e.g., access to health care system, quality of nutrition, access to public recreational infrastructure) in an unique geographical diversity (Gallup et al. 2003), which can influence intrapair similarities in PA levels. Despite this recognition, to date there is no available evidence regarding variation in PA levels among Peruvian siblings, especially embracing the diversity of the three geographical areas (sea-level, Amazon region and high-altitude).

Hence, using sibling data, as well as a multilevel statistical approach (Hedeker et al. 2012), we explored resemblance in PA levels among Peruvian siblings conditioned on the additive effects of their individual characteristics and shared natural environment. This evidence may be useful in the planning and development of intervention programs to promote and retain youths' participation in PA, especially targeting the family orbit. Hence, the present study aims to: (1) estimate sibling resemblance in two PA phenotypes (steps per day and aerobic activity); and (2) investigate the joint associations of individual characteristics (age and BMI) as well as shared natural environment (geographical areas of residence) with intra-pair sibling similarities in each PA phenotype. The following hypotheses will be tested: (1) sibling resemblance is higher in same-sex sibs than in opposite-sex sibs for both PA phenotypes; and (2) individual characteristics and shared natural environment are significantly associated with siblings' PA.

MATERIALS AND METHODS

Study participants

Participants were from “The Peruvian Family Study on Growth and Health” which was conducted between 2009 and 2010, and investigated the association between correlates of Peruvian families' similarity in body composition, PA and metabolic syndrome. The present sample comprises 247 biological siblings (147 females and 100 males), from three geographical areas in the central region of Peru located at different altitudes: sea-level (Barranco = 58 m), Amazon region (La Merced and San Ramon = 751 m), and high-altitude (Junín = 4107 m). Only families that had two or three children, aged between 6 and 17 years, with complete PA data were selected. Participants were natives to their respective regions, i.e., all were non-immigrants, based on information regarding their birthplace and current place of residence, which was collected from individuals' identity cards. The project was approved by the Ethics Committee of the National University of Education Enrique Guzmán y Valle (UNE EGyV).

Individual characteristics

Anthropometry

Body measurements were made according to standardized protocols (Lohman et al. 1988). Height was measured with a portable stadiometer (Sanny, Model ES-2060) holding the child´s head in the Frankfurt plane, to the nearest 0.1 cm; weight was measured with a digital scale (Pesacon, Model IP68), with a precision of 0.1 kg. Body mass index (BMI) was calculated using the standard formula: BMI = [weight(kg)/height(m)^2].

Physical activity

To objectively measure PA we used pedometers, a body movement sensor that validly and reliably assesses PA among children and youth (Lubans et al. 2009; Clemes and Biddle 2013). Pedometers have been used in different populations from different countries (Beets et al. 2010), and their validity has been studied in depth (Tudor-Locke et al. 2004). Subjects used the Omron Model Walking style II pedometer (Omron Healthcare, Inc, Japan) over five consecutive days (three week-days and two weekend days). These pedometers have a multiday memory function that automatically stores the total number of steps per day (a proxy measure of the total volume of PA), and the walking time, in minutes (min·day-1), counted at a pace of more than 60 steps per minute and during more than 10 minutes continuously (a proxy measure of moderate-to-vigorous PA). Siblings were instructed in the use of the pedometer, learning to remove it only for bathing and before sleeping at night. The devices were attached to the trouser belt (strap) using a clip, leaving the unit perpendicular to the ground. For the present study, only data from sib-ships with complete information from five consecutive days (Wednesday to Sunday) with an average of 12 hours·day^{-1} of pedometer use were considered. The percentage of missing data do not significantly differ (p> 0.05) from those considered in the present analysis.

Shared environment characteristics

Natural environment (geographical areas of residence)

Given the country heterogeneity in geographical terms, participants came from the three distinct regions located at different altitudes: sea-level, Amazon region, and high-altitude. Barranco (58 m) was the chosen city at sea-level and this is one of the 43 districts of Lima Province, located on the shore of the Pacific Ocean. The cities of La Merced and San Ramon (751 m) in the Chanchamayo district represented the Amazon region that is the largest of the Peruvian territory and occupies ~60% of its surface. The Junín district (4107 m) was used to represent the high-altitude location on the southern shore of Lake Junín or Chinchaycocha. Table 1 shows the geographic, demographic, socioeconomic, health care and cultural distinct characteristics of these geographical areas, based on information provided by National Institute of Statistics and Informatics (INEI 2018).

Table 1. Geographic, demographic, socioeconomic, health care and cultural characteristics of the three geographical areas located in the central region of Peru

Characteristics	**Sea-level** (Barranco)	**Amazon region** (Chanchamayo)	**High-altitude** (Junín)
Geographic			
Altitude (m)	58	751	4107
Climate	Arid; semi-warm	Rainy; warm	Rainy; cold
Average annual temperature	18°C	24°C	12°C
Demographic			
Total population	8.564.867	411.011	1.272.890
Population density (people/km^2)	236.6	10.2	27.7
Socioeconomic			
Human Development Index	0.72	0.52	0.44
Per capita family income	1440.6	785.1	512.7
Primary production	Trade/Tourism	Agriculture/Tourism	Stockbreeding/Agriculture
Basic access to health care			
Health center	Yes	No	No
Public hospital	No	Yes	Yes
Private clinic	Yes	No	No
Infrastructure for physical activity and sports available			
Parks	Yes	Yes	Yes
Playground	Yes	Yes	Yes
Pool	Yes	Yes	Yes
Multisport indoor	Yes	Yes	Yes
Multisport outdoor	No	Yes	Yes
Gymnastics complex	No	No	No

Data quality control

Data quality control was enhanced by all assessment team members being systematically trained by the lead researchers of the project in order to: i) comply with the correct use of technical body measurement procedures; and ii) instruct parents and children about the pedometer use protocol and persuade them to follow their regular PA routine. Further, IBM-SPSS v26 software was used to facilitate data entry and to cross-check data elements, employing automatic controls to ensure values were not outside known ranges.

Statistical Analysis

Data analysis was performed in a “stepwise” fashion. First, data cleaning, exploratory analysis, outlier identification, and normality checks were conducted. Second, descriptive statistics were computed as means and standard deviations. Third, differences in means of individual variables between geographical areas of residence were computed using analysis of variance (ANOVA). Additionally, the Tukey HSD test was used for multiple comparisons. Aerobic activity (min·day-1) was normalized with a log transformation due to its skewness, and a sum of log-scores was used. All analyses were performed using SPSS v26 software and the alpha level was set at 5%.

Sibling data are clustered by nature, i.e., individuals are nested within their sib-ships. As such, multilevel models were used as a suitable statistical method to analyze the data (Hox et al. 2018). To address the first aim, we estimated separate within and between sib-ship variances, and therefore, different intraclass correlation coefficients (ICC) (ρ), with corresponding 95% confidence intervals for each PA phenotype. Moreover, based on the likelihood-ratio test, we compared a model that constrained ρ to be equal across sib-ship pairs (Null model) to a model that freely estimated ρ across sib-ship pairs (Model 1). The subsequent models were henceforth estimated with the same or different ICC, depending on the result attained from the likelihood-ratio test.

For the second aim, a more complex model (Model 2) was considered with adjustments for individual characteristics such as age and BMI; and ρ was estimated for each sib-type. Finally, a full model (Model 3) was estimated by including the geographical area of residence. Model comparisons were made with the likelihood ratio test. Importantly, because we have only three regions (sea-level, Amazon region, and high-altitude), it is not recommended to treat them as a level in a multilevel analysis (Snijders and Bosker 2012). Therefore, dummy variables for each region were added in the fixed part of Model 3, such that sea-level, the reference category, was coded as 0 0, high-altitude was 1 0 and Amazon region was 0 1. When needed, covariates were centered around their respective means, and sea-level BB pairs were the reference category. All analyses were done in STATA 14, and the alpha level was set at 5%.

RESULTS

Table 2 shows descriptive statistics for all variables. On average, no statistically significant differences (p> 0.05) were found among sib-ship pairs from the three geographical areas for chronological age and height. On average, siblings living in the Amazon region are heavier (F=5.55, p <0.05) and have a higher BMI (F=13.55, p <0.05), compared with theirs peers from the other regions. Further, they also take more steps per day (F=21.52, p <0.05). On the other hand, sib-ships from the Amazon region had lower aerobic activity compared to those at sea-level (F=3.53, p <0.05).

Table 2. Descriptive statistics [means and standard deviations (SD)], F tests and post-hoc comparisons by each geographical region

	Sea-level (S) (n=66)	Amazon region (A) (n=80)	High-altitude (H) (n=101)	*F*	*Post hoc* among areas
		Mean±SD			
Age (yrs)	10.4±2.9	10.6±3.1	10.5±2.9	0.039^{ns}	
Anthropometry					
Height (cm)	138.2±14.8	135.8±15.0	134.0±15.6	1.51^{ns}	
Weight (kg)	35.4±12.8	37.1±12.6	31.5±10.5	5.55^{*}	A>H
BMI (kg/m^2)	18.0±3.9	19.6±3.9	17.0±2.3	13.55^{*}	A>S; A>H
Physical activity					
Steps per day	8155.±2878	11170±3931	11695±3621	21.52^{*}	S<A; S<H
Aerobic activity (log transformed)	0.82±0.45	0.61±0.48	0.67±0.49	3.53^{*}	A<S

*p<0.05; ^{ns} = non-significant

Intraclass correlation coefficients (unadjusted and adjusted) for each PA phenotype are presented in Table 3. Model-based results showed that model 1 did not fit the data significantly better than the null model for both phenotypes, i.e., there is no evidence to reject the assumption that the three different sib-pairs (BB, SS and BS) have the same intraclass correlation coefficient (steps per day = 0.44 (95%CI = 0.31-0.58) and aerobic activity = 0.35 (95%CI = 0.22-0.51). In general, the inclusion of individual characteristics (model 2) as well as the different geographical areas did not significantly influence the size of the intraclass correlations in both phentoypes. Additionally, for aerobic activity the last model (model 3) was not tested since model 2 was not better than the previous model (Δ= -157.54, p=0.43).

Table 3. Intraclass correlation coefficients (ρ) and their 95% confidence intervals for each physical activity phenotype: unadjusted and adjusted for individual characteristics and geographical areas of residence

		BB (95%CI)	SS (95%CI)	BS (95%CI)	Log likelihood (LL)	Δ LL(χ^2)[∞]	*p-value*
Physical activity							
Steps per day	Null model equal ρ	0.44 (0.31-0.58)	0.44 (0.31-0.58)	0.44 (0.31-0.58)	-2352.09		
	Model 1 (without covariates and different ρ)	0.58 (0.26-0.84)	0.58 (0.36-0.77)	0.38 (0.22-0.57)	-2347.73	4.36 (8.72)	0.06
	Model 2 (individual characteristics)	0.46 (0.34-0.60)	0.46 (0.34-0.60)	0.46 (0.34-0.60)	-2343.21	8.88 (17.76)	<0.001
	Model 3 (geographical areas of residence)	0.42 (0.29-0.56)	0.42 (0.29-0.56)	0.42 (0.29-0.56)	-2337.39	5.82 (11.64)	<0.001
Aerobic activity (log transformed)	Null model equal ρ	0.35 (0.22-0.51)	0.35 (0.22-0.51	0.35 (0.22-0.51	-158.91		
	Model 1 (without covariates and different ρ)	0.41 (0.11-0.80)	0.22 (0.05-0.61)	0.40 (0.23-0.59)	-158.15	0.76 (1.52)	0.82
	Model 2 (individual characteristics)	0.34 (0.21-0.50)	0.34 (0.21-0.50)	0.34 (0.21-0.50)	-157.54	1.37 (2.75)	0.43

[∞] Comparison values between models

Multilevel analysis results can be found in Table 4. Model 3 fit the data significantly better than model 2 only for steps per day. In general, PA averages for BB pairs are β=11158.63±1001.06; SS pairs tended to take fewer steps compared with BB (β=-2908.75±954.31), while non-significant differences were found between BS and BB pairs ($p>0.05$). Older siblings tended to take fewer steps (β=-81.26±19.83, $p <0.05$), whereas BMI was not statistically significant ($p>0.05$). Further, siblings living at high-altitude and in the Amazon region tended to take more steps (β=2508.92±737.94, $p<0.05$; β=2213.11±776.63, $p<0.05$, respectively) compared with their peers living at sea-level.

Table 4. Parameter estimates, standard errors (SE) and variance components (σ^2) for steps per day

Full model (Model 3)	**Steps per day** Estimate±SE
Fixed effects	
Intercept (BB)	11158.63±1001.06*
SS	-2908.75±954.31*
BS	-1393.79±806.13^{ns}
Age	63.56±72.47^{ns}
Age^2	-81.26±19.83*
BMI	-115.43±66.10^{ns}
High-altitude	2508.92±737.94*
Amazon region	2213.11±776.63*
Variance components (σ^2)	σ^2±SE
Between siblings (σ^2_B)	
All sibtypes	4638044±1061023
Within siblings (σ^2_W)	
All sibtypes	6306225±758801.7

$^*p<0.05$; ^{ns} = non-significant; BB=brother-brother; SS=sister-sister; BS=brother-sister; BMI= body mass index

DISCUSSION

The present study shows that differences in Peruvian sib-ships resemblance in two PA phenotypes are mainly influenced, apparently, by genetic factors since non-significant differences were found in the intraclass correlation coefficients after adjustments for individual characteristics and geographical area of residence. Further, no significant differences were found between the three sib-ship types.

The available literature has reported varying results. For example, Jacobi et al. (2011), using French nuclear family data in conjunction with pedometer PA measurements, reported low correlations (ρ=0.28) among siblings for the number of steps per day, although adjustments were only made for sex and age. On the other hand, Maia et al. (2014), using the Baecke questionnaire in Portuguese family data, showed differences in a total PA phenotype between sib-types, with BB resembling more than SS and BS. Pereira et al. (2018), also using Portuguese siblings data, and the same PA assessment tool, showed that with increasing levels of covariate adjustments, SS pairs showed stronger resemblance than BS and BB pairs. These correlation discrepancies may be due to different sampling strategies, diverse covariates adjustments, different statistical techniques used to compute correlations, and the phenotypic expression as well as instruments used.

Finding specific genes regulating PA has been a daunting task in molecular genetic studies (Kim et al. 2011; de Geus et al. 2014; Lin et al. 2017; Lightfoot et al. 2018). For example, based on the recent review by the American College of Sports Medicine sponsored roundtable committee, the heritability estimates for PA ranged from moderate to very high (Lightfoot et al. 2018). In another review, de Vilhena e Santos et al. (2012) reported genome-wide linkage data with markers near different PA related genes – EDNRB, MC4R, UCP1, FABP2, CASR, and SLC9A9, while Lightfoot (2011), reported that only 2 candidate genes showed consistent associations in the regulation of PA: dopamine receptor 1 (Drd1) and helixloop helix 2 (Nhlh2). Further, recent genome-wide association studies (GWAS) have indicated a genetic contribution to PA, with Doherty et al. (2018) uncovering 14 loci for device-measured PA, while Klimentidis et al. (2018) identified multiple variants in habitual PA including CADM2 and APOE. Notwithstanding this progress, results are still unclear most probably because of specificities in the production of genome maps in genome-wide linkage studies, uses of different methods to estimate PA, or different ethnic composition of each sample.

Multilevel model results showed that PA averages for BB pairs are 11.159 steps/day, which means that they comply, on average, with the guidelines recommendations for children and adolescents (Tudor-Locke et al. 2011). Consistent with our sibling data, chronological age has been negatively associated with PA (Corder et al. 2016; Pereira et al. 2018). In our study, for each year increase in sibling age, there was an average reduction of 81 step·day-1, whereas Pereira et al. (2018), based on self-reported PA, similarly revealed a decrease among Portuguese siblings. Using non-sibling data, Duncan et al. (2006) also showed a decline in the number of steps per day with age among New Zealand children and adolescents (15,284 weekday steps and 12,948 weekend steps at 5-6 years of age to 14,801 weekday steps and 10,656 weekend steps at 11-12 years of age). Using accelerometry, Alvis-Chirinos et al. (2017) also reported a decline in moderous-to-vigorous PA with age among Peruvian youth (1,354 minutes at 6-9 years to 1,167 minutes at 10-13 years).

Geographical area also had a marked influence on PA in Peruvian siblings given that our results showed that those living at high-altitude and in the Amazon region tended to take more steps daily compared with their peers living at sea-level. This potential influence can be explained by siblings’ distinct daily lifestyles and routine activities given the need for Peruvian families to adapt to environmental and natural particularities of each geographical area (see Table 1). For example, in the city of Barranco, children are exposed to several built constraints like high population density, traffic congestion, and public insecurity, which likely influences their ability to play freely and access public recreational facilities. These environmental limitations help to explain the likelihood of sibling pairs walking fewer steps compared with their peers from the other regions. In turn, in Chanchamayo and Junín, children have plenty of natural space to play freely and diversify their play activities, as well as infrastructure for PA and sports, which may help to explain their greater number of steps per day. However, we could not find a published paper that investigated the links between natural environments (sea-level, Amazon region, or high-altitude) and siblings' PA to make suitable comparisons.

Notwithstanding the importance of the present data, two limitations have to be recognized. First, without data indicating otherwise, it is possible that our sample is not representative of the overall Peruvian sibling population. Second, no adjustments were made for putative influences of family income and/or socioeconomic status, and this may limit other interpretations of our results. While limited, this report also has several unique strengths. First, the relatively large sample of siblings from three unique environmental contexts. Second, the study covered both childhood and puberty periods. Third, the use of standardized and highly reliable and objectives methods for data collection makes significant contributions to the available literature.

CONCLUSIONS

In general, our findings revealed non-significant variations in the intraclass correlation coefficients for PA after adjustment for individual characteristics and geographical area of residence. Further, non-significant differences were found between the three sib-ship types. SS pairs tended to take fewer steps than BB, while non-significant differences were found between BS and BB pairs. Older siblings tended to walk fewer steps, whereas BMI was not associated with PA. Further, siblings living at high-altitude and in the Amazon region tended to walk more steps compared with their peers living at sea-level. Hence, we suggest that shared factors need to be considered when developing more effective and personalized intervention programs to bring about positive changes in physical actvivity among Peruvian youth.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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REFERENCES

Alvis-Chirinos K, Huamán-Espino L, Pillaca J, Aparco JP. 2017. [Measurement of physical activity by triaxial accelerometers n schoolchildren from three peruvian cities]. Rev Peru Med Exp Salud Publica. 34(1):28-35. spa.

Aubert S, Barnes JD, Abdeta C, Abi Nader P, Adeniyi AF, Aguilar-Farias N, Andrade Tenesaca DS, Bhawra J, Brazo-Sayavera J, Cardon G et al. 2018. Global Matrix 3.0 Physical Activity Report Card Grades for Children and Youth: Results and Analysis From 49 Countries. J Phys Act Health. 15(S2):S251-s273. eng.

Beets MW, Bornstein D, Beighle A, Cardinal BJ, Morgan CF. 2010. Pedometer-measured physical activity patterns of youth: a 13-country review. Am J Prev Med. 38(2):208-216. eng.

Bray MS, Fulton JE, Kalupahana NS, Lightfoot JT. 2011. Chapter 7, Genetic epidemiology, physical activity, and inactivity. Genetic and Molecular Aspects of Sport Performance Wiley-Blackwell; p. 79-89.

Carlsson S, Andersson T, Lichtenstein P, Michaëlsson K, Ahlbom A. 2006. Genetic effects on physical activity: results from the Swedish Twin Registry. Med Sci Sports Exerc. 38(8):1396-1401. eng.

Clemes SA, Biddle SJ. 2013. The use of pedometers for monitoring physical activity in children and adolescents: measurement considerations. J Phys Act Health. 10(2):249-262. eng.

Corder K, Sharp SJ, Atkin AJ, Andersen LB, Cardon G, Page A, Davey R, Grøntved A, Hallal PC, Janz KF et al. 2016. Age-related patterns of vigorous-intensity physical activity in youth: The International Children's Accelerometry Database. Prev Med Rep. 4:17-22. eng.

de Geus EJ, Bartels M, Kaprio J, Lightfoot JT, Thomis M. 2014. Genetics of regular exercise and sedentary behaviors. Twin Res Hum Genet. 17(4):262-271. eng.

de Vilhena e Santos DM, Katzmarzyk PT, Seabra AF, Maia JA. 2012. Genetics of physical activity and physical inactivity in humans. Behav Genet. 42(4):559-578. eng.

Doherty A, Smith-Byrne K, Ferreira T, Holmes MV, Holmes C, Pulit SL, Lindgren CM. 2018. GWAS identifies 14 loci for device-measured physical activity and sleep duration. Nat Commun. 9(1):5257. eng.

Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, Lambourne K, Szabo-Reed AN. 2016. Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children: A Systematic Review. Med Sci Sports Exerc. 48(6):1197-1222. eng.

Duncan JS, Schofield G, Duncan EK. 2006. Pedometer-determined physical activity and body composition in New Zealand children. Med Sci Sports Exerc. 38(8):1402-1409. eng.

Gallup JL, Gaviria A, Lora E. 2003. Is Geography Destiny?: Lessons from Latin America. Stanford University Press.

Guthold R, Stevens GA, Riley LM, Bull FC. 2020. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. Lancet Child Adolesc Health. 4(1):23-35. eng.

Hedeker D, Mermelstein RJ, Demirtas H. 2012. Modeling between-subject and within-subject variances in ecological momentary assessment data using mixed-effects location scale models. Statistics in medicine. 31(27):3328-3336.

Hills AP, Andersen LB, Byrne NM. 2011. Physical activity and obesity in children. Br J Sports Med. 45(11):866-870. eng.

Hox JJ, Moerbeek M, Van de Schoot R. 2018. Multilevel analysis: Techniques and applications New York, USA: Routledge.

INEI. 2018. Perfil sociodemográfico del Peru, Informe Nacional. Lima, Perú: Instituto Nacional de Estadística e Informática; [accessed]. https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1539/index.html.

Jacobi D, Caille A, Borys JM, Lommez A, Couet C, Charles MA, Oppert JM. 2011. Parent-offspring correlations in pedometer-assessed physical activity. PLoS One. 6(12):e29195. eng.

Kim J, Oh S, Min H, Kim Y, Park T. 2011. Practical issues in genome-wide association studies for physical activity. Ann N Y Acad Sci. 1229:38-44. eng.

Klimentidis YC, Raichlen DA, Bea J, Garcia DO, Wineinger NE, Mandarino LJ, Alexander GE, Chen Z, Going SB. 2018. Genome-wide association study of habitual physical activity in over 377,000 UK Biobank participants identifies multiple variants including CADM2 and APOE. Int J Obes (Lond). 42(6):1161-1176. eng.

Kracht CL, Sisson SB. 2018. Sibling influence on children's objectively measured physical activity: a meta-analysis and systematic review. BMJ Open Sport Exerc Med. 4(1):e000405. eng.

Lightfoot JT. 2011. Current understanding of the genetic basis for physical activity. J Nutr. 141(3):526-530. eng.

Lightfoot JT, EJC DEG, Booth FW, Bray MS, M DENH, Kaprio J, Kelly SA, Pomp D, Saul MC, Thomis MA et al. 2018. Biological/Genetic Regulation of Physical Activity Level: Consensus from GenBioPAC. Med Sci Sports Exerc. 50(4):863-873. eng.

Lin X, Eaton CB, Manson JE, Liu S. 2017. The Genetics of Physical Activity. Curr Cardiol Rep. 19(12):119. eng.

Lohman TG, Roche AF, Martorell R. 1988. Anthropometric standardization reference manual. Vol. 177. Human kinetics books Champaign, IL.

Lubans DR, Morgan PJ, Tudor-Locke C. 2009. A systematic review of studies using pedometers to promote physical activity among youth. Prev Med. 48(4):307-315. eng.

Maia J, Gomes TN, Trégouët DA, Katzmarzyk PT. 2014. Familial resemblance of physical activity levels in the Portuguese population. J Sci Med Sport. 17(4):381-386. eng.

Marques A, Henriques-Neto D, Peralta M, Martins J, Demetriou Y, Schönbach DMI, Matos MG. 2020. Prevalence of Physical Activity among Adolescents from 105 Low, Middle, and High-income Countries. Int J Environ Res Public Health. 17(9). eng.

Pereira S, Katzmarzyk PT, Gomes TN, Souza M, Chaves RN, Santos FK, Santos D, Bustamante A, Barreira TV, Hedeker D et al. 2018. Resemblance in physical activity levels: The Portuguese sibling study on growth, fitness, lifestyle, and health. Am J Hum Biol. 30(1). eng.

Plomin R, DeFries J, McClearn G, McGuffin P. 2008. Behavioural genetics. New York: Worth Publishers.

Rhodes RE, Guerrero MD, Vanderloo LM, Barbeau K, Birken CS, Chaput JP, Faulkner G, Janssen I, Madigan S, Mâsse LC et al. 2020. Development of a consensus statement on the role of the family in the physical activity, sedentary, and sleep behaviours of children and youth. Int J Behav Nutr Phys Act. 17(1):74. eng.

Sallis JF, Owen N, Fisher E. 2015. Ecological models of health behavior. 5nd ed. San Francisco, CA, US: Jossey-Bass. (In K Glanz, B K Rimer, K V Viswanath Health behavior: Theory, research, and practice.

Snijders TAB, Bosker RJ. 2012. Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling. 2nd ed. London: Sage Publishers.

Tudor-Locke C, Craig CL, Beets MW, Belton S, Cardon GM, Duncan S, Hatano Y, Lubans DR, Olds TS, Raustorp A et al. 2011. How many steps/day are enough? for children and adolescents. Int J Behav Nutr Phys Act. 8:78. eng.

Tudor-Locke C, Williams JE, Reis JP, Pluto D. 2004. Utility of pedometers for assessing physical activity: construct validity. Sports Med. 34(5):281-291. eng.

van Sluijs EMF, Ekelund U, Crochemore-Silva I, Guthold R, Ha A, Lubans D, Oyeyemi AL, Ding D, Katzmarzyk PT. 2021. Physical activity behaviours in adolescence: current evidence and opportunities for intervention. Lancet. eng.

Wahid A, Manek N, Nichols M, Kelly P, Foster C, Webster P, Kaur A, Friedemann Smith C, Wilkins E, Rayner M et al. 2016. Quantifying the Association Between Physical Activity and Cardiovascular Disease and Diabetes: A Systematic Review and Meta-Analysis. J Am Heart Assoc. 5(9). eng.

Wild CP. 2005. Complementing the genome with an "exposome": the outstanding challenge of environmental exposure measurement in molecular epidemiology. Cancer Epidemiol Biomarkers Prev. 14(8):1847-1850. eng.

CHAPTER V

General Discussion, Conclusions, Limitations and Future Research Avenues

GENERAL DISCUSSION AND CONCLUSIONS

The main aim of this thesis was to investigate different facets of human variability in physical growth, body composition, physical activity and motor performance as end-results of adaptive processes in different socio-geographical, educational and cultural contexts in Peru - especially children, youth and siblings living at different altitudes (sea-level, Amazon region and high-altitude).

The thesis was centered around two pillars: Bronfenbrenner’s (1994) bioecological model and the multilevel statistical model (Courgeau, 2003) to accommodate the network of variables underlying human development in a putative unified body of knowledge. It is assumed that the use of such models, and their specific tools, will provide an integrated understanding of the problems tackled in the thesis. Moreover, we also relied on a twofold research design, based on Peruvian Youth Data and Peruvian Sibling Data, using cross-sectional information.

Given the complexity of the issues addressed in the thesis, and the array of phenotypes investigated – physical growth, body composition, physical activity and motor performance – a set of specific aims were outlined based firstly on Peruvian youth data and secondly on sibling data, in order to present a more coherent path in the discussion of the findings.

This chapter presents an overall reading of the key outcomes, yields responses for each specific aim, and provides a general discussion of the main findings. The limitations of the thesis as well as putative suggestions for future research avenues are also presented.

Research based on Peruvian Youth Data

Aim 1: to investigate the variability in growth spurt parameters of Peruvian children and adolescents living at different altitudes;

Aim 2: to investigate the prevalence of stunting and its influence on physical fitness levels of Peruvian children and adolescents;

Aim 3: to investigate the variability in body composition, physical fitness and gross motor coordination of Peruvian children and adolescents, adjusted for individual and environmental characteristics.

A systematical investigation of these aims prompted us to write five papers. A summary of the main findings is below (Table 1).

Table 1. Summary of the main findings addressing in the first three specific aims.

Paper I

Growth velocity curves and pubertal spurt parameters of Peruvian children and adolescents living at different altitudes. The Peruvian health and optimist growth study

- Peruvian children and adolescents' physical growth timing and tempo were influenced by the altitude at which they lived;
- Children living at sea-level experienced an earlier age at peak height velocity (PHV), were taller at time of PHV, had a higher PHV, and had a taller estimated final height compared to those living at higher altitudes;
- Girls and boys differed significantly in their growth parameters. Across all geographical areas, PHV occurred approximately 2 years earlier in girls than in boys. Girls' estimated PHV, size at PHV, and final adult height were lower than in boys;
- Our results for age at PHV, height at PHV, and PHV showed widespread variation when compared with other populations.

Paper II

Stunting and Physical Fitness. The Peruvian Health and Optimist Growth Study

- Stunting prevalence increased with age, was higher in boys than in girls, and was higher in the Amazon region, followed by high-altitude and sea-level;
- Stunting significantly affects Peruvian youth's physical fitness levels, and this influence is sex-, age- and physical fitness test-specific.

Paper III

Correlates of Overweight in Children and Adolescents Living at Different Altitudes: The Peruvian Health and Optimist Growth Study

- The prevalence of overweight in Peruvian children and adolescents decreased with age, was higher in girls, and was also higher at the sea level compared to the Amazon region and high-altitude;
- Multilevel modeling results showed 21% of the total variance in body mass index categories among subjects was at the school-level and 79% of the variance was explained by child-level characteristics;
- Younger subjects as well as those ahead in their maturity status were more likely to be overweight; boys tend to be less likely to be overweight than girls as they get older. Further, being more physically fit protects subjects from being overweight. Subjects living at high-altitude were less likely to be overweight than those living at sea-level;
- Seven out of nine school-level predictors (number of students, policies and practices for physical activity, playground area with obstacles, multi-sports roofed, frequency and duration of Physical Education classes) were significant predictors of overweight.

Paper IV

A multilevel analysis of gross motor coordination of children and adolescents living at different altitudes: the Peruvian Health and Optimist Growth Study

- Multilevel modeling results showed that school context explained 31% of children's gross motor coordination variation, leaving 69% of the total variance as explained by child-level characteristics;
- Boys and older children had higher gross motor coordination than girls and younger children, respectively; overweight was negatively associated with lower gross motor coordination, whereas physical fitness was positively associated with this phenotype. Stunting was negatively associated with gross motor coordination, while biological maturation was not a significant predictor. Further, subjects living in the Amazon region had higher gross motor coordination than those at sea-level;

- Five out of nine school-level predictors (number of students, playground area with obstacles, multi-sports roofed, frequency and duration of Physical Education classes) were significant predictors of gross motor coordination.

Paper V

A multivariate multilevel analysis of youth motor competence. The Peruvian Health and Optimist Growth Study

- Multilevel modeling results showed that school context explained 35% of the joint associations between physical fitness and gross motor coordination, and children's characteristics explained 65% of the total variation;

- On average, with increasing age, there was a greater increase in gross motor coordination than physical fitness; boys outperformed girls and those with lower body mass index and ahead in their maturation had higher physical fitness and gross motor coordination. Further, stunting was negatively related to both phenotypes. High-altitude Peruvians had significantly lower gross motor coordination and those living in the Amazon region had significantly higher physical fitness compared to those living at sea level;

- A higher number of students was negatively related to physical fitness and positively with gross motor; the duration of physical education classes was positively associated with both phenotypes; and the existence of policies for physical activity was only negatively associated with gross motor coordination.

Bearing in mind Professor James Tanner’s maxim (Tanner, 1987) that children’s physical growth is one of the best mirrors reflecting the living conditions and prosperity of different groups within a population, the first main challenge of this thesis (paper I) was to investigate the variability in growth spurt parameters of Peruvian children and adolescents living at different altitudes. Although available literature has consistently reported that the effect of socioeconomic inequalities among rural and urban areas, as well as the exposure to adverse environmental conditions, such as living at high-altitudes, may impair children’s physical growth (Fernald, Kariger, Hidrobo, & Gertler, 2012; Hoke & Leatherman, 2019; Pomeroy et al., 2014), our findings are novel in providing information on the growth spurt parameters in Peruvian youth. For this, we used the Preece-Baines growth model I (Preece & Baines, 1978), that have been successfully applied to cross-sectional data to make inferences about the timing of the adolescent growth spurt, and the age when adult stature is attained.

Our findings support Professor James Tanner's (Tanner, 1987) historical and far-reaching political note, revealing how Peruvian youth's growth and development are influenced by disparities in their life conditions characterized by inequalities in the distribution and access to economic, educational, nutritional, and health resources that still exist among the three geographical areas (Gallup, Gaviria, & Lora, 2003; INEI, 2018). Put differently, Peruvians that are exposed to the presence of adverse environmental conditions, such as living at high altitude, had a clear disadvantage in their growth spurt parameters compared to those living at sea-level. Moreover, our established comparisons with other populations [British (Preece & Baines, 1978), Japanese (Ali, Lestrel, & Ohtsuki, 2001), Guatemalan (Bogin, Wall, & Macvean, 1990), Taiwanese (Lee et al., 2004), Chinese (Mao et al., 2011) and Mexican (Banik, Salehabadi, & Dickinson, 2017)] shed light on a widespread variation and allow a clearer examination of issues of human growth variability and plasticity.

We anticipated another important line of research, and shaped the second specific aim of the thesis. Based on the assumption that biological growth and motor development processes occur simultaneously (Ellison & Reiches, 2012), we believe that it is important to understand the potential negative impact of linear growth retardation (stunting) on children's PF levels. Hence, as reported in other developing countries – Mozambique (Nhantumbo et al., 2013), Senegal (Benefice, 1998), México (Malina, Pena Reyes, Tan, & Little, 2011), and Colombia (Arsenault et al., 2011), linear growth retardation also significantly affects Peruvian youth's PF levels, and this influence is sex-, age- and PF test-specific. We believe that the data gathered in this paper provides valuable information for Peruvian political authorities when designing more efficient strategies to combat the stunting problem, creating a sustained and equitable implementation of multisector interventions, with focus on the poorest regions of the country. Moreover, Peruvian school principals, councils and Physical Education teachers have to bear in mind the significance of these results when designing local intervention programs to help stunted children increase their PF levels.

Given the aforementioned, it is clear that children and adolescents’ growth and (motor) development are characterized by their extraordinary variability and plasticity, so it is also important to scrutinize whether the expression of this variability is due to biological or environment effects, or if it results from the combined interactional dynamism of both. In fact, it is important to note that at the same time that individuals grow, mature and develop, changes are also occurring in their communities. The main challenge here is to capture the integrated levels that shape human development as well as to understand their underlying mechanisms, i.e., the interdependence of characteristics within and without the individual. Put differently, how reciprocal are interactions between individuals and their environments that condition their differences?

Hence, bearing in mind Bronfenbrenner’s theoretical framework (Bronfenbrenner, 1994), as a template that emphasizes the need to understand individuals’ development within their environments, as well as the multilevel model as a statistical procedure to adequately analyze clustered data such as children nested within schools (Hox, Moerbeek, & Van de Schoot, 2018), we specifically addressed the third specific aim of this thesis, i.e., to investigate the variability in body composition, physical fitness and gross motor coordination of children and adolescents, adjusted for individual and environmental characteristics.

Altogether, our findings obtained in the papers III, IV and V shed light on a key take-home message: although biological characteristics, namely age, sex, biological maturation, and stunting explain the major portion of the total variation in all phenotypes used in this thesis, the natural environment (geographical areas of residence) as well as the built environment (school context) also play important roles in shaping body composition, PF and GMC in Peruvian children and adolescents. Our results are novel in providing this information to Peruvian youth, with a variance attributable to school level ranging from 21% to 35% in explaining these phenotypes. Previous studies have reported similar trends among

Portuguese (Chaves et al., 2015), American (Zhu, Boiarskaia, Welk, & Meredith, 2010) and British (Pallan, Adab, Sitch, & Aveyard, 2014) youth. Thus, there is no doubt that the school has a wide range of possibilities to play a key role in sustainable growth and (motor) development given that youth spend a large amount of their awake time at school.

In turn, the influence of the natural environment, namely the circumstance of Peruvian children living at different altitudes, also is crosscut to all phenotypes used in this thesis, confirming our initial assumption that cultural variation and social contrast in Peru, along with an enormous biological diversity, generate complex environments rich in factors that help to determine children and adolescents' physical growth and (motor) development processes.

Hence, we believe that the data gathered in papers III, IV and V provide relevant information for Peruvian school authorities, school councils, and physical education teachers, highlighting the importance to appraise the specificities of cultural and social strata of each geographical region when designing and implementing diversified strategies to prevent overweightness and obesity, and to improve children's PF and GMC levels from an early age, helping them reach their full potential.

In paper V we presented a novelty and shift the usual paradigm i.e., instead of looking at each phenotype in isolation, we viewed youth from a broader perspective using a multivariate modeling approach (Snijders & Bosker, 2012) to best understand the relationships between PF and GMC, and investigate the joint influence of predictors affecting their levels across age. The main findings of this study revealed that PF and GMC levels do not develop in the same timing and tempo across age and in the same magnitude in both sexes, which may reflect a non-synchronicity in development. Further, their putative joint predictors affect them differently, that is, with distinct effect sizes. So, it is important to recognize that biological and environmental characteristics exerted different influences on youth, meaning that while some factors may exert effects on one characteristic, they can also be unrelated to others. However, when the focus is directed to human development as a whole, there is a need to consider all these factors together, even though they do not simultaneously affect all phenotypes to a similar degree to promote a sustainable growth and development.

Research based on Peruvian Siblings Data

Aim 4: to investigate the sibling resemblance in physical fitness and physical activity, and joint associations of individual characteristics and shared natural environment in intra pair sibling similarities in each physical fitness component and in each physical activity phenotype.

To help address this multifaceted aim two studies were conducted. The main findings are presented in Table 2.

Table 2. Summary of the main findings addressing in the fourth specific aim.

Paper VI

Sibling resemblance in physical fitness components. The Peruvian Sibling Study on Growth and Health

- Individual characteristics and shared natural environment were significantly associated with siblings' health-related fitness components. Only in some cases, sibling resemblance was higher in same-sex sibs than in opposite sex siblings, depending upon the physical fitness component considered;
- Multilevel modeling results showed that older siblings were the best physical fitness performers, but those with higher body mass index had higher waist circumference performed worse in standing long jump and shuttle-run. More mature subjects had higher skinfold thickness and performed better in handgrip strength, but stunted siblings had lower waist circumference and were worse performers in the muscular and motor components. Sister-sister pairs living at high-altitude and in the Amazon region were more agile than brother-brother pairs.

Paper VII

Sibling resemblance of physical activity levels. The Peruvian Family Study on Growth and Health

- Differences in Peruvian sib-ships resemblance in two PA phenotypes (steps per day and aerobic activity) are mainly influenced by genetic factors since non-significant differences were found in the intraclass correlation coefficients after adjustments for individual characteristics and geographical area of residence. Further, no significant differences were found between the three sib-ship types;

- Multilevel modeling results showed that sister-sister pairs tended to take fewer steps than brother-brother, while non-significant differences were found between brother-sister and brother-brother pairs. Older siblings tended to walk fewer steps, whereas BMI was not associated with PA. Further, siblings living at high-altitude and in the Amazon region tended to walk more steps compared with their peers living at sea-level.

In papers VI and VII we used sibling data in order to extend our investigation about the intra- and inter-population variation in child-adolescent growth and (motor) development. As previously mentioned, most behaviours and traits, like PF and PA are developed and expressed within the familial orbit, which constitutes an interactive-interdependent linkage and a source of multiple genetic and environmental influences to unravel the variation between related subjects.

Altogether, the findings of these studies allowed the inference that despite siblings sharing of a substantial part of their genes identical-by-descent, on average 50%, they also differ in many other factors, like in their biological characteristics (e.g., age, sex, biological maturation), their lifestyle behavioural choices, and their unique environments that can also influence their dissimilarity. Definitely, the main challenge here is to understand the differences that shape siblings.

Throughout papers VI and VII, when sequential multilevel models of increasing complexity were tested, i.e., adjusted for individual and environmental covariates, changes in sibling resemblance were observed, in addition to different variations depending on the sib-type and the phenotype considered. Some characteristics tended to maintain their resemblance; however, others increased or decreased their intraclass correlation values, revealing a fluctuation in the impact of genetic, individual, and environmental characteristics on the expression of these phenotypes. For example, in the PF phenotype our results confirmed that individual characteristics and shared natural environment were significantly associated with siblings' health-related PF components, but found that only in some cases sibling resemblance was higher in same-sex sibs than in opposite sex siblings depending upon the PF component considered. Hence, although previous GWAS studies provided significant evidence that variation across populations in PF is associated with polymorphisms in several genes (Hughes, Day, Ahmetov, & Williams, 2011; Isen, McGue, & Iacono, 2014; Wen et al., 2016), individual and environmental covariates seems to be the main factors that make Peruvian children and youth, growing up in the same family, different from one another. Conversely, for PA phenotype, the results were dissimilar, i.e., differences in Peruvian sib-ships resemblance are mainly influenced, apparently, by genetic factors since non-significant differences were found in the intraclass correlation coefficients after adjustments for individual characteristics and geographical area of residence. These results support recent GWAS studies that have indicated a genetic contribution to PA (Kim, Oh, Min, Kim, & Park, 2011; Lightfoot et al., 2018).

In any case, and bearing in mind the complexity and variability inherent to human (motor) development, results from the present thesis claim the attention of agents to consider the combined influence of shared and non-shared factors, i.e, the complex and intertwined relationships of individual, familial and environmental characteristics, instead of inspecting the effect of each characteristic separately, in order to bring about positive changes in PF and PA among Peruvian youth.

Overall, we believe that the data gathered in this thesis provides important information for researchers enhancing a broader understanding of the multivariate nature of physical growth, body composition, physical activity and motor performance of Peruvian children, youth and siblings - their adaptability to different environmental exposures and resulting variability.

LIMITATIONS

Notwithstanding the framework within which this thesis was conceived and its outreach in scientific terms, the reported empirical results should be considered in the light of potential limitations.

First, the cross-sectional nature of the design does not allow a dynamic analysis of intraindividual changes and interindividual differences in physical growth, body composition, physical activity and motor performance during childhood and adolescence. Nonetheless, the importance of shifting towards an integrated multidisciplinary approach to analyse children and adolescents’ growth and development processes has been highlighted in this thesis, providing a detailed “cross-sectional picture” about the different degrees of relationship in phenotypes involved in physical growth and development of Peruvian children, youth and siblings, as well as the examination of entwined individual and environmental features.

Second, notwithstanding the reasonable size of our sample, it is not representative of the Peruvian population and care must be taken when trying to generalize our results. Yet, no study is apparently available in South America sampling hundreds/thousands of children and adolescents within an important time window in their growth and development and from different socio-geographic areas. Further, the sample is large enough and covers a wide age range, which are important issues when using multilevel models to minimise bias, as well as the preciseness of the regression coefficients estimates, variance components, and standard errors (Maas & Hox, 2005; Snijders & Bosker, 2012).

Third, we were not able to obtain information about dietary habits, and no adjustments were made for putative influences of family income and/or socioeconomic status, which may have limited further understanding concerning their importance. As this should be considered in future work.

Fourth, no systematic information was collected about objectively measured physical activity (except data from “The Peruvian Family Study on Growth and Health”), since it would probably be a daunting task given the large sample size of children and adolescents, the geographical locations and financial costs to run the study.

Fifth, the indirect estimation of maturity (maturity offset procedure) has its limitations and the use of questionnaires to collect information about school characteristics can be prone to errors.

Lastly, due to time constraints, some of the sibling data was left unexploited in this thesis. Nonetheless, the available data will be used in a near future to continue providing meaningful empirical evidence about intertwined sibling relationships during childhood and adolescence.

FUTURE RESEARCH AVENUES

From the large set of data collected in the three projects, only a small portion was used in this thesis. Despite the relevance of the findings we provided, several issues still deserve attention. Hence, the following suggestions for future research:

The Peruvian Health and Optimist Growth Study

1. To identify the timing, intensity, and sequence of development of muscular strength, and cardiorespiratory fitness, i.e., to examine if there are putative sensitive periods for each physical fitness component using the Preece-Baines model I.

2. To identify the timing, intensity, and sequence of development of gross motor coordination peak spurts, i.e., to examine if there are putative sensitive periods for each gross motor coordination component (balance, rhythm, strength, laterality and agility) again using the Preece-Baines model I

3. To identify multivariate profiles of children's multifaceted motor characteristics, and test if they are similar in the three geographical areas.

The Peruvian Sibling Study on Growth and Health

1. To unravel the influence of school context on Peruvian siblings' resemblance in physical growth, body composition, physical activity and motor performance.

2. To investigate the relationship between physical fitness and gross motor coordination in Peruvian sib-ships and their links with individual characteristics, geographical area of residence and school context.

Further, it will be imperative to utilize longitudinal studies of large representative samples of siblings, ideally covering multiple developmental periods (i.e., childhood to young adulthood), in order to adequately address the issues of intraindividual changes and interindividual differences in physical growth, body composition, physical activity and motor performance.

The Peruvian Family Study on Growth and Health

Using data from this project, it is possible to expand the analysis to nuclear families to better capture familial resemblance, as well as different degrees of relationship in phenotypes involved in human development, but also the examination of shared and non-shared factors. Hence, the following suggestions:

1. To estimate the magnitude of genetic factors responsible for the architecture of individual traits (e.g. metabolic syndrome markers, physical activity) and to study the potential genotype-environment interactions, considering the particularities of each geographical area.

2. To explore if inherited traits or life experiences play a more important role in shaping individuals.

REFERENCES

Ali, M. A., Lestrel, P. E., & Ohtsuki, F. (2001). Adolescent growth events in eight decades of Japanese cohort data: sex differences. *American Journal of Human Biology: The Official Journal of the Human Biology Association, 13*(3), 390-397.

Arsenault, J. E., Mora-Plazas, M., Forero, Y., Lopez-Arana, S., Jáuregui, G., Baylin, A., . . . Villamor, E. (2011). Micronutrient and anthropometric status indicators are associated with physical fitness in Colombian schoolchildren. *Br. J. Nutr., 105*(12), 1832-1842.

Banik, S. D., Salehabadi, S. M., & Dickinson, F. (2017). Preece-Baines Model 1 to Estimate Height and Knee Height Growth in Boys and Girls From Merida, Mexico. *Food Nutr Bull, 38*(2), 182-195. doi:10.1177/0379572117700270

Benefice, E. (1998). Growth and motor performances of rural Senegalese children. *Physical Fitness and Nutrition During Growth: Studies in Children and Youth in Different Environments, 43*, 117-131.

Bogin, B., Wall, M., & Macvean, R. B. (1990). Longitudinal growth of high socioeconomic status Guatemalan children analyzed by the Preece-Baines function: An international comparison. *American Journal of Human Biology, 2*(3), 271-281.

Bronfenbrenner, U. (1994). Ecological models of human development. In M. Gauvian & M. Cole (Eds.), *International Encyclopedia of Education* (Vol. 3, pp. 37-43). Oxford: Elsevier.

Chaves, R., Baxter-Jones, A., Gomes, T., Souza, M., Pereira, S., & Maia, J. (2015). Effects of Individual and School-Level Characteristics on a Child's Gross Motor Coordination Development. *Int J Environ Res Public Health, 12*(8), 8883-8896. doi:10.3390/ijerph120808883

Courgeau, D. (2003). *Methodology and epistemology of multilevel analysis: approaches from different social sciences* (Vol. 2): Dordrecht: Kluwer Academic Publishers.

Ellison, P. T., & Reiches, M. W. (2012). Puberty. In N. Cameron & B. Bogin (Eds.), *Human growth and development.* (pp. 81-108). New York: Academic Press.

Fernald, L. C., Kariger, P., Hidrobo, M., & Gertler, P. J. (2012). Socioeconomic gradients in child development in very young children: evidence from India, Indonesia, Peru, and Senegal. *Proc Natl Acad Sci U S A, 109 Suppl 2*(Suppl 2), 17273-17280. doi:10.1073/pnas.1121241109

Gallup, J. L., Gaviria, A., & Lora, E. (2003). *Is Geography Destiny?: Lessons from Latin America*: Stanford University Press.

Hoke, M. K., & Leatherman, T. L. (2019). Secular trends in growth in the high-altitude district of Nuñoa, Peru 1964-2015. *Am J Phys Anthropol, 168*(1), 200-208. doi:10.1002/ajpa.23736

Hox, J. J., Moerbeek, M., & Van de Schoot, R. (2018). *Multilevel analysis: Techniques and applications* New York, USA: Routledge.

Hughes, D. C., Day, S. H., Ahmetov, I. I., & Williams, A. G. (2011). Genetics of muscle strength and power: polygenic profile similarity limits skeletal muscle performance. *J Sports Sci, 29*(13), 1425-1434.

INEI. (2018). Perfil sociodemográfico del Peru, Informe Nacional. Retrieved from https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1539/index.html

Isen, J., McGue, M., & Iacono, W. (2014). Genetic influences on the development of grip strength in adolescence. *Am J Phys Anthropol, 154*(2), 189-200.

Kim, J., Oh, S., Min, H., Kim, Y., & Park, T. (2011). Practical issues in genome-wide association studies for physical activity. *Ann N Y Acad Sci, 1229*, 38-44. doi:10.1111/j.1749-6632.2011.06102.x

Lee, T.-S., Chao, T., Tang, R.-B., Hsieh, C.-C., Chen, S.-J., & Ho, L.-T. (2004). A longitudinal study of growth patterns in school children in Taipei area I: growth curve and height velocity curve. *Journal-Chinese Medical Association, 67*(2), 67-72.

Lightfoot, J. T., EJC, D. E. G., Booth, F. W., Bray, M. S., M, D. E. N. H., Kaprio, J., . . . Bouchard, C. (2018). Biological/Genetic Regulation of Physical

Activity Level: Consensus from GenBioPAC. *Med Sci Sports Exerc, 50*(4), 863-873. doi:10.1249/mss.0000000000001499

Maas, C. J., & Hox, J. J. (2005). Sufficient sample sizes for multilevel modeling. *Methodology, 1*(3), 86-92.

Malina, R. M., Pena Reyes, M. E., Tan, S. K., & Little, B. B. (2011). Physical fitness of normal, stunted and overweight children 6-13 years in Oaxaca, Mexico. *Eur J Clin Nutr, 65*(7), 826-834.

Mao, S. H., Li, H. B., Jiang, J., Sun, X., Cheng, J. C., & Qiu, Y. (2011). An updated analysis of pubertal linear growth characteristics and age at menarche in ethnic Chinese. *American Journal of Human Biology, 23*(1), 132-137.

Nhantumbo, L., Ribeiro Maia, J. A., Dos Santos, F. K., Jani, I. V., Gudo, E. S., Katzmarzyk, P. T., & Prista, A. (2013). Nutritional status and its association with physical fitness, physical activity and parasitological indicators in youths from rural Mozambique. *Am. J. Hum. Biol., 25*(4), 516-523.

Pallan, M. J., Adab, P., Sitch, A. J., & Aveyard, P. (2014). Are school physical activity characteristics associated with weight status in primary school children? A multilevel cross-sectional analysis of routine surveillance data. *Arch Dis Child, 99*(2), 135-141. doi:10.1136/archdischild-2013-303987

Pomeroy, E., Stock, J. T., Stanojevic, S., Miranda, J. J., Cole, T. J., & Wells, J. C. (2014). Stunting, adiposity, and the individual-level "dual burden" among urban lowland and rural highland Peruvian children. *Am J Hum Biol, 26*(4), 481-490. doi:10.1002/ajhb.22551

Preece, M. A., & Baines, M. J. (1978). A new family of mathematical models describing the human growth curve. *Ann Hum Biol, 5*(1), 1-24. doi:10.1080/03014467800002601

Snijders, T. A. B., & Bosker, R. J. (2012). *Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling* (2nd ed.). London: Sage Publishers.

Tanner, J. M. (1987). Growth as a mirror of the condition of society: secular trends and class distinctions. *Acta Paediatr Jpn, 29*(1), 96-103. doi:10.1111/j.1442-200x.1987.tb00015.x

Wen, W., Kato, N., Hwang, J.-Y., Guo, X., Tabara, Y., Li, H., . . . Li, S. (2016). Genome-wide association studies in East Asians identify new loci for waist-hip ratio and waist circumference. *Scientific reports, 6*, 17958.

Zhu, W., Boiarskaia, E. A., Welk, G. J., & Meredith, M. D. (2010). Physical education and school contextual factors relating to students' achievement and cross-grade differences in aerobic fitness and obesity. *Res Q Exerc Sport, 81*(3 Suppl), S53-64. doi:10.1080/02701367.2010.10599694