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Individual, school and natural environment influences on children with motor coordination problems: The Peruvian Health and Optimist Growth Study

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Abstract

This study investigates the interplay between individual and natural environments, as well as the effects of school characteristics, on Peruvian children and adolescents' gross motor coordination (GMC) problems. The sample comprises 7401 participants (4121 girls) aged 6–14 years from three geographical regions: sea-level, Amazon and high-altitude. GMC categories (normal and with problems) were defined from the *KörperkoordinationsTest für Kinder* test battery. Stunting (height-for-age) and nutritional status (BMI-for-age) were obtained from WHO Growth Standards. Biological maturation was estimated, and physical fitness was measured. School context information was obtained from an objective audit. Logistic multilevel analysis was used. Results showed a high prevalence of GMC problems in Peruvian youth. Sex, age, geographical area of residence, biological maturation, nutritional status, stunting and physical fitness were important predictors of GMC problems. Moreover, there was an interaction between age, sex, and geographical area showing that girls, older subjects, and those from sea level regions were more likely to display GMC problems. The school context was less important in predicting GMC problems than the interplay between individual characteristics and the natural environment. The early identification as well as educational and pediatric care interventions are of utmost importance to reduce GMC problems among Peruvian children and adolescents.

Introduction

Gross motor coordination (GMC) is defined as the harmonious and economical interaction of musculoskeletal, nervous, and sensory systems that produce accurate and balanced motoric actions with minimal energy expenditure.[1] Children with GMC problems experience considerable difficulties in performing motor tasks as well as challenges in their daily activities, school performance and social participation [2–4]. It is estimated that about 6% of children around the world have a GMC disorder [5]. Additionally, the prevalence of GMC problems ranges from 8.8 to 28% in children and adolescents [6–8] and appears to be higher in countries with lower human development index [9]. Moreover, if these GMC problems are not resolved as early as possible, they can extend into adulthood, interfering with individual's professional laboring demands and daily activities.

It has been reported that GMC levels vary substantially among children and adolescents[10–12], and that individual demographic and biological variables (e.g., age, sex, body mass index, physical fitness, gestational age, socioeconomic status, parental education, number of siblings, or birth order) and environmental characteristics (e.g., time spent outdoors in playing spaces, parents' physical activity and family interactions), seem to modulate them [10–12]. Yet, the role of environmental factors on explaining GMC variation is apparently unresolved. For example, a systematic review [11] showed inconsistent results regarding the influence of socioeconomic status on GMC, which is similar to data from Niemistö, et al. [13] of Finnish children from three geographical regions of the country scattered by residential density areas. Previous studies have rarely explored sets of putative covariates' influences in children chances of having a GMC problem, and have instead concentrated mostly on the associations with physical fitness and body composition [8,14–16].

Natural environmental differences within a country may play an important role in shaping motor development and GMC among children and adolescents, and thus needs to be considered [17]. Peru is typically described in terms of three broad regions: the arid Coastal region in the west at sea level, the Sierra central region at high-altitude and the forested Amazonia in the east. Further, systematic differences in children and adolescents´ lifestyles in these three regions are notorious because of their vastly different daily chores and subsistence activities [18]. All of these exert different influences on an individual's growth and development [19]. For example, de Chaves, et al. [8] reported that Peruvian children and adolescents living at sea level or at high-altitude were more likely to suffer from GMC difficulties than those living in the Amazon region.

Children and adolescents spend a large portion of their waking hours at school [20], and it is expected that school characteristics may also play an important role in resolving GMC problems. Indeed, Santos, et al. [21] reported that in Peruvian children, 31% of the total variance in GMC (based on continuous raw scores) was explained by school characteristics. Also, interactions between the natural and built environments with individual characteristics in shaping GMC are expected to occur. To our knowledge, there is a lack of information on the interplay of GMC problems with individual characteristics (such as age, sex, biological maturation, physical fitness) and hence our understanding of their potential integrative influences on GMC problems is limited. We may come closer to this integrative understanding by using the multilevel statistical framework and probing the network of independent and interaction links between individual and environmental characteristics on GMC problems. Hence, the aim of this study is to address the following research questions: (1) are age, sex and geographical areas associated with children and adolescents' GMC problems during childhood and adolescence? (2) If yes, do age-by-sex, age-by-geographical area, and sex-by-geographical area interactions predict GMC problems? (3) If the two-way interactions are significant, do age-by-sex-geographical area predict GMC problems? (4) What are the relations of child-level characteristics on the likelihood of GMC problems? (5) Do school-level variables also relate to GMC problems?

Results

Descriptive statistics. Table 1 shows the child-level characteristics by GMC levels (normal and with problems). An increase in prevalence of GMC problems from 6–10 years to 11–14 years was observed (χ^2 = 216.035, $p < 0.05$). Girls (50.6%) had higher prevalence of GMC problems compared to boys (18.3%, χ^2 = 824.33, $p < 0.05$). Children and adolescents from sea-level (49%) and high-altitude (45.4%) had higher prevalence of GMC problems compared to their Amazonian peers (27.5%). Moreover, children and adolescents with stunting had a higher prevalence than non-stunted children and adolescents (40.0% vs 5.8%, χ^2 = 7.150, $p < 0.05$). A similar result was observed regarding weight status in which youth who were overweight and obese had a higher prevalence of GMC problems than their normal weight peers (40% vs

34.8%, $\chi^2 = 17.875$, $p < 0.05$). Finally, those with high levels of physical fitness had a lower prevalence of GMC problems (22.7%) when compared with those showing low (48.4%) and medium (37.0%) levels of fitness.

Table 1
Child-level characteristics by gross motor coordination

		Gross motor coordination			
		Normal	Problems	χ^2	Comparisons[¥]
		N (%)	N (%)		
Age Class	6–10 years	2647 (72.0)	1030 (28.0)	216.035***	11-14y > 6-10y
	11–14 years	2069 (55.6)	1655 (44.4)		
Sex	Girls	2036 (49.4)	2085 (50.6)	824.334***	Girls > Boys
	Boys	2680 (81.7)	600 (18.3)		
Geographical area	Sea-level	749 (51.0)	719 (49.0)	305.716***	S > A H > A
	High-altitude	1017 (54.6)	847 (45.4)		
	Amazon region	2950 (72.5)	1119 (27.5)		
Stunting	Non-stunted	4269 (64.2)	2378 (35.8)	7.150**	Stunted > non-stunted
	Stunted	447 (59.3)	307 (40.7)		
Nutritional status	Normal weight	3416 (65.2)	1820 (34.8)	17.875***	OW/O > NW
	Overweight/obese	1300 (60.0)	865 (40.0)		
Physical fitness	Low	950 (51.6)	892 (48.4)	266.569***	L > M > H
	Medium	2339 (63.0)	1375 (37.0)		
	High	1427 (77.3)	418 (22.7)		

[¥] Direction of association for GMC problems.

School-level characteristics are shown in Table 2. Eighty-three percent of schools were located in urban areas, with the number of students per school ranging from 96 to 1200. Furthermore, 83.3% of schools had a playground without obstacles, and 33.3% had access to an indoor multi-sports complex. Forty-four percent of schools had neither policies nor practices for physical activity, whereas 16.7% had policies and 38.9% had practices for physical activity. In 55.6% of schools, physical education classes were more than 90 minutes in duration once a week, and children and adolescents active time during classes was, on average, 78 min. Additionally, 77.8% of schools offered extracurricular activities, and 38.9% allowed students to use school infrastructures outside of school activities.

Table 2
Descriptive statistics of the school-level characteristics [counts (n), frequencies (%), means, standard deviations (SD) and ranges].

	n	%
School setting		
Mixed	3	16.7
Urban	15	83.3
Policies and practices for physical activity		
No	8	44.4
Only Policies	3	16.7
Only Practices	7	38.7
Playground obstacles		
Without obstacles	15	83.3
With obstacles	3	16.7
Indoor Multi-sports		
No	12	66.7
Yes	6	33.3
Physical education classes duration		
≤90 minutes	8	44.4
>90 minutes	10	55.6
Extracurricular activities		
No	4	22.2
Yes	14	77.8
	Mean (SD)	Range
Number of students per school	453 (263)	96-1200
Active time during physical education class	78 (16)	50–110

Results of the multilevel analysis are presented in Table 3. The null model (data not shown) indicated that 15% of the total variance in GMC categories was explained by school-level characteristics, with the remaining 85% associated with distinct children and adolescents' traits.

Question 1: are age, sex and geographical area associated with children and adolescents' chances of having GMC problems? Model 1 results show that older individuals were more likely to exhibit GMC problems than their younger peers (OR = 1.686; 95%CI = 1.454–1.956). Moreover, boys (OR = 0.183; 95%CI = 0.161–0.209) and those living in the Amazon region (OR = 0.366; 95%CI = 0.230–0.581) were less likely to show GMC problems than girls and their sea-level peers, respectively.

Question 2: do age-by-sex, age-by-geographical area, and sex-by-geographical area interactions condition GMC problems? Model 2 was a better fit than Model 1 ($\chi^2 = 21.04$, 5 df, $p < 0.001$) as indicated by a significant drop in the deviance statistic, and indicated that interaction effects were statistically significant. The age-by-sex interaction results revealed that although both boys and girls increased the probability of having GMC problems from 6–10 years through to 11–14 years, the increase with age was greatest in girls (see Fig. 1a). For the age-by-geographical area interaction, a significant effect ($p < 0.05$) was only observed between sea-level and amazon regions, indicating that sea-level youth have a greater chance of having GMC problems. Figure 1b shows a lower probability for Amazonian subjects in both age classes (6–10 years = 23% and 11–14 years = 36%) to demonstrate GMS problems when compared to sea-level peers (6–10 years = 45% and 11–14 years = 53%) and high-altitude peers (6–10 years = 45% and 11–14 years = 50%). However, it is important to note that the difference in rates of GMC problems for Amazonian subjects tend to be higher (~ 14%) than their counterparts from sea-level (~ 8%) and high-altitude (~ 5%) across age. Finally, there is a significant interaction in the sex-by-geographical area interaction (Fig. 1c), but only between sea-level and high-altitude Peruvian youth of both sexes.

Question 3: If the two-way interactions are significant, do age-by-sex-geographical area predict GMC problems? Model 3 was a better fit than Model 2 ($\chi^2 = 15.16$, 2 df, $p < 0.001$) indicating the importance of three-way interactions in both categories. Figure 2 shows that girls from the Amazon region had higher increases of the probability of having GMC problems between 6–10 years through to 11–14 years (23%) than sea-level (5%) and high-altitude (3%) peers. Boys showed a different pattern: at 6–10 years boys from sea-level and high-altitude had equal probability of having GMC problems (24%) and higher probability than Amazon region (11%). Additionally, boys from high-altitude and Amazon region from 6–10 years to 11–14 years displayed residual increases in their probability of having GMC problems (2% and 3%, respectively), although boys from the sea-level presented higher increases in their probability (19%).

Question 4: what are the relations of child-level characteristics on the likelihood of GMC problems? Model 4 was a better fit than Model 3 ($\chi^2 = 434.28$, 5 df, $p < 0.001$), and showed that those ahead in their biological maturation (OR = 1.820; 95%CI = 1.651–2.005), stunted (OR = 1.491; 95%CI = 1.232–1.804), and being overweight or obese (OR = 1.291; 95%CI = 1.131–1.473) were more likely to have GMC problems. However, Peruvians with medium (OR = 0.419; 95%CI = 0.361–0.487) and higher (OR = 0.150; 95%CI = 0.122–0.185) physical fitness levels had lower odds, i.e., were more protected of displaying GMC problems than their peers with low physical fitness levels.

Question 5: do school level variables also relate to GMC problems? Finally, when school-level covariates were added (Model 5), no improvement in model fit was found relative to Model 4 (χ^2 = 11.08 with 9 df, $p > 0.05$). This suggests that, after accounting for individual characteristics and geographical location as well as their significant interactions, school-level characteristics did not significantly predict Peruvian children and adolescents' chances of having GMC problems.

Table 3

Parameters estimates [odds ratios (OR) and 95% confidence intervals] and variance components for gross motor coordination.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Variables	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
Age (11–14 years)	1.686 (1.454–1.956)***	1.621 (1.217–2.159)**	1.268 (0.919–1.749)	0.556 (0.385–0.801)**	0.582 (0.406–0.835)**
Sex (boys)					
Geographical area (high-altitude)	0.183 (0.161–0.209)***	0.338 (0.198–0.578)***	0.221 (0.119–0.409)***	0.126 (0.064–0.247)***	0.077 (0.037–0.160)***
Geographical area (amazon region)	0.904 (0.554–1.476)	1.263 (0.709–2.246)	1.239 (0.669–2.293)	1.514 (0.740–3.098)	1.505 (0.369–6.148)
Interactions (two-way)					
Age-by-sex	0.366 (0.230–0.581)***	0.360 (0.212–0.614)*	0.319 (0.181–0.561)***	0.425 (0.220–0.821)*	0.711 (0.279–1.811)
Age-by-geographical area (11–14 years/high-altitude)		0.722 (0.564–0.925)*	1.918 (1.008–3.651)*	0.872 (0.438–1.737)	0.703 (0.361–1.367)
Age-by-geographical area (11–14 years/amazon-region)					
Sex-by-geographical area (male/high-altitude)		0.886 (0.591–1.330)	1.057 (0.662–1.690)	0.854 (0.520–1.403)	0.825 (0.496–1.372)
Sex-by-geographical area (male/amazon region)		1.450 (1.019–2.063)*	2.131(1.420–3.197)***	2.428 (1.570–3.756)***	2.406 (1.575–3.674)***
Interactions (three-way)					
Age-by-sex-by-geographical area (11-14y/male/high-altitude)		0.560 (0.319–0.984)*	0.786 (0.395–1.565)	0.578 (0.275–1.212)	0.947 (0.427-2.100)
Age-by-sex-by-geographical area (11-14y/male/amazon region)		0.673 (0.387–1.170)	1.252 (0.395–1.565)	1.120 (0.550–2.282)	1.838 (0.848–3.980)
Other child-level characteristics			0.439 (0.205–0.944)*	0.512 (0.229–1.142)	0.633 (0.289–1.386)
Maturity offset			0.247 (0.119–0.514)***	0.269 (0.124–0.581)**	0.325 (0.154–0.687)**
Stunting (yes)					
Body mass index (overweight/obese)					
Physical fitness (medium)					
Physical fitness (high)					

***p < 0.001 ; **p < 0.01 ; *p < 0.05 ; [a]normal GMC ;[b] normal growth is the reference ; [c]girls are the reference ; [d]thiness/normal weight is the reference ; [e]Amazon region is the reference ; [f]mixed is the reference ; [g]number of students divided by 10 ; [h]no policies nor practices is the reference ; [i]without obstacles is the reference ; [j]no is the reference ; [l]<90 minutes is the reference;

School-level characteristics	Model 1	Model 2	Model 3	Model 4	Model 5
School setting (urban)[f]				1.820 (1.651–2.005)***	1.823 (1.652–2.011)***
Number of students [g]				1.491 (1.232–1.804)***	1.484 (1.227–1.795)***
Policies or practices for physical activity (only policies) [h]				1.291 (1.131–1.473)***	1.284 (1.125–1.465)***
Policies or practices for physical activity (only practices) [i]				0.419 (0.361–0.487)***	0.419 (0.360–0.486)***
Playground obstacles (with obstacles)[j]				0.150 (0.122–0.185)***	0.150 (0.122–0.184)***
Indoor Multisports (yes)[j]					1.030 (0.487–2.178)
Physical education classes duration (≥ 90 minutes)[l]					0.999 (0.998-1.000)
Active time during physical education classes					3.197 (1.014–10.080)*
Extracurricular activities (yes)[j]					0.948 (0.504–1.783)
					1.597 (0.881–2.897)
					1.551 (0.730–3.296)
					0.979 (0.586–1.638)
					1.010 (0.992–1.027)

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; [a]normal GMC ;[b] normal growth is the reference ; [c]girls are the reference ; [d]thiness/normal weight is the reference ; [e]Amazon region is the reference ; [f]mixed is the reference ; [g]number of students divided by 10 ; [h]no policies nor practices is the reference ; [i]without obstacles is the reference ; [j]no is the reference ; [l]<90 minutes is the reference;

	Model 1	Model 2	Model 3	Model 4	Model 5
					0.525 (0.279–0.987)*
Deviance	8210.68	8189.64	8174.48	7740.20	7729.12
Number of parameters	6	11	13	18	27
Δ in Deviance from previous model (Δ in number of parameters)	775.15 (4)***	21.04 (5)***	15.16 (2)***	434.28 (5)***	11.08 (9)
***p < 0.001 ;**p < 0.01 ; *p < 0.05 ; [a]normal GMC ;[b] normal growth is the reference ; [c]girls are the reference ; [d]thiness/normal weight is the reference ; [e]Amazon region is the reference ; [f]mixed is the reference ; [g]number of students divided by 10 ; [h]no policies nor practices is the reference ; [i]without obstacles is the reference ; [j]no is the reference ; [l]<90 minutes is the reference;					

Discussion

There is apparently no doubt that identifying children with GMC problems as well as their putative covariates is by itself a commendable effort given their implications for education and pediatric care [22]. We believe that the uniqueness of the present study is in the examination of the interactions between individuals and their environmental characteristics in explaining the presence of GMC problems. This is of chief importance for children living in developing countries such as Peru, and can be extended to other South-American children living in regions marked by geographical, cultural, and socioeconomic differences.

An important finding of this study is that the main fraction of GMC categories' variance (85%) was explained by Peruvians' individual characteristics, which is similar to a report of Portuguese children [23]. Also, consistent with previous results, Peruvian girls are more likely to display GMC problems than boys [8,21]. This sex difference in GMC suggests a complex interplay between biological and cultural factors, which are probably linked to differences in sport participation, daily chores and distinct physical activities chosen by girls compared to boys. For example, Peruvian girls tend to spend their time after school in home activities (e.g., cleaning, cooking, etc.) whereas boys spend their time in sports' participation as well as in other varied physical activities.

We showed that older Peruvians were more likely to have GMC problems, which is a similar finding to Flemish children aged 5–12 years [24]. One plausible explanation for such results may be linked to differences in the timing and tempo of the growth spurt. This growth period is marked by an asynchrony in the growth of different parts of the body [25,26] that can adversely affect motor control, a phenomenon termed "clumsiness" or "adolescent awkwardness" [27]. For example, Bisi and Stagni [28] in an experimental study compared the gait performance of growing (height increase > 3 cm in 3 months) and not growing (height increase < 1 cm in 3 months) male adolescents during a walking task and showed that the growth spurt influenced gait variability, smoothness and regularity. Additionally, whereas some children may perform some motor tasks awkwardly, others who grow steadily may be able to cope with their physical growth changes and thus maintain smoothness and regularity in some motor tasks. This was previously reported in Flemish male soccer players [29] as well as in Belgium boys [30]. Indeed, these authors showed a temporary decline in performance during the growth spurt. Nevertheless, more longitudinal studies are needed to better understand the potential associated mechanisms [31] as well as differences between boys and girls [32].

The main challenge of the present study was to investigate how geographical areas interacted with individual-level characteristics (age and sex) to predict GMC problems. Based on a three-way interaction between age, sex, and geographical area we showed that older girls living at sea level are more likely to display GMC problems, whilst the youngest boys from the Amazonian region were less likely to have GMC problems. These results urge us to identify differences between these three regions that may have contributed to different probabilities of developing GMC problems, especially between the sea level and the Amazon regions. One possible explanation is associated with differences between these three regions in their natural, sociodemographic, health care and cultural characteristics (see Table 4 for more detailed information) that may influence lifestyle behaviors and routine activities. For example, the sea-level region has a higher human developmental index, high income and consequently better urban development and higher population density, where children tend to adopt certain lifestyle behaviors and other daily routine activities closer to youth from developed countries i.e., more sedentary activities and lower levels of physical activity. In fact, Sharma, et al. [33] showed that 78% of Peruvian adolescents living at sea-level do not meet the WHO recommendations for moderate-to-vigorous physical activity. On the other hand, children and adolescents from the Amazon region tend to live in cities with less population density but larger areas. Peru's sea-level region represents 11% of the total area of the country but it is occupied by 65% of the total population, while the Amazon region represents 60% of the total area but only 5% of the total population reside in this region (approximately 1.6 million) [34]. Moreover, most families in the Amazon region are dependent on agricultural production and children tend to help their parents with these activities, especially during the weekend. The time spent in agriculture may provide children with rich opportunities to play freely in natural environments that increases their physical activity and improves their GMC.

Finally, when considering main effects of other individual characteristics, our results are consistent with previous research; biological maturation (favoring those less advanced), nutritional status (favoring normal weight), stunting (favoring non-stunted) and those more physically fit were less likely to have higher GMC problems [10,21]. These results are important pointers regarding their adverse or protective effects on the development of GMC problems. More specifically, nutritional status and stunting are risk factors while physical fitness is a protective factor in showing GMC problems. Moreover, these findings are concordant not only with other Peruvian studies [8,21] but also with data from Portuguese [11] and Flemish [24,35] children and adolescents.

There is no doubt that schools are important when considering optimum physical growth, fundamental motor skills as well as GMC development [1]. Our findings showed that 15% of the total variance in GMC categories is accounted for by the school contexts. However, in the final model (model 5) when we added school characteristics after adjusting for individual characteristics, natural environments as well as their interaction, this model did not fit the data better than the previous one (model 4). This result most probably suggests that individual characteristics and natural environments seem to play more important roles than school characteristics to predict GMC problems in these Peruvian children and adolescents. This apparently reinforces our previous suggestion about the differences between regions being highly important in explaining differences between children and adolescents with GMC problems. This reiterates their impact on population lifestyles and consequently in children and adolescents GMC. However, these results highlight the importance for more research to tease out differences between countries and regions as well as contrasting high-income versus low-income countries.

This study is not without limitations. Firstly, the cross-sectional design does not allow any causal interpretation into the dynamics of individual and environmental complex relationships on changes in GMC problems. Secondly, we do not have information on other behaviors that can influence the links between stunting and GMC problems such as lifestyle behaviors (e.g., physical activity). Yet, given the sample size and the age range, this would be a daunting task and most probably an “impossible mission”. Thirdly, we do not have information about the manifold aspects of home environments that may interact with individual characteristics and their development, which, in turn, may have a protective or negative effect on GMC disorders.

In conclusion, we showed a high prevalence of GMC problems in Peruvian children and adolescents which is more pronounced in girls, those aged 11–14 years and those living in the sea-level region. Further, these findings highlight the importance of individual and environmental characteristics influencing GMC problems, and this has key implications for physical education teachers to promote adequate levels of GMC development, as well as for pediatric care within local health-systems. Altogether, these results revealed the need to offer distinct physical education programs according to regions (i.e., sea level, high-altitude and amazon region) to accommodate their very dissimilar characteristics. Further, early identification of overweight/obesity status, stunting and physical fitness levels aligned with biological maturation may also help to implement precise intervention programs tailored to children and adolescents’ characteristics. If subjects differ in some characteristics that condition their GMC unfolding, then there is a need to develop suitable pediatric care to foster and enhance their healthy growth and proper motor development.

Methods

Participants and geographical area of residence. Participants in the current study were drawn from *"The Peruvian Health and Optimist Growth Study"*, which was conducted between November 2009 and July 2010. This study investigated the relationships between physical growth, motor development and health in Peruvian children and adolescents and their families [36]. Participants were recruited from 18 randomly chosen schools from the 78 schools in these three regions, and the original sample consisted of 10,424 boys and girls 6–17 years of age. Complete data were obtained from 7401 participants (4121 girls; 3280 boys 6 to 14 years old) – the age range of the GMC test battery is from 5 to 14.99 years.

Given the country's heterogeneity in geography, participants came from three distinct regions: sea-level, Amazon region and high-altitude. Barranco was the chosen city at sea-level in the Lima region. The cities of La Merced and San Ramon in the Chanchamayo district represented the Amazon region, and the Junín district was used to represent the high-altitude location. Participants included in the present study were natives of their respective regions (non-immigrants). Information with regards to birthplace and current place of residence was collected from individual's identity cards. Table 4 shows the distinct characteristics of these geographical locations, based on information provided by National Institute of Statistics and Informatics (INEI) [37], city-halls [38–40] and the digital platform of the Ministry for the Environment [41].

Written informed consent was obtained from legal guardians, and the project was approved by the local school and political authorities, as well as by the Ethics Committee of the National University of Education Enrique Guzmán y Valle (UNE EGyV). All methods were performed in accordance with the relevant guidelines and regulations. Moreover, the study was performed in accordance with the ethical standards established in the Declaration of Helsinki

Table 4
Natural, socioeconomic, demographic, health care and cultural features of the three regions

	Sea-level (Barranco)	Amazon region (Chanchamayo)	High-Altitude (Junín)
Natural characteristics			
Altitude (m)	58	751	4107
Precipitation, and temperature (average)	Arid; semi-warm (18ºC)	Rainy; warm	Rainy; cold
		(24ºC)	(12ºC)
Humidity	Humid	Very humid	Humid
Socioeconomic characteristics			
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
Demographic characteristics	8.564.867	411.011	1.272.890
Population (total)	236.6	10.2	27.7
Population density (people/km^2)			
Basic access to health care	Yes	No	No
Health center	No	Yes	Yes
Public hospital	Yes	No	No
Private clinic	No	Yes	Yes
Hospital campaigns and tracking at school			
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

Anthropometry. Body measurements were made according to standardized protocols [28]. Height and sitting height were measured using a portable stadiometer (Sanny, Model ES-2060) with the subject's head positioned in the Frankfurt plane, to the nearest 0.1 cm. Body mass was measured to the nearest 0.1 kg using a digital scale (Pesacon, Model IP68). Technical error of measurement (intra-observer error) was 0.2 cm for height, 0.1 cm for sitting height, and 0.1 kg for body mass. BMI was calculated by dividing weight (kg) by height squared (m^2).

Stunting and nutritional status. Stunting (height-for-age) and nutritional status (BMI-for-age) were predicted using age- and sex-specific WHO Child Growth Standards [42,43]. Two stunting groups were created: normal growth [height-for-age Z score ≥ -2 standard deviation (SD)], and stunted growth (height-for-age Z score < -2 SD). Normal growth was used as the reference category in the models. Three nutritional status groups were created: thinness (BMI-for-age < -2 SD), normal weight (BMI-for-age between ≥ -2 SD to ≤ 1 SD), and overweight/obese (BMI-for-age > 1 SD). However, given that only 40 subjects were classified with thinness (0.5% of the sample, representing 25 females and 15 males, 2 from sea-level, 15 from high-altitude and 23 from Amazon region), in the final models only normal weight and overweight/obese groups were considered and a thinness/normal weight grouping was used as the reference category.

Biological maturation. Biological maturation was assessed using a measure of somatic maturity predicted from anthropometrics to calculate a maturity offset value [44]. Maturity offset (years from peak height velocity) is an estimated temporal distance and is expressed in decimal years. Age at peak height velocity (PHV) is calculated as chronological age at assessment minus maturity offset. A positive (+) maturity offset indicates the number of years the participant is beyond attainment of PHV, whereas a negative (-) maturity offset represents the number of years the participant is before attaining PHV. This method has been widely used in children and adolescents [45–47] and was previously used in other Peruvian studies [19,48].

Physical fitness. Physical fitness was assessed using four tests: handgrip strength (static muscle strength component); standing long jump (explosive muscle strength component); shuttle-run (speed and agility component); and 12 min run (cardiorespiratory component). These tests are part of the EUROFIT test battery [54] and the American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD) test battery [55]. Reliability was estimated, and intraclass correlation values ranged from 0.79 in the shuttle-run test, to 0.85 in the handgrip test. Age-, and sex-standardized z-scores were computed for each test (the shuttle-run time was inverted), and then summed to obtain a total physical fitness z-score for each individual, as recommended [56,57].

Gross motor coordination. Gross motor coordination was assessed using the *Körperkoordination Test für Kinder* battery (KTK), developed by Kiphard and Schilling [49] for children and adolescents aged 5-14.99 years of age. This test battery has systematically been used in European [50], African [51], and South-America populations [8,52]. The KTK is explained in detail elsewhere (39). In brief, the battery contains four tests: walking backwards along a balance beam, hopping on one foot, jumping sideways, and moving sideways on boxes. A total KTK score is obtained from summing the scores obtained from each test. This unweighted sum of the scores, adjusted for age and sex, is named as the motor quotient (MQ), and has the following categories: (i) not possible (MQ < 56); (ii) severe motor disorder (MQ 56–70); (iii) moderate motor disorder (MQ 71–85); (iv) normal (MQ 86–115); (v) good (MQ 116–130); (vi) high (MQ ≥ 131). For the present study, we only considered two broad categories: children and adolescents with normal GMC if MQ > 85, and children and adolescents with GMC problems if MQ ≤ 85 as recommended by Schilling [53]. In our statistical models, the normal GMC was used as the reference category. ANOVA-based intraclass correlation reliability estimates of children and adolescents GMC performance ranged from 0.78 in the moving sideways test to 0.92 in the walking backwards test.

School characteristics. Information concerning school characteristics was obtained via a questionnaire completed by a school administrator, assisted by a research team member. 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 was used [58]. The questionnaire included information from five domains: school size and characterization (number of children, number of teachers and school setting); healthy eating and physical activity policies (the existence, or not of policies and practices used by the school board); extracurricular activities (the existence and type of extracurricular activities available in the school); frequency and duration of physical education classes; school facilities (playground dimension and characterization, multi-sports roofed existence and dimension, number of structures and equipment available for physical education classes). For the present study, we only used information related to: school setting [mixed (reference category) or urban], number of students (continuous variable), policies and practices for physical activity [three categories: no policies nor practices (reference category); only policies; only practices], playground characteristics [with or without obstacles (reference category)], indoor multi-sport [existence or not (reference category)], physical education classes duration [two categories: <90 min (reference category) and ≥ 90 minutes], active time during physical education classes (continuous variables), extracurricular activities [two categories: no (reference category) and yes] and availability of school infrastructures outside of school activities [two categories: no (reference category) and yes].

Statistical analysis. Descriptive statistics are reported as means, standard deviations, and percentages as appropriate. Since the data were hierarchical in nature, i.e., participants nested within schools (two-levels), we used a multilevel logistic model (0 = normal GMC; 1 = GMC problems) with a step-by-step modeling approach with increasing complexity: first, a null model with no predictors was estimated to calculate how much of the total variation in GMC categories was explained by the schools; second, five sequential models were built with varying complexity levels. Model 1 used age, sex and geographical area; model 2 built on model 1 and tested for two-way interactions: age-by-sex, age-by-geographical area and sex-by-geographical area; in model 3 a three-way interaction was added, namely: age-by-sex-by-geographical area; model 4 included other child-level characteristics such as stunting, BMI, maturity offset and physical fitness; model 5 included school-level characteristics. All model parameters were simultaneously estimated using maximum likelihood procedures, and when appropriate covariates were centered at their means as generally advocated [59]. Deviance (-2 log likelihood value) was used as a relative measure of model fit, with smaller values indicating a better fit to the data. When comparing nested models, we relied on differences in deviance, which follows a chi-square distribution with degrees of freedom equal to the difference in the number of estimated parameters from both models. Stata 14 was used in all analyses, and the significance level was set at 5%.

Declarations

Conflicts of Interest:

The authors declare no conflict of interest.

Author Contributions

Statement: Conceptualization, S.P., C.S. and J.M.; formal analysis, S.P., D.H. and J.M.; investigation, A.B. and J.M.; data curation, A.B.; writing—original draft preparation, S.P., C.S., P.T.K and J.M.; writing—review and editing, S.P., C.S., P.T.K., J.M., D.H., G.T., R.G., O.V. and A.B.J.

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Figures

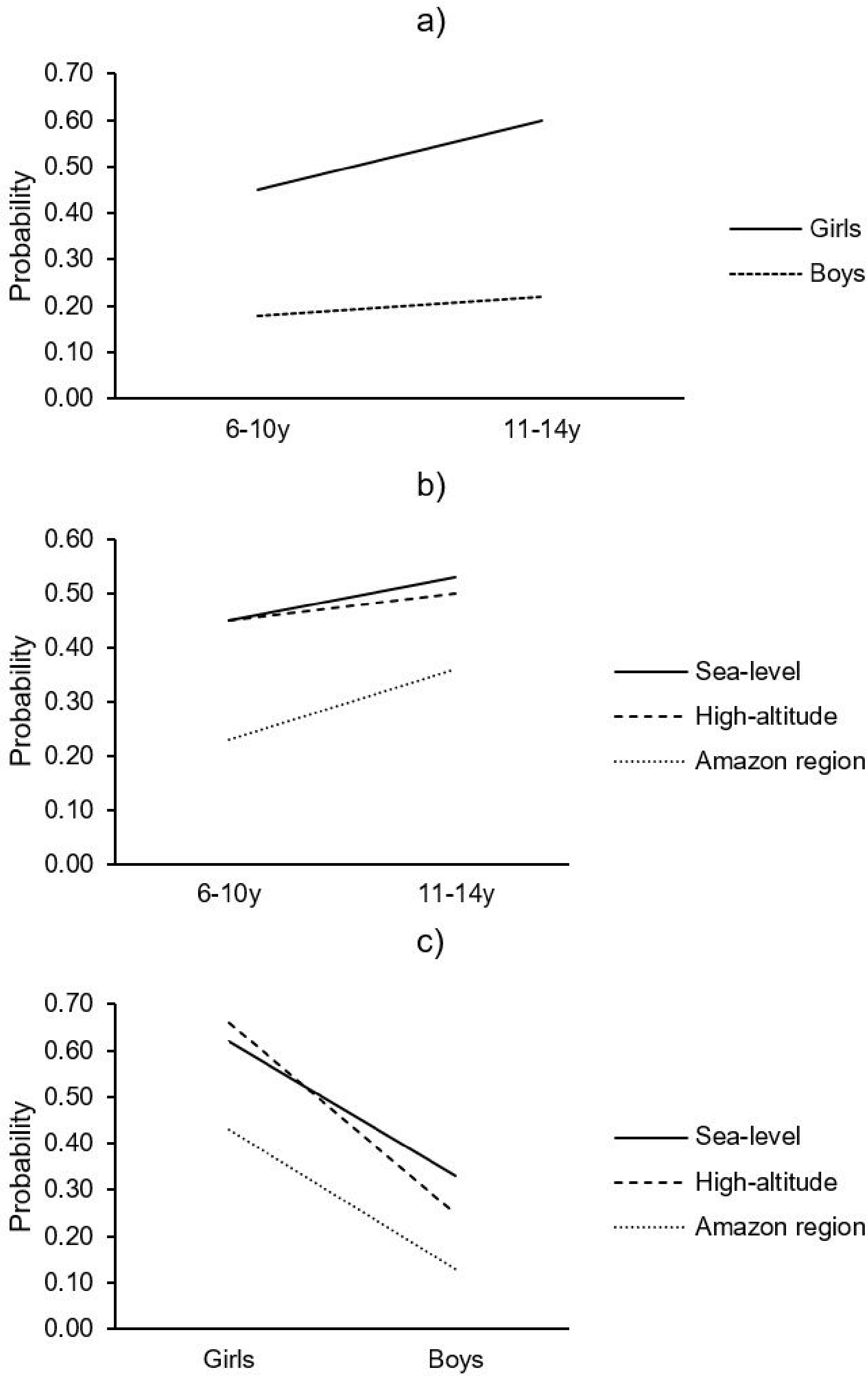

Figure 1

Plots of probabilities of having GMC problems: age-by-sex (a) age-by-geographical location (b) and sex-by-geographical location (c) interactions.

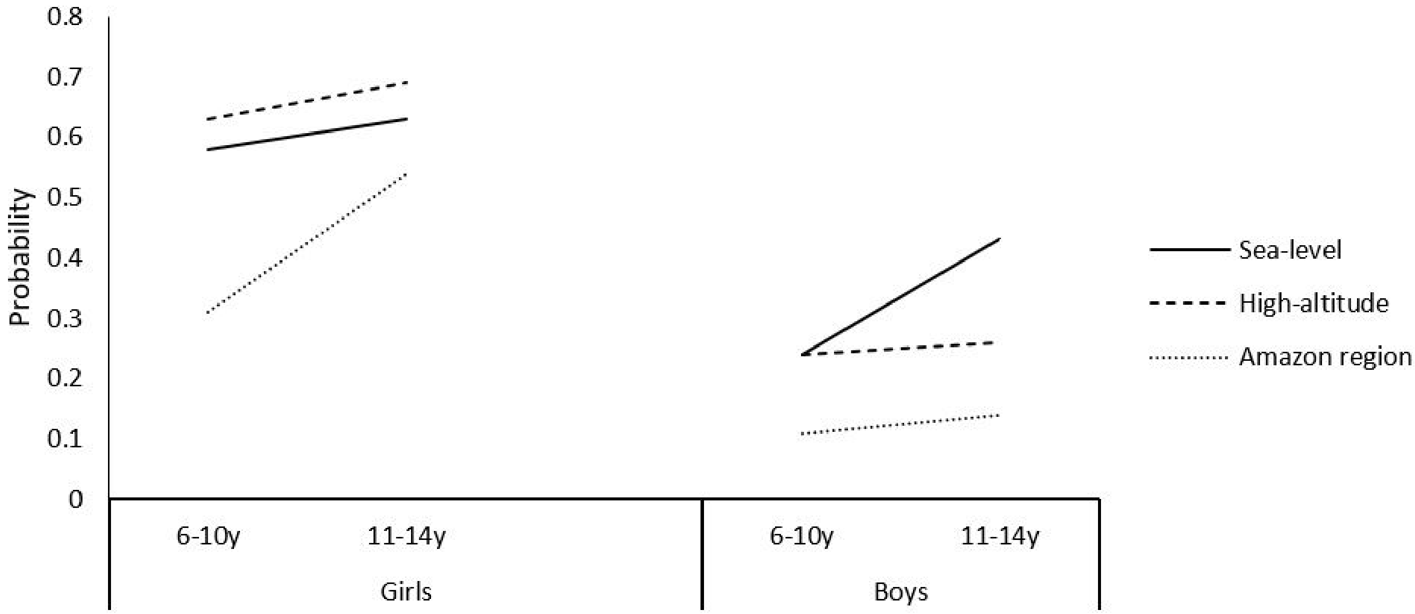

Figure 2

Plots of probabilities of having GMC problems: age-by-sex-by-geographical area interaction