PHYSICAL CONNECTEDNESS AND BODY HEIGHT

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*Recent evidence suggests that social networks play an important role in the regulation of adolescent growth and adult height. We further investigated the effect of physical connectedness on height. We considered Switzerland as a geographic network with 169 nodes (district capitals) and 335 edges (connecting roads) and studied effects of connectedness on height in Swiss conscript from 1884-1891, 1908-1910, and 2004-2009. In 1884-1891, in 1908-1910, and in 2004-2009, 1st, 2nd and 3rd order neighbouring districts significantly correlate in height (p<0.01) indicating that height in a district depends on height of physically connected neighbouring districts. The strength of the correlation depends on the order of connectedness, and declines with increasing distance. The present data suggest that people can be short because their neighbours are short; or tall because their neighbours are tall (*community effect on growth*). The vision adds a new dimension to the current concept of growth as a mirror of health and economic prosperity.*

Keywords: *body height, connectedness, community effect, conscripts, Switzerland*

There are two contrasting aspects of human growth and final height in modern auxology: there is the idea of growth as a target-seeking process regulated by genes, nutrition, health, and the state of an individual's social and economic environment – optimal conditions are expected to result in the achievement of a person's maximum height reflecting full genetic potential [Tanner, 1986] – and on the other hand, there is the observation that historic populations even under apparently prosperous socio-economic circumstances, were significantly shorter than today. European populations of all social strata have increased in height by some 15-19 cm since the mid-19th century [Komlos, 2009; Schönbeck et al., 2013].

There are good arguments for the assumption that some steady improvements of living conditions, food, health, and modern environment, must have led to the observed rise in recent European adult height [Hermanussen, 2013]: the implementation of modern health surveillance systems, the successful fighting against most infectious diseases, elimination of starvation, and the improvement of socioeconomic conditions particularly of the lower social classes since the first half of the 20th century in most European countries.

But, this view has also been questioned. Height increases of some 15-19 cm within little more than 100 years appear to be far beyond that expected by simple improvements in nutrition. Except for the time before 1870 and during and shortly after World War I and II, the affluent members of the urban European societies never experienced food shortages or major nutrient deficiencies. Grandmothers cooking books provide unquestionable examples. Yet, the 19th century societies were short. Also chronic illness fails to appropriately explain significant effects on final height. E.g. Aswani and co-workers [Aswani et al., 2003] showed that cystic fibrosis (CF) patients grew poorly at all ages, but eventually achieved normal final height. Wiedemann and co-workers [Wiedemann et al., 2001] stated that in a group of 4.306 CF patients, the initially low height SD scores increased with age, and normal height was reached in the adult age group. There is no evidence that other chronic pulmonary diseases such as tuberculosis which used to be endemic in the 19th century, might have led to growth impairment similar or exceeding that seen in cystic fibrosis. Several short stature historic European regions suffered from iodine deficiency [e.g. Staub, Rühli, 2013], but also historic societies with no impairment of iodine sustenance e.g. living in coastal regions, were short in those days.

In the nineteenth century, all European people were short compared to their modern descendants

[Komlos, 2009]. In 1863, the average Dutch conscript reached 165 cm [Schönbeck, 2013]. Less than 1% of these conscripts reached 184 cm, the mean body height of modern Dutch men [Fredriks et al., 2000]. Thirty percent of the historic Dutch conscripts stayed below 157 cm in height which is more than 3.5 standard deviations below the modern average. Height distributions of European conscripts shifted *in toto*, with surprisingly little overlap between historic and modern height: height tends to cluster.

But who sets the target for final height? What mechanism produces the catch-up of the short migrant child in the new surroundings? Why was adolescent height gain in the late 19th century so mingy? Why were the wealthy subjects in the late nineteenth century closer to the late nineteenth century average height than to the height of their modern descendants, and even shorter than the underprivileged subjects of today? Was it nutrition? Was it health? Was it the socioeconomic situation? What mechanism keeps individual height so close to average height? These questions matter. Physical growth and attained body height belong to the most delicate biological parameters for estimating health and economic prosperity in developing countries; they are of major importance for everyday paediatric decisions.

Recent evidence suggests that the social network may be an important factor in the regulation of adolescent growth and adult height (*community effect on growth* [Aßmann, Hermanussen, 2013]). We further analyzed this phenomenon in large cohorts of Swiss military conscripts. Switzerland is small and separated from the neighbouring countries by several mountain chains rising to more than 4500 meters with great river valleys in between. Politically it is divided into 26 independent cantons and each canton, into districts. Two thirds of the population speak German, about 20% French, about 7% Italian and less than 1% Romansh in the canton of Graubünden. The distinct internal geographic and language barriers in combination with long term political stability make Switzerland an ideal region for studying the effect of physical connectedness and disconnectedness on body height.

In order to study the relationship between growth and characteristics of geographic connectedness within the Swiss society, we used data from military conscript. Annual documents of nation-wide military conscription are available since 1874 [Staub et al., 2011, Panczak et al., 2013]. The data were obtained in 1884–1891, in 1908–1910 [Schweiz. Statistisches Bureau 1910, 1885–1892] and in 2004–2009 at the district level provided, in anonymised form by the Swiss Army [Staub et al., 2012/2013]. Swiss conscription has been mandatory and standardized since 1875 and the measurement procedure for height has not changed. The measurements are taken under medical supervision, and the records also include the height of those young men subsequently exempted from military service. It has been shown that during the late 19th century the conscript subpopulation and the 19-year-old-male-resident census subpopulation were almost identical [Staub et al., 2010]. Height data from Swiss conscription remain a reliable source for population studies; the 2004–2012 Armed Forces census still represent over 90% of living young male Swiss citizens [Panczak et al., 2013].

We then formed an idealized geographic network of Switzerland consisting of 169 nodes (district capitals) and 335 connecting edges (direct road connections) (Figure 1), and analysed conscript height in respect to geographic vicinity [Hermanussen et al., 2014]. First order neighbours within this network are district capitals with direct road connections, second order neighbours are district capitals that are not directly connected, but can be reached by passing through an interposed district capital.

District height clusters within the geographic network of Switzerland: conscripts from first order neighbouring districts are similar in height. Similarity in height even extends to second and higher order neighbouring towns. We found significant height correlations between 1st, 2nd and 3rd order neighbours in 1884–1891, in 1908–1910, and in 2004–2009 ($p<0.01$); in the 2004–2009 cohort we found significant correlations in height up to 4th order neighbours. I.e. short stature districts tend to have short, tall stature districts tend to have tall neighbours. Also height increments cluster. Some districts increased in average height by 18.5 cm since the end-19th century (e.g. Bühler), others by little more than 10 cm (e.g. Cevio). We found large secular height increments in the neighbouring mountain districts around Bühler, and the opposite in the mountainous neighbourhood of Cevio. The data indicate that also trends in height depend on connectedness.

At first view this may not surprise. Neighbour districts share similar socio-economic and disease environments. In order to further investigate the potential impact of environmental confounders on apparent connectedness, we studied height and connectedness in exponential-family random graph models. Analogue to the Swiss network of real roads and cities, we created virtual networks that also consisted of 169 nodes and 335 edges. In contrast to the real Swiss road map, the cities of the virtual networks were connected at random by 335 «fantasy»

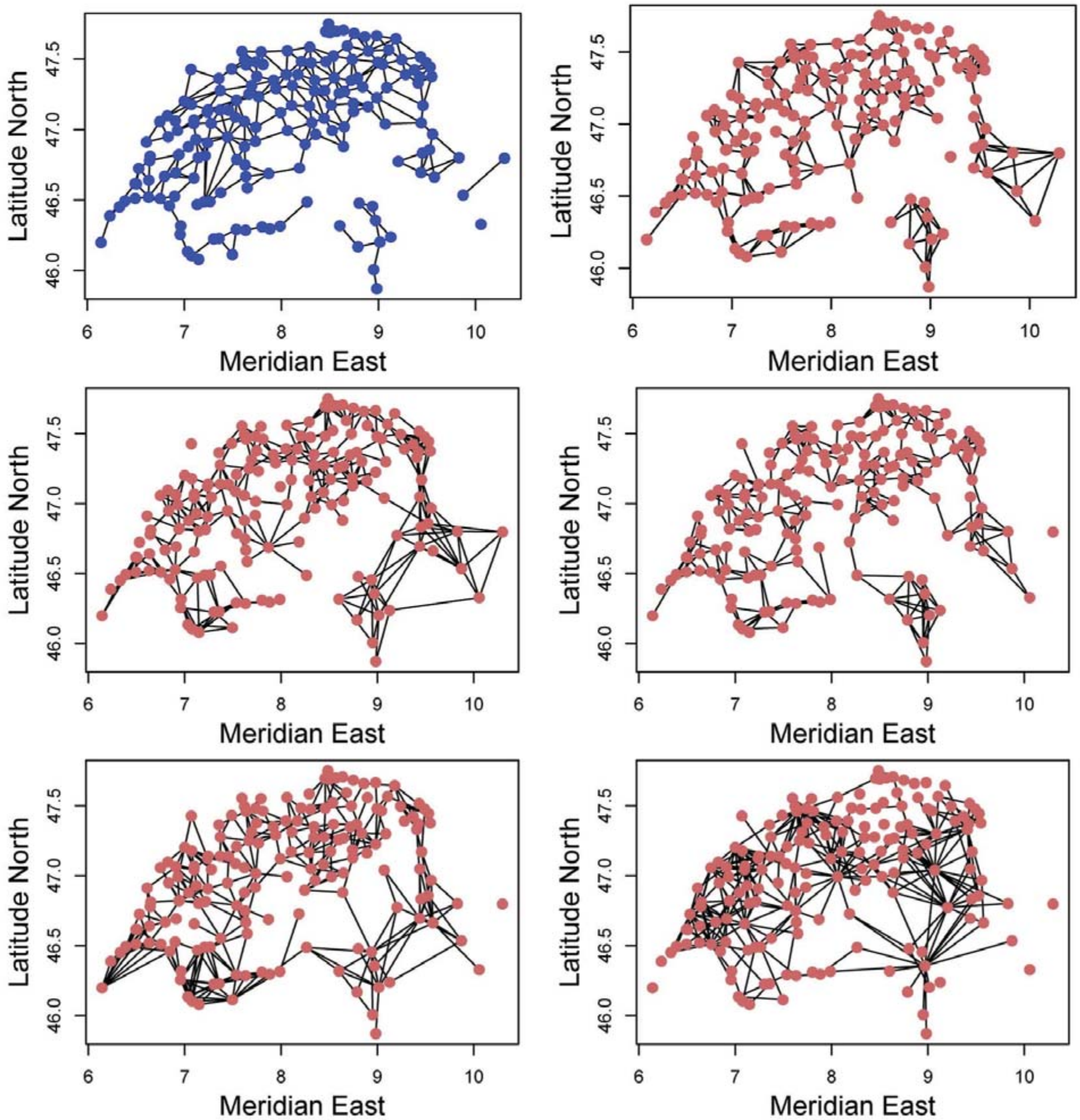

Figure 1. Idealized Swiss road map network (blue), and representative examples of random networks (brown) that randomly connect the closest 6 (upper right), 8 (centre left), 10 (centre right), 12 (lower left) or 20 neighbours (lower right). Real people usually construct roads between neighbouring cities. *N neighbour* networks thus do not only consist of random «fantasy» connections but also of really existing roads. *n=10 neighbour* random networks are similar to the real Swiss road map in terms of average city-to-city distances, but only contain 40-44% real roads (centre right).

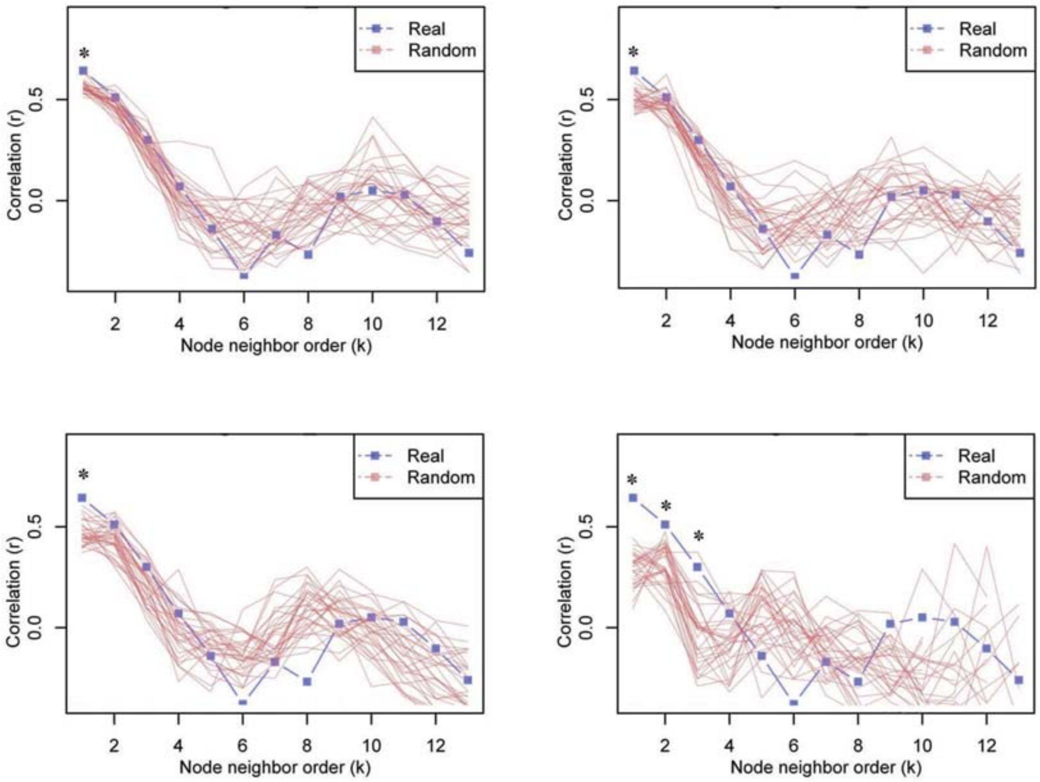

Figure 2. The correlation of average district height in the idealized Swiss road network of 335 roads and 169 district capitals (blue, cohort 1884–1891) and in 30 random networks (brown) connecting the closest 6 (upper left), 8 (upper right), 10 (lower left), and 20 (lower right) neighbours. The present statistics is based on random networks connecting the closest 10 neighbours (lower left). Asterisks indicate significant differences of height correlations between the random networks and the Swiss road network of 1884–1891. Height-height correlations between first order neighbouring districts are stronger along the real roads (blue) than along the «fantasy» roads in the random networks.

roads. Using this approach, we were able to separately investigate effects that were transmitted via the really existing roads.

In an *all neighbour approach* we totally ignored the true geographic locations of the cities and the Euclidian distances between them, and randomly connected any district capital with any other district capital. In this «fantasy setting», Bern could become a 1st order neighbour of distant cities like Poschiavo. In the *all neighbour approach* there were no associations between height and connectedness. In the subsequent *n neighbour approaches* we did pay though partial attention to the geographic location, and randomly connected district capitals between the n geographically closest neighbours. Whereas the *n neighbour approach* pays attention to the geographic location of each city, it still ignores the mountain ranges and interposed lakes. Thus it essentially differs from the real Swiss road map (Figure 1).

Figure 2 illustrates height correlations in virtual *n neighbour approaches*. Height correlations increase in virtual *n neighbour approaches* with increasing vicinity (decreasing n) of the neighbours (height correlations in n=20 < height correlations in n=10 < height correlations in n=8 < height correlations in n=6). But virtual or «fantasy» road maps do not completely differ from real road maps. *n neighbour* networks rely on geographic vicinity, but also the real roads are constructed between neighbouring cities. *n neighbour* networks, thus, never consist of only random connections, but also include the really existing roads. n=6 random neighbour networks contain more than 60% real roads. This implies a dilemma. There is no random network that both looks perfectly like a Swiss road map, and in the same instant, lacks real city-to-city connections. We therefore decided to use a compromise, and worked with *n=10 neighbour* random networks; *n=10 neighbour* random networks are similar to the real Swiss road map in terms of average city-to-city distances, but only contain 40-44% real roads.

We find *direct road effects* on growth. Height-height correlations are significantly stronger along real roads than along «fantasy roads» (Figure 2). It is interesting to note that the magnitude of the *direct road effects* on body height depends on the historic context: in 1884–1891, *direct road effects* were only visible among 1st order neighbours. In 1908–1910, the *direct road effect* extended to 2nd and 3rd and in 2004–2009 also to 4th order neighbours (not shown). This might reflect that in the late 19th century, transportation facilities were limited and worked at shorter distances than today. Also the secular increments in height depend on road connections. The secular trend in height since 1884–1891 is more similar in districts along real roads than along «fantasy» roads in the virtual networks, suggesting *direct road effects* also in height trends.

Everybody is connected. Not only psychosocial information [Auhagen, Salisch, 1997], also smoking [Christakis, Fowler, 2008], drinking behaviour [Rosenquist et al., 2008] and even biological parameters such as body mass index have been shown to be transmitted through social networks [Christakis, Fowler, 2007]. Observations in migrants [Bogin et al., 2002] and in formerly isolated island populations [Rebato, 1998] who physically merged due to increasing mobility and later also assimilated in height suggest that connectedness may even affect bodily growth. The present data suggest that people can be short simply because their neighbours are short; or tall because their neighbours are tall (*community effect on growth*, [Aßmann, Hermanussen, 2013]). Further research is necessary as the biological mechanism of this effect is not understood.

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ФИЗИЧЕСКОЕ ОКРУЖЕНИЕ И ДЛИНА ТЕЛА

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Недавние исследования показывают, что социальные взаимосвязи играют существенную роль в регуляции подросткового роста и размеров тела взрослого. Настоящая статья продолжает наши исследования в области изучения влияния физического окружения на длину тела. Швейцария рассматривается как географическая сеть со 169 узловыми центрами (районные центры) и 335 границами (соединяющие дороги). Эффект физического окружения на длину тела изучался по материалам обследования швейцарских новобранцев 1884–1891, 1908–1910 и 2004–2009 гг. В 1884–1891, 1908–1910, и в 2004–2009 гг. длина тела новобранцев из соседних районов 1го, 2го и 3го порядка обнаруживала достоверную корреляцию (p<0.01), свидетельствуя о том, что длина тела населения в данном районе зависит от соответствующих показателей в соседних районах.

*Величина корреляционных связей зависит от того, насколько близко расположены районы и убывает пропорционально расстоянию между ними. Полученные данные показывают, что люди могут быть невысокими, потому что их соседи невысокие, и наоборот – высокими, если их соседи высокие (*эффект сообщества*). Эта концепция добавляет новое измерение к современному взгляду на рост как зеркало здоровья и социально-экономического процветания.*

Ключевые слова: *длина тела, окружение, эффект сообщества, новобранцы, Швейцария*