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How altitude above sea level affects intelligence

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ABSTRACT

The influence of altitude above sea level on intelligence has received only tangential attention in the literature despite that, firstly, the scarcity of oxygen occurring at high altitude impairs cognitive functioning; second, UV radiation, which is stronger at high altitude, is theorized to negatively affect intelligence; and third, the rugged terrain of high altitudes has negative effects on economic activity, which in turn affects cognitive development. This study evaluated the three potential causes using Math and Reading scores from a national census of schools that targeted children of approximately eight years of age in their 2nd year of instruction in Peru. It was limited to the 5° to 13° S latitudinal segment (N = 1073 districts). The Western and Eastern slopes of the Andes Mountains and altitudes below and above 2300 m were compared. The evidence indicates that oxygen deprivation does not explain observed negative effects of altitude on intelligence. Differences in intelligence along altitude and between Western and Eastern regions are attributable to UV radiation and the economic impacts of ruggedness. Sexual attitudes and infectious diseases in the lower Amazon region may account for an observed altitude x region interaction.

1. Introduction

The influence of altitude above sea level on complex cognitive ability CCA – a construct measured by IQ scores and/or student achievements in Math, Reading, and/or Science (Rindermann, 2007) - has only received tangential attention in the literature (León & Burga León, 2014) despite that the scarcity of oxygen occurring at high altitude impairs cognitive functioning. Insufficient oxygen in the brain causes brain vasodilatation whereas reduced partial pressure of carbon dioxide produces arterial vasoconstriction (West, Schoene, & Milledge, 2007). These conflicting processes are known to affect cognitive functioning as people reach over 2500 m (Cavaletti, Moroni, Garavaglia & Tredici, 1987; Hackett, 1999; Hackett & Roach, 2001; Pagani, Ravagnan, & Salmaso, 1998). The evidence points to short-term memory (Hopkins, Kessner & Goldstein, 1995; Hornbein, Townes, Shoene, Sutton, & Houston, 1989; Wang, Ma, Fu, Guo, Yang, Luo, & Han, 2014); perceptual problems (Hayashi, Matsuzawa, Kubo, & Kobayashi, 2005); language deficits such as transitory aphasias (Botella, Garrido, & Catalá, 1993); problems with working memory (Yan, Zhang., Gong, & Weng, 2011a, 2011b) and other more specific deficits, such as a difficulty for evoking proper nouns (Pelamatti, Pascotto, & Semenza, 2003). Researchers Virue-Ortega Garrido, Javierre, & Kloezeman (2006) suggest that executive function may be damaged in this process. Finally, a slow fetal and neonatal development at high altitude has also been proven (Giusianni, Phillips, Anstee, & Barker, 2001; Moore, Shelton, & Colleen, 2011; Saco-Pollitt, 1981). Genetic adaptation to high altitude may prevent these cognitive deficits. Compared to Peruvians and Bolivians residing at high altitude, who only have 14,000 years of adaptation to their habitat, Tibetans and Nepalese, who have over 35,000 years of adaptation, present twice the capacity of hypoxic ventilation response and other physiological advantages assumed to influence cognitive functioning (Beall, 1997, 2000, 2006; Beall, Worthman, Stallings, Strohl, Brittenham, & Barragan, 1992; Monge, Bonavía, León-Velarde, & Arregui, 1990; Nieremeyer, Zamudio, & Moore, 2001). Processes of individual or population *cognitive* adaptation are not known. But it has been shown that the CCA of Peruvians declines with altitude (León & Burga León, 2014).

Altitude is related to UV radiation as well, and the latter has been theorized to influence intelligence. Since UV photons are more abundant at high altitude because the ozone layer is thinner in the higher atmosphere, effective fabrication of vitamin D by the human skin and retina increases with altitude (Engelsen, Brustad, Aksnes & Lund, 2005). Because vitamin D promotes the production of sexual hormones (Jones, Strungnell, & DeLuca, 1998), estrogen and testosterone present higher levels at high altitude (Gonzales, Tapia, Gasco, & Gonzales-Castañeda, 2011; Gonzales & Ortíz, 1994; Gonzales & Villena, 1997). Therefore, families can be expected to be larger at higher altitude and thereby offer a more impoverished intellectual environment at the home (Zajonc & Mullally, 1997) and less schooling opportunities to the child (Booth & Kee, 2009), with negative effects to his/her cognitive

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development (Deary, 2012; Nisbett, Aronson, Blair, Flynn, Halpern, & Turkheimer, 2012). It should be noted, however, that other forms of influence are possible; for example, prenatal gestational risks which increase with the number of pregnancies (Kristensen & Bjerkedal, 2007). On the other hand, the literature is ambiguous with respect to the direction of causality; larger families may impair cognitive development (Bjerkedal, Kristensen, Skjeret, & Brevik, 2007) or more intelligent parents, who have more intelligent offspring, may have shorter families (Kanazawa, 2012). León and Burga León (2014, Figure 3) reported that at the Peru national level altitude presented net negative influences on children's CCA through its positive effects on fertility rate, a proxy for family size. UV radiation has also been theorized to negatively influence intelligence through a different route: vitamin D promotes brain dopamine (Kesby, Eyles, Bume & McGrath, 2011), which motivates playing (Sivyi, 1998), and playing may keep children from study tasks (León & Burga León, 2014, 2015). Furthermore, UV radiation is known to cause oxidative stress (Meng, Zhang, Zhu, Wang, & Lei, 2009) and, hence, fatigue (Kennedy, Spence, McLaren, Hill, Underwood, & Belch, 2005), possibly reducing industriousness (DeYoung, Quilty, & Peterson, 2007) and, thus, wealth. Low income affects CCA (Nisbett et al., 2012) because poverty impairs cognitive functioning (Mani, Mullainathan, Shafir, & Zhao, 2013). There is also the case of folate, important in pregnancy and infancy, which is degraded by UV radiation (Jablonski & Chaplin, 2010) and related to cognitive performance (Kerac, Postels, Mallewa, Allusine, Voskuijl, Groce, … & Molyneux, 2014). Considering that UV radiation decreases with absolute latitude, the UV Radiation Theory of Intelligence predicts a positive correlation between absolute latitude and CCA (León, 2015, 2016; León & Burga León, 2014, 2015).

Altitude may also affect intelligence in another way. Terrain ruggedness makes economic activity difficult: agriculture faces severe erosion problems; construction of buildings, roads and bridges is more costly with ruggedness; and the higher the altitude, the less the population and the greater its isolation and poverty. Thus, families who work the land with 16th century techniques can be found at 3500 m and above in Peru. Because poverty impairs cognitive functioning through its negative effects on emotions (Mani et al., 2013) and isolation deprives children of intellectual stimuli, the lower intelligence of high altitude populations can be attributed to the economic consequences of high altitude. Quite meaningful in this perspective are León & Burga León's (2014, Figure 3) reported higher path coefficients for the altitude → socioeconomic development → CCA link than the altitude → birth rate → CCA link.

Still another relevant variable may be cultural. The Andes Mountains divide the Peruvian territory into Western and Eastern regions. Western slopes fall from 3000 to 6000 m and level-off at the Pacific Ocean coast whereas eastern slopes level-off at the flat Amazon rainforest. The 16th century Spaniard invaders adapted better to the coast, which became the Peruvian point of entry for all cultural influences from Europe, and now Amerindian languages are severely diminished on the Western slope of the Andes. Amerindian cultures have been better conserved on the Eastern slope. León and Avilés (2013) showed negative effects of altitude on CCA on both sides of the Andes and reported cognitive effects which were mostly explained by urban versus rural residence, fertility rate, wealth, and school access. However, cultural implications were not discerned.

The study presented here tests the Western and Eastern regions of Peru for several hypotheses that are relevant to the oxygen, UV radiation, economic, and cultural perspectives reviewed above, which were not addressed by the León and Avilés (2013) study. One of the rationales is that cognitive altitude effects found below altitudes of 2300 m are not attributable to insufficient oxygen. Effects of hypoxia could be indicated by a direct influence of altitude on CCA independent of social development and latitude. Confirmation of net altitude → fertility rate → CCA effects on both sides of the Andes would uphold the expectancy that UV radiation affects cognition through family size. Confirmation of net altitude → CCA effects independent of social development below 2300 m of altitude would indicate an influence of dopamine, oxidation, and/or folate. Differences observed in these relationships between the Western and Eastern sides of the Andes would suggest that culture moderates the cognitive influence of the physical variables.

The study also compares the altitude → socioeconomic development → CCA link with an altitude → CCA → socioeconomic development path of causation. The idea is that not only parental socioeconomic status influences child intelligence (Deary, 2012; Nisbett et al., 2012) but also that the level of cognitive ability of a population creates conditions for the generation of wealth (Meisenberg & Lynn, 2012; Rindermann & Thompson, 2011).

2. Method

2.1. Geographical context

Fig. 1 depicts the territory covered, from 5° S to 13° S. In Peru there are no significant mountains north of 5° S and no significant Amazonian plains south of 13° S. The division of western and eastern slopes was reached based on the origin of the rivers going to the Pacific versus the Atlantic Oceans (the latter via Amazonian tributary rivers).

2.2. Subjects

The data base used is a portion of that utilized by León & Burga León (2014), which covers districts from 0° 02′ to 18° 21′ S. The cognitive data originated from a national census carried out in 2011 by the Peruvian Ministry of Education that obtained Math and Reading scores from 506,347 children in 2nd grade of primary instruction, i.e., aged approximately eight years of age (51% boys, 49% girls). Districts were the units of analysis ($N = 1073$).

2.3. Measurements

2.3.1. Complex cognitive ability

Reliable Math ($\alpha = 0.89$) and Reading ($\alpha = 0.87$) scores correlated 0.89. The data set was lent by the Peruvian Ministry of Education.

2.3.2. Physical variables

Altitude and latitude data were obtained from the Peruvian Ministry of Education online portal. We used the map of Peruvian Administrative Regions of Fig. S1 available at Online Supplementary Material to measure access to sea, assigning 3 points to regions on the Pacific Ocean coast, 2 points to regions separated from the sea by one region, and 1 point to those separated from the sea by two or more regions.

2.3.3. Social variables

We replicated the León & Burga León (2014, p. 293) procedures: "The student census database supplied information on the number of children enrolled at a school, whether the school was private or public, whether it had one or several teachers, and the proportion of female students. Income, education, and life expectancy were reported at district level by the Peru 2009 Human Development Report (PNUD, 2010). Per capita family income of the report was calculated in national currency (actually, expenses). Educational achievement per district of the report is an average of literacy and school attendance; the latter was calculated as the percentage of the population between five and 18 years of age attending school. Life expectancy of the report was calculated considering the infant mortality rate. We obtained from the 2007 National Census (INEI, 2008) a family size index calculated per district as the average number of children ever had by men and women."

2.4. Analytic strategy

The statistical analyses were conducted separately in four data sets: Western region below 2300 m, Western region above 2300 m, Eastern