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Growth and maturity: A quantitative systematic review and network analysis in anthropometric history

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ABSTRACT

This paper reviews the current wealth of anthropometric history since the early efforts of Robert Fogel in the 1970s. The survey is based on a quantitative systematic review of the literature and counts a total of 447 peer-reviewed articles being published in the main leading journals in economic history, economics and biology. Data are analysed using network analysis by journal and author and the main contributions of anthropometric history are highlighted, pointing to future areas of inquiry. The contributions of books and book chapters are also quantified and analysed.

1. Origins of anthropometric history

Almost four decades ago, a group of historians led by Robert Fogel began to explore the potential of anthropometric measurements (principally, records of human height and weight), for answering a range of historical questions, largely, but not limited to, those concerning health and wellbeing.[1] Height, a useful indicator in historical research, especially in circumstances where data on more conventional or modern indicators are lacking, is a cumulative measure of conditions affecting the life of the individual throughout the growth period, and is affected by the quality and quantity of an individual's diet, and by the demands placed on the body's resources by exposure to disease and the use of energy for play and work. Despite genes being very important at the individual level (around 80% of the height component is genetic), nutritional and environmental conditions from conception to maturity determine which or how much genetic potential is realised during development (Tanner, 1978).[2]

The controversy which surrounded the publication of *Time on the Cross* (Fogel and Engerman, 1974) provided the basis to begin working on the examination of mortality decline in North America between 1650 and 1910, in which Fogel and a long list of collaborators argued that height data derived from Civil War records could be used to examine the extent to which changes in mortality were associated with food supply (Fogel et al., 1978).[3] They showed that increases in average heights paralleled improvements in mortality rates and economic performance and were content to use height as an indicator of nutritional wellbeing.

Due to the potential utility of these records for addressing the long-running controversies in economic and social history, from the 1970s the use of anthropometric data constituted a

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[1] Although the first historians to make any significant use of anthropometric evidence within a large population were Le Roy Ladurie et al. (1969), it is arguable that it was Fogel's work that first made use of anthropometric sources for comparative purposes in the study of economic and demographic history.

[2] While height primarily accounts for conditions of health during the growing years (chiefly, there are two peaks of rapid growth in a well-nourished child: the first immediately after birth and a second, the so-called "growth spurt," at the advent of adolescence), weight is a more immediate measure of nutritional status than height. Weight responds most quickly to changing nutritional levels and in the absence of adequate nutrition, a child first slows in weight gain, and if the deprivation is of long enough duration, stature is also affected.

[3] The controversy was due to the threat to the conventional interpretation of slavery. Fogel and Engerman argued that American slaves were much better treated and possessed greater physical and psychological wellbeing than previously believed. For a critique see Sutch (1975).

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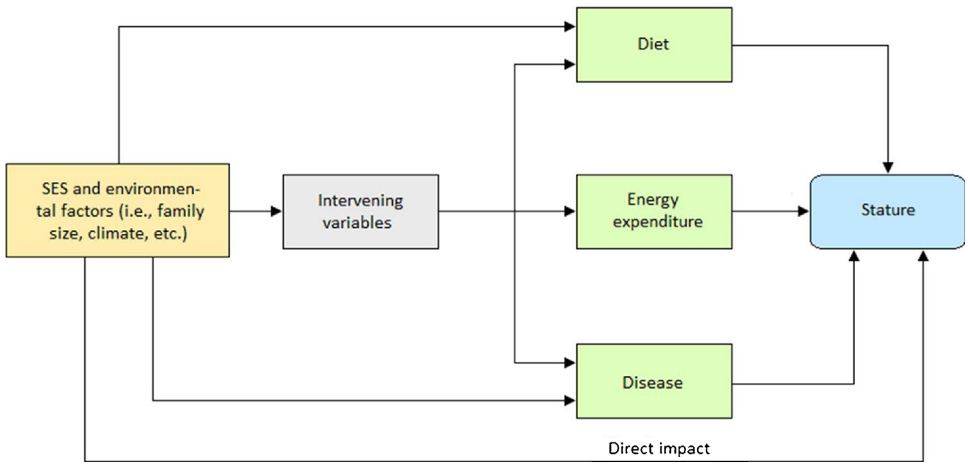

Fig. 1. Flow diagram of the conceptual framework.

springboard for research into long-standing debates such as the health of the slaves in the antebellum US South (Steckel, 1977). Meanwhile, such investigations have spawned many other inquiries and the publication of height statistics for a large number of other countries around the world, though not always for exactly the same time periods.

The number of height investigations started to intensify during the 1980s. Most notably, Floud and Wachter started an investigation on the heights of nearly 50,000 poor London children of the Marine Society in 1982 (Floud and Wachter, 1982), which, later, using also records from the Royal Marines and the British Army, was used to explore the living standards during the British Industrial Revolution (Floud et al., 1990). Other scholars started work in Sweden (Sandberg and Steckel, 1987), Spain (Martínez-Carrión, 1986), the Habsburg Empire (Komlos 1985, 1989), India (Brennan et al., 1994; Guntupalli, 2007), Germany (Baten, 1999) and the Netherlands (Drukker and Tassenaar, 1997), just to name a few.

In these studies, a number of factors were found to influence stature. Urbanisation was found to be important, as London urban children and those from other urban centres were likely to be, on average, smaller than those from rural families. However, in other countries and in modern populations, the reverse also appears to be true (Eveleth and Tanner, 1990). For instance, Martínez-Carrión and Moreno-Lázaro (2007), despite discovering that early 19th century men living in rural areas of Castile-Leon (in Northern Spain) were taller by 0.5 cm and could expect to live 5–6 years more than those living in urban areas (Pérez Moreda et al., 2015), also found that across the 20th century a reversal occurred. When urban centres began the fight against mortality, with public health interventions, sanitary reforms and new investments in infrastructure, around the 1920s and 1930s, the *urban penalty* fell and living in a rural area was no longer a better option in terms of health and longevity. There is also evidence of 19th century poor health in Italian and Dutch towns and cities as breeding grounds for diseases, with a reverse thereafter (A'Hearn, 2003; Drukker and Tassenaar, 1997).

The level of diseases and infection also stunted growth. Malaria, which nowadays accounts yearly for more than one million deaths worldwide, has a greater effect on morbidity than mortality, weakening the immune system of individuals and raising susceptibility to other diseases. For example, Martínez-Carrión (1994) observed that in 19th century Murcia (Spain), the shortest recruits were born in the countryside where malaria was more endemic. Hong (2007) reported that Union Army veterans who spent their childhood in the most malarial counties of the US were nearly 3 cm shorter at enlistment than those who grew up in the least malarial county. Whilst malaria is a major killer disease, it actually infects many more people than it kills, and has important consequences for the health of the survivors. Scrimshaw and SanGiovanni (1997) also found that disease and infection interplay with nutrition as protein absorption is reduced by 10–30% (and sometimes by as much as 40%) in children with diarrhoea.

There are also important height differences by social class. In pre-industrial London, at the age of 13, poor boys from the Marine Society were shorter by nearly 16 cm compared to rich boys from the Sandhurst Academy, widening the gap to 22 cm at the age of 16 (Komlos, 2007). Hence, average height varies with social class, infection load and socio-economic position, between nations and over time, in a way that clearly shows that a wide range of social, economic and environmental factors influence human growth. Baten and Mumme (2013) have studied inequality of height over the past two centuries and found that it increases civil war probabilities. Baten and Blum (2014) also find that in a global comparison changes in stature due to nutritional quality are dependent not just on the pre-existing income levels but also on agricultural specialization such as dairy farming. There is also a close association between height, weight and the risk of dying at each age. In the 1980s, Waaler found that height was inversely related to the risk of mortality from tuberculosis and cardiovascular diseases (Waaler, 1984). Floud et al. (1990) also discovered a close correspondence between the timing of the increase in stature in the 19th century Britain and the onset of the improvement in age-specific mortality rates.[4] Additionally, using the Union Army data, Fogel also found that individuals who were shorter and had a lower BMI also suffered from higher prevalence of chronic diseases, revealing an association between height and morbidity.

It is possible to see in more detail the different ways in which each of the factors outlined above can influence stature using a new conceptual framework (Fig. 1). As already seen, height is a measure of net nutrition and, as such, it reflects the impact of both diet, disease and work intensity. Well-nourished children tend to be taller than those undernourished and those who grow up in a disease-free environment tend to be taller than those who develop in a more disease-ridden environment. Whether the diet of a particular individual is nutritionally adequate also depends, in part, on the level of energy expenditure including work load. In turn, these proximate determinants (highlighted by green boxes),

[4] Health represents more than the absence of ill health and only a small proportion of diseases result in premature mortality.

are themselves related to a variety of social, economic and demographic 'intervening variables', which might modify the relationship between these proximate determinants and stature.

Let me provide two examples of how this conceptual framework works. As discussed by Hatton and Martin (2010a,b) and Bailey et al. (2016a) family size is one factor affecting stature, which determines how food is allocated differently across siblings depending on the number of siblings under the same roof. Crowded houses are also exposed to a higher transmission of infectious diseases and, as stressed by Humphries (2010), historically the number of siblings determined which siblings go to school or to work. Hatton and Martin (2010a,b) also showed a direct impact of family size on stature; insofar older siblings affect the life history of younger siblings with large families having a greater influence on the last birth (relative to births at lower parities). Finally, family size can influence other factors which may themselves affect stature. For example, being born into a wealthy family might mitigate some of the negative effects of family size on growth.

Another example to read Fig. 1 is through the impact of climate on stature. Weather and climate determine the cultivation of crops and the availability of food, being agriculture the main source of nutritional intake. However, climate is also connected to some vector-borne diseases such as diarrhoea, cholera and malaria. Periods of abundant rainfall can also cause flooding, creating conditions ideal for the transmission of water-borne diseases and food-borne infections, inhibiting the proper digestion and absorption of nutrients. Climate can also affect stature directly, for instance, Sharpe (2012, p. 1485) noted that "in cold weather energy is preferentially used to generate heat rather than for growth", and lack of sunlight hours, having vitamin D a strong influence on the growth rates, also stunt growth. She also observed that in 19th century Britain children were stunted because the effects of urban pollution denied them access to sunlight (Sharpe, 2012). These influences might also be altered by some 'intervening variables'. Torrential rains might damage infrastructures and transport networks reducing trade and increasing food shortages. This might lead to population movements or conflicts over the distribution of resources. Some other intervening variables may also confound the relationship between climate and stature, insofar as changes in the relationship between height and climate may reflect geographical changes in the distribution of wealth, which are themselves associated with climatic variables. For example, if wealthier people migrate to warmer regions, their children will be taller, but the height of the children might reflect the wealth of the parents more than the warmth of the climate.

This paper surveys the current historical height literature by systematically reviewing the literature, and suggesting further lines of enquiry. For previous qualitative assessments see Komlos (1994a), Harris (1994), Floud (2002), Komlos and Baten (2004), Inwood and Roberts (2011) and Floud et al. (2011, 2014). See also Steckel (1995), for a review of the papers published between 1974 and 1994 and Steckel (2009) for a review of the papers published from 1995 to 2008.

The paper makes four contributions. The first contribution is a quantification of the literature used by anthropometric historians in terms of papers, books, book chapters, and other editorial material. Since most of the resources used in the literature are papers, the first contribution is a quantitative systematic review of the literature. For this review, the main journals publishing papers on anthropometric history have been selected and the main papers analysed. The second aim is to use network analysis to discuss patterns between article publications and citations. For each journal, the main information on citation and co-citation has been extracted from Web of Science (WoS) (Section 2) and analysed quantitatively (Sections 3 and 4). The third aim is to quantify the contribution of books in the literature (Section 5). This is indeed an important contribution, as the majority of the systematic reviews of the literature omit books and book chapters. The fourth aim is to discuss the current debates and wealth of the height literature (Section 6), suggesting further areas of enquiry (Section 7).

Table 1
List of Journals and Acronyms used, Number of papers being selected in parenthesis.
Notes: The papers published in the journal *Research in Economic History* are considered as articles instead of book chapter.

Journal (number of papers selected)
American Journal of Human Biology (AJHB, 21)
Annals of Human Biology (AHB, 56)
Australian Economic History Review (AEHR, 9)
Cliometrica (CLIO, 10)
Continuity and Change (C&C, 2)
Demography (DEM, 7)
Economics and Human Biology (E&HB, 118)
Economic History Review (EHR, 35)
European Review of Economic History (EREH, 9)
Explorations in Economic History (EEH, 38)
Historical Methods (HM, 19)
History of the Family (HF, 13)
Journal of Development Economics (JDE, 1)
Journal of Economic History (JEH, 38)
Journal of Health Economics (JHE, 5)
Journal of Interdisciplinary History (JIH, 26)
Oxford Economic Papers (OEP, 2)
Research in Economic History (REH, 7)
Revista de Historia Económica (RHE, 11)
Social Science History (SSH, 19)

2. Data extraction procedure

Data extraction followed a three-step procedure[5]:

(1) The first step was to identify journals in economic history, economics and biology that regularly publish papers in anthropometric history. Table 1 below shows the selection of journals.[6]

(2) From these journals papers were only selected if they used height, and where possible weight and other anthropometric indicators, to explore key aspects of humanity's past; in particular, the health and wellbeing of past generations. Some methodological papers of interest were also included.

(3) Finally, once a comprehensive list of papers had been made, WoS was used to depict the details of each paper in terms of citations and co-citations, the basis of the network analysis.

For the first step, a total of 20 journals were shortlisted (Table 1).[7] For the second step, papers were selected manually by examining the details of the abstract (data accessed 20 May 2017), and papers that used height or other anthropometric indicators as variables of interest but were not relevant for the debates in economic history were excluded. Most exclusions occurred because they use only modern medical surveys such as the

[5] A first version of the paper attempted to locate papers directly from WoS. The idea was to use a 'search criteria' that would help to narrow the list of papers and identify papers in anthropometric history. For instance, some combinations such as "height AND health AND anthropometric history", "height AND anthropometry AND nineteenth OR twentieth" or "height OR weight AND history" were used. However, the returns using combinations of search terms omitted a large number of relevant papers that were relevant in anthropometric history. Additionally, the list of potential papers was too large to be surveyed (between 8,000–10,000 papers) and included papers outside the boundaries of anthropometric history, mostly papers on development economics using height as an indicator of wellbeing in Africa or Asia. In sum, this avenue turned out to be fruitless.

[6] From the selection of journals two of them published a special issue on anthropometric history: *EEH* (Volume 46, Issue 1, 2009) and *SSH* (Volume 28, Issue 2, 2004).

[7] The absence of studies published in political science and sociology journals remains somewhat puzzling.

Demographic Health Surveys (DHS). This was mostly the case of papers in biology and development economics journals. Despite being useful for extending historical trends in developing countries to recent decades, the DHS 'only' provide information on individuals who had achieved their mature height in the 1990s and born after the 1940s-1950s. Additionally, the use of DHS data, which contributes to a different literature (biology but also development and health economics), would require the addition of a significant number of papers unrelated to anthropometric history and debates in economic history. For instance, there are 2,530 articles listed on the DHS Program website making use of primarily DHS data, and none of the papers come from an economic history journal (data accessed 21 September 2017).[8] The total number of publications estimated by the systematic review of anthropometric history amounted to 447 papers, and the complete list of references being used is available in the online Appendix A1.

To perform a network analysis of the height literature, the title of each paper by the journal's name was inserted in WoS. WoS returns information on the number of citations and co-citations. However, while this is a valuable source of information, there are several limitations worth noting. First, WoS only considers journals that appear in the WoS Science Citation Index (SCI). While journals in SCI are typically the most consistently high impact titles in scientific disciplines, some important journals that published interesting papers on anthropometric history are omitted.[9] For example, *Revista Historia Agraria* (RHA) is omitted from the survey. Additionally, WoS only considers papers in journals edited in English. Hence, *Revista de Historia Industrial* (RHI) and *Jahrbuch für Wirtschaftsgeschichte* are also omitted. These journals have been publishing papers on anthropometric history and the two above Spanish journals have published a special issue on the topic.[10] Yet, it might be also argued that these journals are biased towards a group of scholars and countries (Spain and Latin America or Germany) and non-accessible to English readers. Regarding books, there is not much literature for non-English readers. For instance, there is not a single book primarily concerned about the anthropometric history of Spain (or another country) written in Spanish.[11]

WoS also omits non-peer reviewed journal publications (this accounts for reviews, notes, meeting abstracts, letters, corrections, book reviews and proceedings and obviously working papers series). However, given the relevance of some of this editorial material, replies and comments have been included as an expansion of a publication or controversy.[12] Books, despite being omitted by WoS, are discussed in Section 5. There are other potential caveats worth noting. When discussing the number of publications by journal one might note that not all the journals began work in the same year. Yet, despite the height literature flourished in the 1970s and 1980s, some journals, such as *E&HB*, began its quest in January 2003.[13] Articles in more recent journals would have a smaller chance of being cited when compared with older journals. While the analysis of this review is based on 20 journals, these being the main outlets in anthropometric history, there are other journals that published important papers and that are not surveyed in this review. For instance, *Economic Journal* and *Quarterly Journal of Economics* published few papers.

Finally, when indexing the papers in WoS from a total sample of 447 papers, 60 of them were initially missing from WoS. WoS was contacted and from the missing 60 papers they updated the details of 39 papers. The reason for not updating the remaining 21 papers is that they are too recent (being published in 2017) or that the details do not appear in their system. These 21 papers missing from the network analysis are marked with an asterisk in the online Appendix A1.

3. Historical height publications

3.1. Number of publications over time

How does this figure of 447 articles compare with previous reviews? The qualitative review made by Steckel in 2009 (which is his most cited paper) found that "since 1995 approximately 325 publications on stature have appeared in the social sciences" (Steckel 2009, p. 1), although, curiously, in the following page he referred to 326 on two occasions and in the bibliography he listed 336 references. Of the list of publications in the bibliography, only 293 concerned peer-reviewed articles. If in the current systematic review of the literature the sample is restricted for the period 1995 and 2008, the current survey counts 177 articles. Additionally, for the period 1970s to 1994 Steckel counted 145 references. For the period 1975 and 1994 the current systematic review of the literature counts 87 articles. Hence between the 1970s and 2008 Steckel found around 470–480 publications (including articles, working papers, books and book chapters) and the current survey 264 peer-reviewed journal articles. Why does such a discrepancy exist between the two reviews? Steckel's figures and the results of this survey are only comparable to a certain extent. Steckel's qualitative review is a personal review of articles, working papers, proceedings in conferences, and books, rather than a systematic review of peer-reviewed articles. Yet, although there is not a systematic direction in his review, its wealth rests in the informative way he organized and described the main body of material under subject headings, all arranged in alphabetical order, like an encyclopaedia. Hence, the discrepancy exists due to sample design and strategy.

As shown in Fig. 2, which plots the cumulative number of papers over time, the number of height publications has only been increasing since the 1970s. There was a steady constant rise from the early 1970s until around 2003, with an acceleration thereafter. While Steckel (2009, p. 2) argues that "first appearing in 2003, one might think this journal [*E&HB*] alone was the source of the large upswing in height publications. This is not the case, however. Even if all its height articles were removed from consideration, and

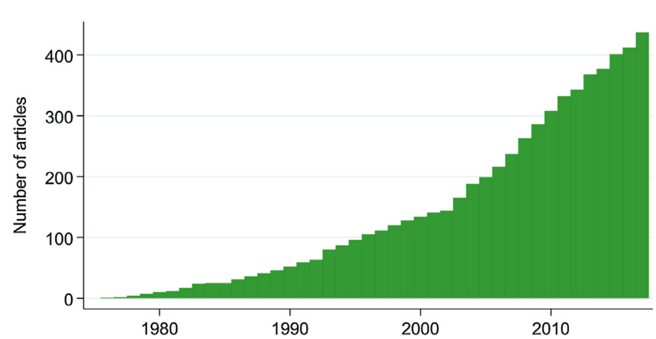

Fig. 2. Cumulative number of publications per year.
Sources: See text. Notes: Only include articles published before May 2017.

[8] For the complete list see http://dhsprogram.com/publications/. There are 3 papers using DHS data published in the *Journal of Family History* and 1 in the *Journal of History and Social Sciences*, but these are clearly not journals in economic history.
[9] For the complete list see http://ip-science.thomsonreuters.com/mjl/
[10] Issue 47 (2009) for *RHA* and Volume 25 and Issue 64 (2016) for the *RHI*.
[11] In *La Conquista de la Salud* (Pérez Moreda et al., 2015) the Spanish authors include a chapter describing heights as a measure of health and wellbeing in Spain (Chapter 7). But the book is not concerned about changes in height.
[12] For instance, the papers published in 1993 in the journal *EHR* following the findings from Floud et al. or the papers on the impact of smallpox on height from Voth and Leunig (1996) (see Section 6.2 for the debates).
[13] Additionally, the number of papers being published in each journal are unequal and also journals published different number of papers across time.

under the unlikely assumption this research would not have appeared elsewhere, the annual rate of height publications since 1995 would decline by only 4.6 articles per year . . . Therefore this new and useful journal reflects a trend, rather than the cause of growing interest in anthropometric research". Yet, while under a counterfactual of no *E&HB* the number of height publications would have continued increasing, it seems possible that this journal accounts for the marked rise in the number of height studies, as since 2003 this journal has published 120 papers (or 26.8% of the total papers since 1975).

3.2. Network analysis of height publications

Fig. 3 displays a bibliometric map of journal publications. The maps are produced in VOSviewer Version 1.6.5. VOSviewer uses network clustering algorithms that calculate the spatial location for each journal by minimizing the weighted sum of the squared Euclidean distances between all pairs of journal citations. Weights correspond to the strength of co-citation, with higher values reflecting a greater tendency for journals to be cited together in the same article. Minimization of the distance between journals is subject to the constraint that the average distance between two items equals 1 (van Eck and Waltman, 2010). Each cluster represents different subject areas and is associated with a colour reflecting communities identified by the VOSviewer clustering algorithm. Three journal clusters are visible in Fig. 3, broadly corresponding with the research fields: biology (yellow), demography and development economics (red), and economic history (green). The first figure (number of publications) displays the total number of articles published by each journal, and the second (number of citations) the total number of citations received in other journals. The third figure (link strength) indicates the connections with papers that have received at least 20 citations, and the fourth figure (normalized number of citations) weighted each citation by the number of papers: that is, if a document cites m other documents, each m citation is weighted by $1/m$.

The single most important outlet in terms of publishing papers in anthropmetric history is *E&HB*, as it is the journal with the largest bubble and occupies the centre of the scape of the diagram, showing, in turn, a good connection with biology journals (yellow

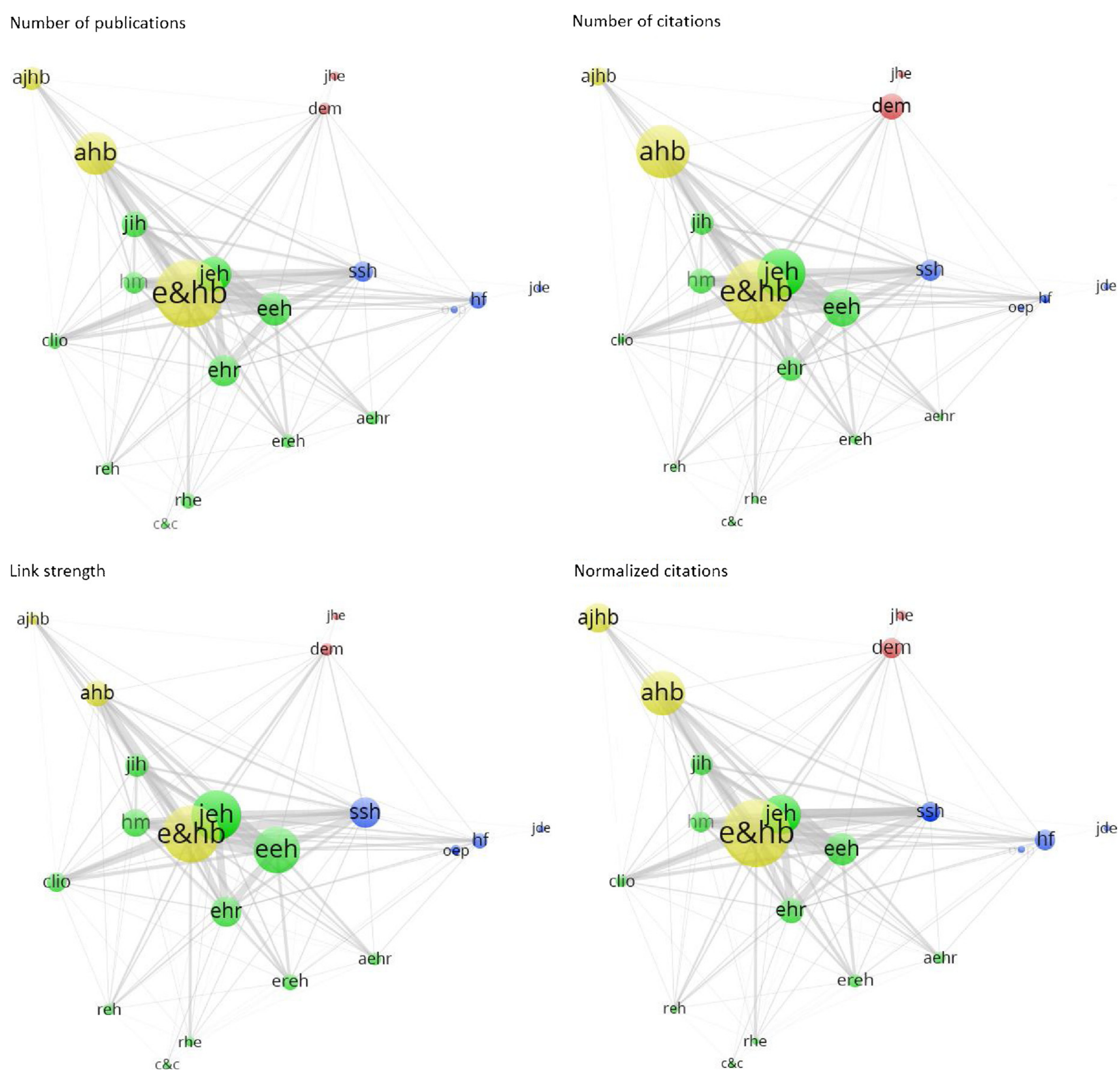

Fig. 3. Number of publications and co-citations by Journal.
Notes: Proximity bubbles corresponds to the frequency with which journals are cited together in other journals. Colours reflect communities identified by VOS clustering. Produced in VOSviewer Version 1.6.5. See text for description of nodes.

bubbles) and with all other journals through thicker links between bubbles. Yet, a look at the number of citations (and normalized citations) shows that *E&HB* loses weight, and although it is the journal that publishes more papers, it is not the journal that recieves more citations. Indeed, the ratio between number of citations over the number of publications shows that on average *E&HB* recieves 16.3 citations per published paper. This is below the number of citations received by the some journals in economic history (for instance papers in *JEH* got 30.1 citations per published paper, 22.7 *HM*, 21.7 *EEH*, 19.2 *SSH* and 17.0 *HF*), below *DEM* (64.4), *JDE* (28.0) and a journal in biology, *AHB* (25.5). It is, nevertheless, above *AJHB* and the other 10 journals listed on Table 1. Similarly, in terms of most cited papers, *E&HB* has three papers in the top 25 publications compared to 5 *AHB*, 4 *JEH* and *DEM*, 3 *EEH* and 2 *HM*. Not surprisingly, a link strength analysis also shows larger bubbles for *JEH*, *EEH*, *SSH*, *EHR* and *HM* as these journals (despite publishing few papers in the height literature) published papers with a large number of citations (above 20). Link strength also shows that this is a general phenomenon for journals in biology, as the size of the bubbles for *AHB* and *AJHB* are also reduced compared to their sizes in the first figure (number of citations).

4. Authorship of publications

It is possible to extend the network analysis to scholars (Fig. 4). John Komlos and Richard Steckel occupy the centre of the diagram and serve as a node to all other authors. Despite clustering being more difficult to identify, yellow bubbles show British scholars or scholars who worked at British universities (mainly Oxford and Cambridge) researching on wellbeing in England since 1750. Red bubbles relate to scholars who collaborated with Robert W. Fogel and green bubbles with scholars that collaborated with John Komlos. Blue bubbles seem to identify a variety of scholars who either worked on a specific country (e.g., José Miguel Martínez-Carrión's work on Spain) or that collaborated with a large number of scholars and research topics.

In terms of publications, John Komlos is the most prolific scholar and his publications alone (39) account for 8.9% of the total publications of the systematic review. 5.8% of the papers included in this systematic review are published by Richard Steckel (26). This list is followed by another American and two German academics: Scott Alan Carson (19), Joerg Baten (18) and Marco Sunder (9), and by a long list of authors such as Deborah Oxley (9) and Kris Inwood (8) with the rest of authors with 7 or less publications. However, there is not a trade-off between the number of publications and citations, and this hierarchy is not maintained when we look at the number of citations and the number of citations per published paper. The most cited author relative to number of publications is Robert W. Fogel (for each publication, on average, he receives 46.6 citations). His most cited paper (168 times) is 'A theory of technophysio evolution', co-authored with Dora Costa. This is followed by Stephen Nicholas (40) and Richard Steckel (36.8). Steckel's most cited paper is his review of the literature 'Heights and human welfare', with 126 citations. Despite Nicholas publishing few papers (4 in total), his paper with Steckel "Heights and living standards of English workers" received 70 citations. John Komlos also get a significant number of citations per paper (32) and out of the top five most cited papers, he authored three of them: "Shrinking in a growing economy?" received 178 citations, "The height and weight of West Point cadets" (135) and "From the tallest to (one of) the fattest" (133). For each paper Roderick Floud received on average 25.3 citations and Joerg Baten 20.9. Yet, some authors who published several papers got few citations such as Scott Alan Carson, that on average receives 9.6 citations per paper. This might be partly explained by the fact that Carson's publications are dated later than those of the other authors. The most cited paper is from Tim Cole "The secular trend in human physical growth" published by *E&HB*

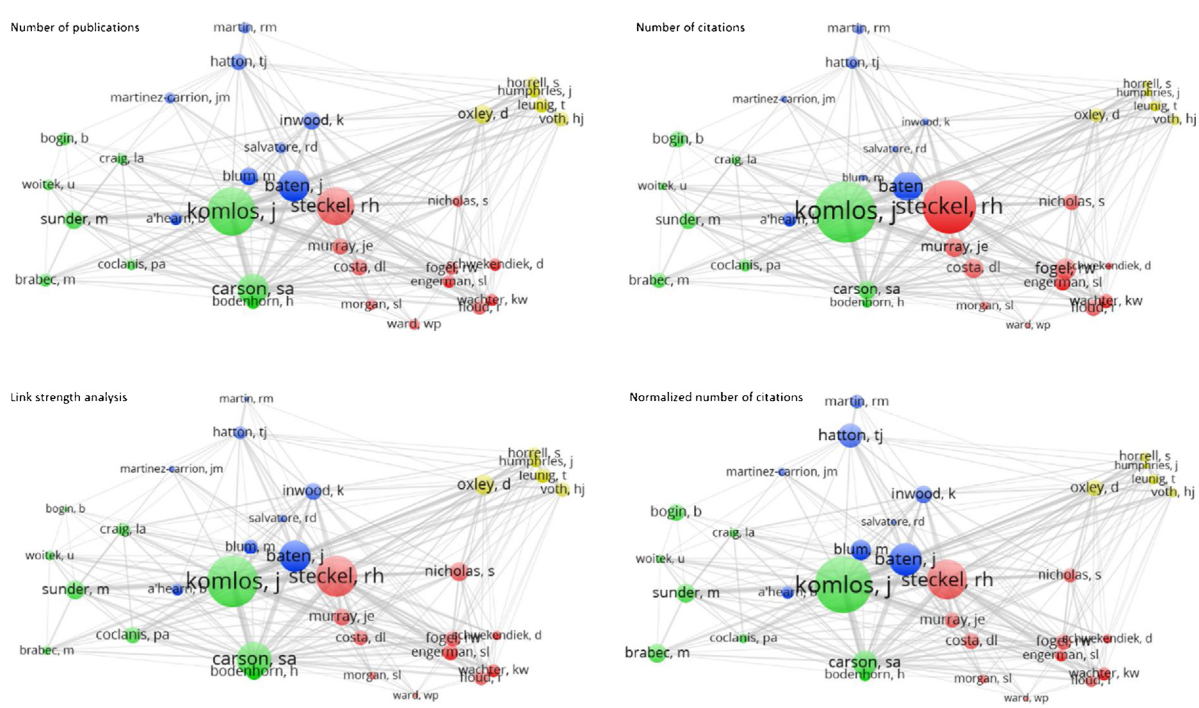

Fig. 4. Number of publications and citations by author.
Notes: Single authored and co-authorship are included. The minimum number of documents of an author is above 4 and the minimum number of citations of an authors is also above 4. Proximity of bubbles corresponds to the frequency with which authors are cited together by other authors. The colours reflect communities identified by VOS clustering. Produced in VOSviewer 1.6.5.

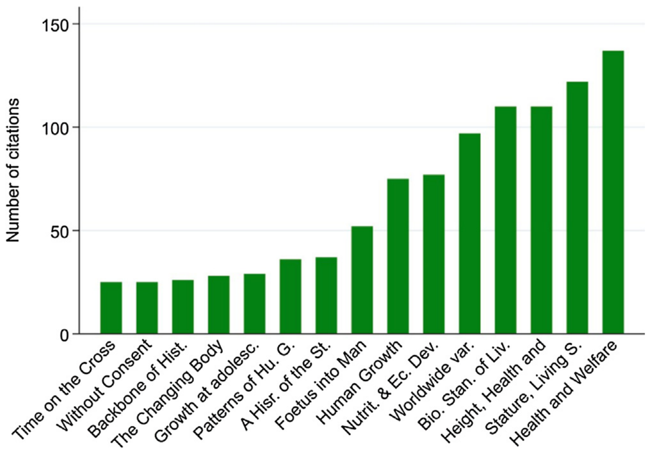

Fig. 5. Number of book citations.
Notes: Figures include numbers of books and book chapters.

with 215 citations, discussing trends in European heights since the mid-19th century.

5. Books and book chapters

It is also possible to quantify the contribution of books, book chapters and other editorial material listed in the paper's references. For each paper listed in the systematic review (n = 447) all references in the bibliography, amounting to 19,554, have been examined. Papers and journal articles represent the main resource in the literature (70.2% of all resources used). Books and books chapters represent 26.6% of the total, with books alone amounting to 18.6%. 2.5% data and archival material, 0.6% doctoral and master dissertation and the rest including press releases and other editorial material.[14]

The main books used in the literature are editorial books coordinating a number of essays. As Fig. 5 shows, the main cited book is *Health and Welfare during* Industrialization (1997), edited by Richard Steckel and Roderick Floud with 137 citations. These ten essays examine the health and welfare during and after industrialization in Western countries. The second most cited book is *Stature, Living Standards and Economic Development* (Komlos, 1994b), edited by John Komlos (with 122 citations), with a collection of essays studying height and weight data from 18th and early 19th century in Europe, North America and Asia. Instead of a collection of essays, the third most cited book is *Height, Health and History* (Floud et al., 1990), written by Roderick Floud, Kenneth Wachter and Annabel Gregory (cited 110 times). In this book, the authors explored the changing heights of Britons during the industrial period, establishing an important dimension to the long-standing controversy about living standards during the Industrial Revolution. The fourth most cited book is *Biological Standard of Living in Comparative Perspective* (Komlos and Baten, 1998), edited by John Komlos and Joerg Baten, collecting 28 essays on changes in height in the Americas, Asia and Australia and Europe.

These main editorial books are followed by books in biology and auxology (the study of human physical growth) mainly edited or written by James Tanner and colleagues. These citations represent the efforts of historians to understand biological data. For instance, *Worldwide Variation in Human Growth* (Eveleth and Tanner, 1976) is a compilation of growth data assembling the details of heights, weight, skinfolds and other body measurements from all parts of the globe. Eveleth and Tanner published a second (and completely rewritten) edition of *Worldwide Variation in Human Growth* in Eveleth and Tanner (1990). The three volumes of *Human Growth, A Comprehensive Treatise* (Tanner and Falkner, 1986) are a collection of essays that bring together the results of many developments of human growth, from postnatal growth to changes in the central nervous systems alongside methodological chapters' explaining how anthropometric data can be used to address different questions about human plasticity. *Foetus into Man* (Tanner, 1978) surveys the basics of growth: cell division, hormonal control and differential growth of body tissues, and accounts for the longitudinal growth of the foetus to the development of sex differences at puberty. Tanner also published a substantially-rewritten version of *Foetus into Man* in 1990.

A History of the Study of Human Growth (Tanner, 1981) traces the history of studies of the physical growth of children from the time of the Ancient Greeks onwards, revealing the potential of surveys of child growth for answering historical questions. Similar to the above books in biology, *Patterns of Human Growth* (Bogin, 1988), accounts for the forces that shaped the evolution of the human growth pattern and *Growth at Adolescence* (Tanner, 1955), for the dynamic process of growth and the complex interplay between genetic and environmental factors.

Between books in biology, the fifth most cited book in the ranking is *Nutrition and Economic Development in the Eighteenth-Century Habsburg Monarchy* (Komlos, 1989), where John Komlos examines the industrial expansion and development of height of the Habsburg empire. Despite the *Changing Body* (Floud et al., 2011) not being the most cited book, if we only account for citations after 2011 (when the book was first published), this is the main book cited in the recent literature, with 1 out of 4 papers published after 2011 including this reference. This book presents an accessible account to the field of anthropometric history, surveying the causes and consequences of changes in health and mortality in the Western world since 1700. The *Backbone of History* (Steckel and Rose, 2002) gathers skeletal evidence on seven basic indicators of health (including stature data) to assess chronic conditions that affected individuals who lived in the Western Hemisphere from 5000 BCE to the late 19th century. Finally, the books *Time on the Cross* (Fogel and Engerman, 1974) and *Without Consent and Contract* (Fogel, 1989) deal with the economic foundations of American slavery.

Although they are not the most cited books, the last few years have witnessed the appearance of a number of important books in the literature. In 2004, Robert W. Fogel published *The Escape from Hunger and Premature Death* (Fogel, 2004). This book shows that despite chronic malnutrition being the norm throughout most of human history, over recent decades improvements in technology and human physiology has enabled humans to more than double their average longevity and to increase their body size. In 2012 he also published *Explaining Long-Term Trends in Health and Longevity* (Fogel, 2012), with a theory and measurement of aging and health-related variables, and explored how anthropometric data helped historical research to reinterpret the nature of economic growth. In 2014, Roderick Floud, Robert W. Fogel, Bernard Harris and Sok Chul Hong edited *Health, Mortality and the Standard of Living in Europe and North America since 1700* (Floud et al., 2014), a two volume book that brings together important and influential articles and papers on different aspects of the history of health and welfare (in total the book collects 76 articles). The introductory chapter in the first volume is a clear and accessible account of anthropometric history and changes in health and mortality over time.

Last year, John Komlos and Inas Kelly edited the *Oxford Handbook of Economics and Human Biology* (Komlos and Kelly,

[14] In the discussion of books, number of books citations include direct citation to a book or a citation to a book chapter.

2016), with a collection of 38 essays showing how economic conditions can affect human wellbeing and how human health influences economic outcomes (for a review see Harris, 2017). Also in 2016, Joerg Baten edited *A History of the Global Economy* (Baten, 2016), with a collection of 22 essays about the welfare development of the global economy. Another relevant book in the height literature is *The Great Escape* (Deaton, 2013), where Angus Deaton contributed to the big question of why some people are healthier, wealthier and live longer. He argues that about 250 years ago, some parts of the world experienced sustained progress, opening up a gap and setting the stage for today's disproportionately unequal world. Finally, a couple of books also traced the evolution of heights in Latin America. *Living Standards in Latin American History* (Salvatore et al., 2010) is a collection of 8 essays exploring the development of heights mainly in Argentina, Brazil and Mexico going back to 19th century and in *Measuring Up*, Moramay López-Alonso (2012), discussed her highly contrasted height estimates for Mexico going back to the colonial era.

6. Main contributions

6.1. Main contributions in anthropometric history

As commented by Floud et al. (2011) and Hatton (2014), the most important finding in anthropometric history is that since 1850, or over the course of some 6–7 human generations, heights in Europe and North America have progressed into previously uncharted territories. For instance, Spanish men grew from 162.21 to 175.30 cm (or 1.01 cm per decade) and Dutch men, being today the tallest in the world, from 166.52 to 182.70 (1.24 cm). Better diets, a lower frequency of sickness, better access to sanitation, healthcare and medical technology, along with shorter workdays and improved family and housing conditions in less polluted cities, also permitted longer lives.[15] Not surprisingly, the average life expectancy at birth also skyrocketed, with Dutch life expectancy between 1850s and 1990s increasing form 36.56 years to 77.77 years (or 2.75 years per decade). These developments also led to a much more crowded planet and between the 1850s and 1990s the Dutch population increased by a factor of 4.78.[16]

Yet, there is a need to stress that in less wealthy parts of the world these improvements have been less spectacular –if we can talk in terms of improvements. For instance, in India between the 1850s and 1970s heights increased from 161.99 cm to 164.82 cm (or 0.22 per decade) and in Ghana heights increased from something near 167 cm to 168 cm between the 1880s and 1960s. Today life expectancy in these countries is also far below Western standards: by 2014, life expectancy was 68 years in India and 61 years in Ghana.[17] Hence, although there is a large literature showing that wealth and income inequality between countries declined in recent decades (Sala-i-Martin, 2006), the gains in health have been by far more unequal.

Anthropometric history also offered new insights into dense areas by old means of research.[18] Although most papers overlap with two or more categories, a thematic review of the height literature shows that the majority of papers (190) were devoted to explaining the secular trend in heights of different populations, including the development of height, weight, BMI, age of menarche over time, while longitudinal studies are also included in this category. Male height trends in Europe have been reviewed by Hatton and Bray (2010) and worldwide by Baten and Blum (2012). This is followed by a total of 25 methodological papers. These statistical papers aim to analyse historical data proposing different ways to circumvent problems such as minimum height recruitments in military samples or age/height heaping. For a review on methods see Fogel et al. (1983), Komlos (2004), and Floud et al. (2011). Many papers have also been written on heights during the British Industrial Revolution (21), the health of the slaves in North America (19), and the Antebellum Puzzle (18) (discussed in Section 6.2).

Papers also discussed causes of height variation: 17 look at diseases as an explanation, household and family composition (16), race and migration (15), inequality (13), changes in income (11), institutions (12), human capital and education (8), urbanization and urban penalty (7), environmental conditions and geography (9), and demography (6). These papers highlight the interest in understanding what drove changes in the height of historical populations. As Tanner (1962) observed, there are a range of economic, social and environmental factors that affect human growth, including diet, infection, climate, psychosocial stress, urbanisation, family size and socioeconomic position, and coined the phrase that growth was "a mirror of the condition of society". To this list, we can also add developments in medical knowledge, sanitary reforms and technological changes (Floud et al., 2011).

Beyond height and weight, anthropometric historians also explored other ways to measure wellbeing. 13 articles use child heights and weights instead of the height or weights derived from adults. In 1988 Bernard Harris published aggregate records for height and weight of schoolchildren in many parts of Britain between 1900 and 1950 (Harris, 1988), these records then were used by Hatton and Martin (2010a,b) and new individual records from children in training ships in Britain are currently being analysed by Eric Schneider and Pei Gao. These records allow the study of children's heights at specific ages and growth patterns, which represents a significant methodological innovation. Indeed, anthropometric historians did not restrict research to adult or child records, but also started to study conditions *in utero* and in early-life using records from birthweights (Costa 1998, 2004; Goldin and Margo, 1989; Ward, 1993). These indicators, when available, allow scholars to test the newest theories in human biology to interpret historical data and answer historical questions. The systematic review includes 8 papers examining birthweights or neonatal conditions.

Additionally, 12 papers use skeletal remains to explore changes in health over millennia, permitting the examination of health far beyond written records and exploring if there were very long-run trends and swings in health conditions that micro-level studies do not capture (see Steckel, 2004; Galofré-Vilà et al. 2018). 10 papers explore changes in health and wellbeing of females instead of males. In analysing female heights, it is important to observe that with the exception of some growing periods such as the earlier adolescence (i.e., between the ages of 10 and 13), girls tend to be shorter than boys in early- to middle-childhood; they reach adolescence at younger ages; that there are physiological differences in the reactions of males and females to adverse circumstances[19]; and that the likelihood of gender discrimination during

[15] For instance, for changes in nutrition as a driving improvement in stature over the last 100 years see Gazeley and Newell (2015).

[16] Male height data are from Hatton and Bray, life expectancy data are from Floud et al. (2011) and population data are from the Maddison Project.

[17] Indian height data are from Galofré-Vilà et al. (2016) and African height data are from Moradi (2008, p. 1113, Fig. 2). Life expectancy data are from the World Bank.

[18] Height data might be a more reliable indicator of the welfare of the historical working classes. See Fogel et al. (1983).

[19] Girls are more resistant than boys, and more likely to maintain their natural growth rates in the face of adverse conditions.

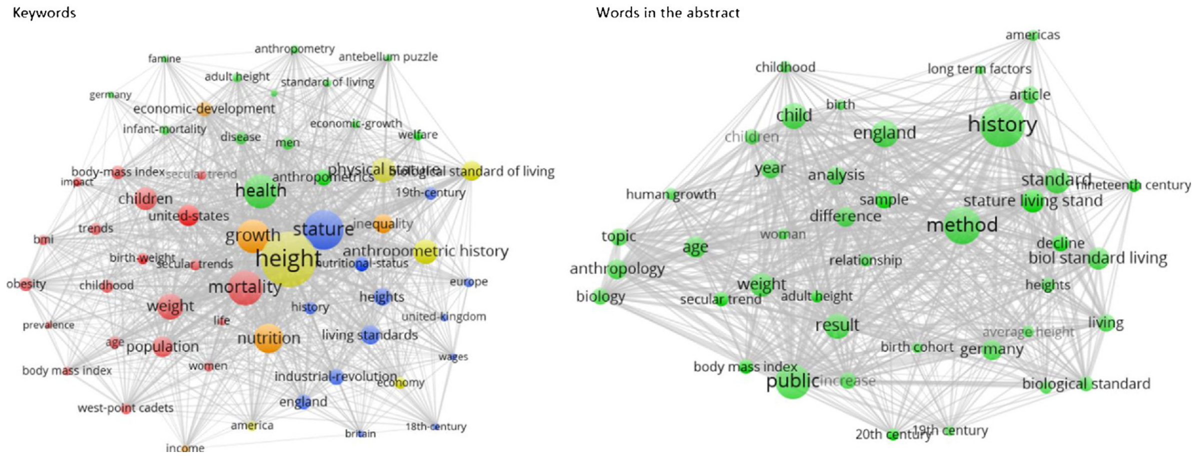

Fig. 6. Most frequently used words as keywords and words in Abstract.
Notes: In words appearing in the abstract (right figure), words such as 'aim', 'article', 'end', etc. have been removed as they are not adding relevant information to the network. Also references and names of authors and journal's names have been removed. Words need to appear at least 20 times to occupy a place in the network. Bubble sizes correspond to the relative magnitude of use in the abstract. The proximity of bubbles corresponds to the frequency with which journals use the words in the abstracts. Colours reflect communities identified by VOS clustering. Produced in VOSviewer Version 1.6.5.

childhood and at older ages. Additionally, much of what we do know is derived from female convicts and prisoners with the necessity of exploring the representativeness of the sample and selection due to changes in policing and sentencing policies (see Harris, 2009, for a review of the literature). 9 papers link changes in height and mortality and 8 are reviews of the literature (see page 4 for the different reviews in the journals included in the systematic review and other journals).

Anthropometric history also contributed answers to big questions of contemporary relevance, such as whether increased longevity leads to greater productivity or, instead, imposes social burdens through the payment of pensions and higher healthcare costs. In the *Changing Body*, the authors addressed this question through the elaboration of the *technophysio evolution* (the synergism between rapid technological change and the improvement in human physiology). They argue that over the last 300 years, with greater inputs of energy and emancipation of environmental conditions, human beings increased their size and their physical and intellectual work, transcending the limitations of the previous generation's physical capacity for work. Thus, humans not only expanded their productivity but also enabled it to make a greater contribution to the welfare of the next generation. Indeed, this finding was observed by Margo and Steckel (1982) when they noticed that taller and heavier slaves commanded significantly higher prices and by Steckel some years later showing that nowadays taller workers receive higher wages (Schick and Steckel, 2015). For the geographical coverage, most papers in the systematic review have discussed topics concerning the United Kingdom (60 in total), Germany (20), Spain (13), Italy (11), Netherlands (11) and other European countries (81); the USA (120); Korea (11), China (8) and other Asian countries (16); Australia and New Zealand (9), Canada (5), Russia (5), Africa (6), Latin American countries (25) and Middle Eastern countries (4) or some uncharted papers on global heights or methods (42).

Finally, to highlight the main areas of research it is also possible to summarise the most widely used terms by authors as keywords and words directly appearing in the abstract (Fig. 6). Most keywords describe the nature of the research and indicators used, with terms such as 'height', 'stature', 'adult height', 'weight', 'body mass index' and 'growth,' with topics also related to 'health', 'mortality' and 'living standards'. In the text mining of the abstract, the word 'method' is quite large and centred in the middle of the network, highlighting the quantitative component of the research in anthropometric history. Some bubbles also include '19th century' and '20th century,' highlighting the historical component of the research, and also the specific work in some areas such as 'Germany' and the 'Americas'. Hence, some long-standing debates including living standards during periods of industrialization, during the British Industrial Revolution, and the Antebellum Puzzle in the US (discussed in the next Section 6.2) are still today the engine of the discipline. Other areas such as gender, inequality, and household composition have rapidly gained interest over time, while there is less appetite for studies on convergence and methods.

6.2. Big ongoing debates[20]

Although anthropometric history has been making important contributions to economic history, there remain some ongoing debates. In *Height, Health and History* Floud et al. found that there was an overall height increase between the 1740s and 1820s. By contrast, for the same period, Komlos (1993a, 1993b), Komlos and Küchenhoff (2012) and Cinnirella (2008), argue the opposite, an overall downward trend. Meredith and Oxley (2014, 189, Fig. 4) took an intermediate position: an increase between the 1730s and 1770s (similar to Floud et al.) followed by a decrease between the 1780s and 1860s. Since all the authors use the same data (the data originally collected by Floud et al.) the real issue is then about how data are being analysed. Floud et al. argued that since recruits from the Army and Royal Marines were drawn from the same population, the allocation of recruits was a matter of military convenience. However, Komlos, Komlos and Küchenhoff, and Cinnirella argue that the two services recruited men from different sections of the population (not all from the male working class) and should be treated separately. Meredith and Oxley (2014, 188) agree with Floud et al. that data were drawn from the same

[20] Another important debate not reviewed here regards the impact of smallpox on stature in England. Voth and Leunig (1996) used Floud et al.'s (1990) data and argued that smallpox led to shorter statures by 1 cm. They received a number of comments from Razzell (1998, 2001), Heintel and Baten (1998) and Oxley (2003, 2006), and these comments were then contested (Leunig and Voth, 2006, 1998, 2001).

population, but weighted the number of recruits, given the different numbers of recruits in the Army and Marine according to their share of recruitment.[21] Unfortunately, new data did not shed further light on the British debate.

This hotly debated area has important connotations for another important debate: Komlos' findings of an incipient Malthusian crisis in Europe after 1750. Komlos (1985, 1989) argued the stature in the Habsburg Empire declined for those born after the 1750s, reflecting the impact of population pressure on resources and argued that this pressure was only eased, in the long run, by the advent of industrialisation. However, the extension of the model of a Malthusian crisis in Europe before the onset of the Industrial Revolution does not fit with the findings in Britain (Floud et al., 1990) though with southern Germany in the 18th century (Baten, 2001). Additionally, Voth (1996) challenged Komlos's view of a Malthusian crisis, arguing that if the effect of additional working days due to institutional changes are discounted, there was no such trend towards smaller statures. This interpretation was then challenged by Komlos and Ritschl (1995).

If these are probably the two most important debates on the old continent, in North America the single most important point of contention is about the 'Antebellum' puzzle. The puzzle arises because in the US heights began to decline in the 1830s and did not recover until the early 1900s. While white infant mortality rates also show a deterioration of health during this period (Floud et al., 2011) and Haines (2004) found a decline of life expectancy between the early and the middle-19th century, this trend is not observed in other countries and it is puzzling because this was a period of economic expansion.[22] This debate is fuelled by Bodenhorn et al. (2017) who recently have argued that volunteer army and prison height records can be a biased sample of the underlying population because varying conditions of the economy and trade brought forward, at different times, recruits from different social classes. The argument on sample selection-bias (SSB) is as follows: people would be more likely to join the army or commit crimes during hard economic and social times, and thus trends in heights derived from some samples such as volunteer armies, convicts or migrants say something about the factors determining the choices that people made at the time of recruitment and not what happened in childhood circumstances. Therefore, Bodenhorn et al. argue that some findings, such as the Antebellum puzzle, reflect interactions between height and the recruitment process rather than between environmental and nutritional conditions and growth prior to recruitment, implying that anthropometric historians have failed to take account of the impact of sample selection factors.

This argument raises two important questions: To what extent should we assume that volunteer army and prison samples represent a consistent sample of the underlying population over time? And, more generally, to what extent have anthropometric historians failed to account for the impact of sample selection-bias? For the first issue, from the samples being used by anthropometric historians, SSB does not apply to conscript armies or medical surveys since there was no choice about enlisting, migrating or committing crime. For the 19th century US case, the argument that the decline in heights in the face of economic growth is a statistical artefact of SSB has not been universally accepted. For instance, their description of the recruitment process does not fit with that made by Costa and Kahn (2008), and Komlos and A'Hearn (2016) also detected major flows in their statistical work: "we also replicated the regressions of Bodenhorn, Guinnane, and Mroz and found two mistakes that, when corrected, overturned their assertion that heights remained unchanged in the antebellum decades" (see also Zimran, 2017). For the second issue, Bodenhorn et al.'s critique is not a new argument in the literature and SSB was already discussed by Fogel et al. (1983) and Floud et al. (1985, 1990). Yet, despite these and other particularities, Bodenhorn et al.'s (2017) contribution does not diminish the importance of SSB in the height literature (rather the opposite), representing an important warning when analysing historical records.[23]

7. Future areas on enquiry

This paper has sought to provide a systematic review of the wealth of anthropometric history. From *Time on the Cross* to *Height, Health and History*, the examination of SSB in historical height samples, anthropometric historians have generated considerable controversy and developed a wide range of sophisticated statistical techniques and ways to analyse historical data, allowing for the exploration of key aspects of humanity's past. One important feature of the recent height literature is that given the remarkable improvement in health and wellbeing witnessed in recent decades, the focus of attention moved towards research on the 20th century, rather than on previous periods. This shift had a positive an important side-effect, as brought economic historians to work closer with development economists, policy makers and medical specialists increasing the interdisciplinary component of anthropometric history and increasing links (including collaborations) across disciplines.

One of the limitations of anthropometric studies is that, although we now know the details of the average height of men in many parts of the world since the mid-19th century and even before, due to the nature of the data on which they are based (e.g., armies), they tend to contain very little direct information on the heights of women or the weights of both sexes. Existent female records come mostly from female convicts with the need to establish the representativeness of the convict data or migrants and, in any case, the representativeness of the data should be taken with care and below male convicts. More research on how the impact of industrialisation and urbanisation affected female heights (not just in England, but also in other countries) is thus necessary.

[21] Note, as explained by Harris et al. (2015), that if one agrees that the Army and Marines drew its recruits from the same population, it is then right to use unweighted samples of soldiers and marines for the same reason. Regarding the analysis of new data on the British debate, Galofré-Vilà et al. (2018) used data from skeletal remains to explore wellbeing in England and found a decline in stature between 1740s and 1820s. However, for this period, most of their data comes from London, with a lack of representativeness for England as a whole. Height data from the Irish convicts transported to Australia from Nicholas and Steckel (1991), and from men imprisoned in London from Meredith and Oxley (2014), also showed an overall decline in height, but it is difficult to argue that convict records are representative of the overall British population. On the other hand, mortality data from Wrigley and Schofield (1981) show that the overall trend in life expectancy between 1740s and 1820s was upward, suggesting improvements in health during this period.

[22] Fogel's height estimates for this period are interpolated from the Ohio National Guard produced by Steckel and Haurin (1982), with lack of representativeness power for the US.

[23] Regarding the analysis of height data for SSB, Steckel (2013, p. 408) concedes that "it is important to interrogate the data and the reasons they were created, suspecting the possibility of selection, and if selection is suspected, then one needs to find alternative sources of evidence for comparison". It should be possible to compare different indicators of wellbeing and explore if changes in stature, life expectancy and the number of calories per capita move in the same direction and if stature, infant mortality and overall mortality move in the opposite direction. It should be also possible to compare the samples under review with the structure of the occupation by geographical origin, literacy and other observed characteristics to the population as a whole. This information should be available in the census and statistical yearbooks at least since the late 19th century in most Western economies.

The literature also prioritizes the discussion of adult heights, and while final or mature height reflects the cumulative impact of environmental and nutritional conditions throughout the period of growth, it says little about the direct nutritional and environmental conditions during the growing period. Harris (2008) also found that in general there is little evidence to support the view that females suffered systematic neglect in childhood or that such neglect results in sex-specific differences in mortality rates. As he comments, this is puzzling, given the marked inequalities in consumption by gender and age within families in poor countries nowadays. Yet, greater deprivation for girls than for boys is found in 19th-century England (Horrell and Oxley, 2016). Following the schema of the *technophysio evolution* as outlined above, wasting and stunting in a mother reflect her own deprivation during the growing period, but also nutritional deficiencies of her own mother and grandmother; and poor nutritional status will be passed to her own baby. Poor conditions of the foetus inside the womb not only could lead to perinatal mortality but a relevant literature has shown that infants exposed to poor conditions *in utero* are also at higher risk of susceptibility to certain diseases such as type 2 diabetes, heart disease and strokes in later life. This idea is closely related to the 'foetal origins' literature or Barker's hypothesis, which argues that the poor nutritional status of a foetus can predispose a person to develop a number of diseases in adulthood.

Perhaps still beyond the current agenda, another potentially vigorous area of study would be to convert the height records (that we already have) into a longitudinal dataset to unravel individual- and period-specific effects in background and behaviour to answer new questions. For example, in the medical inspections that men had to pass to join the army, height details were included alongside the individuals full name, date of birth and place of birth (along with occupation and ability to read and write which have already been used as controls). With the name of the recruit and his place and date of birth it is possible to triangulate him and locate him in the census.[24] Census data will provide the occupation of his parents, number of siblings and household conditions, if the boy was father- or mother-less, if he migrated to another place, the name of the street in which he grew (we can know the characteristics of the building), all these data opening new frontiers of research. It should be also possible to link to marriage records and death registers.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ehb.2017.12.003.

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[24] Note that nowadays a large number of census are being digitised in platforms such as *findmypast.org* and *ancestry.com*, with the data available online. Examples of this approach include Bailey et al. (2016a, 2016b) and recent work using records of men in WW1.

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