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Childhood Conditions and Exceptional Longevity

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Abstract

A number of previous studies found interesting links between the early-life experiences and a subsequent mortality in later life. Such findings justify further advancement of these studies by exploring possible links between childhood conditions and exceptional longevity (survival to 100 years). However a number of methodological issues have to be resolved (such as data availability, quality, as well as research approaches), before starting a comprehensive research project on childhood predictors of exceptional longevity. This paper represents an attempt to do a preliminary study of related methodological issues in order to ensure feasibility of the subsequent large-scale research efforts. The following questions are explored in this study: Where to get data on exceptional longevity and childhood conditions? What is the quality of this data, and how can this data quality be checked and improved? What methods of data analysis to use? What are the hypotheses to test, and what are the preliminary findings to validate?

The study presents a detailed analysis of available data resources on exceptional longevity and childhood conditions, a rigorous evaluation of data quality and testing different approaches to improve the quality of the data. As a result of these methodological explorations the following multi-step procedure of data collection and data cleaning has being suggested and tested in practice:

Step 1. To extract data on alleged centenarians and their childhood conditions from computerized genealogies, pre-selected on the basis of their expected sufficient data quality (a number of indicators of data quality has been identified for this purpose). Following this procedure we extracted detailed family data for 991 alleged centenarians born in 1875-1899 in the United States from publicly available computerized genealogies of 75 million individuals identified in our previous study (Gavrilova, Gavrilov, 1999).

Step 2. To validate the claims of exceptional longevity by cross-checking these records with the US Social Security Administration database on deceased person for the entire US population.

Step 3. To double-check the validated centenarian claims again for the accuracy of birth date information by matching the records with the early US Censuses (1900, 1910, 1920 and 1930).

Step 4. To enhance further the quality of records with confirmed exceptional longevity by adding information on childhood conditions available in the early US Censuses.

This multi-step procedure of data collection and quality evaluation is described in this paper in great detail, to demonstrate how this approach works in practice. A new validated dataset on exceptional longevity and childhood conditions has been successfully developed in this study using this multi-step procedure of data collection and validation. This validated dataset contains information on 485 centenarians born in the United States in 1890-1900 and the families where they were raised. Thus, this multi-step approach has been tested in practice and it could be recommended for a subsequent large-scale research project on childhood predictors of exceptional longevity.

At the next step of this study we used the collected and validated dataset on exceptional longevity and childhood conditions as a sandbox for applying different methods of data analysis and testing a number of specific hypotheses about childhood predictors of exceptional longevity. Specifically, we followed the earlier studies by Preston and Haines (1991) who found that the lowest sickness burden in early life (measured through the level of child mortality) was observed in the families of farmers, and families living in the Western region of the United States in the 1900s. This leads to a testable prediction that centenarians should occur more often in the families of farmers, and in families living in the Western region of the United States, if more healthy childhood conditions are indeed conductive for exceptional longevity later in life. We tested these hypotheses using a method of multiple logistic regression to

compare household characteristics of 'centenarian' families in the 1900s with household characteristics of representative sample of the 1900 US Census (IPUMPS data). Indeed it turned out that centenarians were born more often in the families of farmers, and in families living in the Western region as predicted by the 'childhood conditions' hypothesis.

We also explored different approaches to study the effects of the birth order on exceptional longevity, starting with analysis of a simple summary statistic like the 'centenarian birth order ratio' and the 'centenarian birth order difference', followed by more sophisticated analysis based on multiple logistic regression. These studies revealed that there is a statistically significant association between the chances of exceptional survival and the birth order.

Finally, a method of within-family analysis has been applied to investigate the occurrence patterns for centenarians among siblings, which allows researchers to avoid confounding caused by between-family variation. This approach was implemented using conditional logistic regression with a binary outcome variable describing either a centenarian, or non-centenarian survival outcome. For this in-depth analysis the 198 validated centenarians born in USA in 1890-1893 were identified, and their family histories were reconstructed using the US Censuses, the US Social Security Administration database, genealogical records and other supplementary data resources. The following predictor variables were explored: sex, birth order, paternal age at person's birth, maternal age at person's birth, and the season of birth.

The study found that first-born siblings are more likely to become centenarians when compared to later-born siblings (odds ratio = 1.77, 95% CI = 1.18 - 2.66, P = 0.006). This protective effect of first-born status can not be simply explained by differences in child mortality, because it persists when a comparison is made with those siblings only who survived to adulthood (age 20): odds ratio = 1.95, 95% CI = 1.26 - 3.01, P = 0.003. Moreover, even at age 75 it still helps to be a first-born child in order to become a centenarian (odds ratio = 1.66, 95% CI = 1.02 - 2.69, P = 0.04).

In order to find out the mechanism of the birth-order effect, a multivariate analysis with included parental age variables was performed. This multivariate analysis found that the protective effect of being first-born is driven mostly by the young maternal age at person's birth (being born to mother younger than 25 years). Being born to young mother is the major predictor of human longevity (odds ratio = 2.03, 95% CI = 1.33 - 3.11, P = 0.001). Moreover, even at age 75 it is still important to be born to young mother in order to survive to 100 years (odds ratio = 1.87, 95% CI = 1.15 -3.05, P = 0.01).

The results of this study demonstrate that childhood conditions are indeed very important in determining the chances of exceptional longevity and justify the feasibility of the subsequent large-scale research efforts in this direction.

INTRODUCTION

Centenarians (people living to age 100 and beyond) represent one of the fastest-growing age groups of the American population, with obvious implications for demographic studies. The number of U.S. centenarians is growing at a rate of about 4.1 percent per year, so their numbers have increased by 51 percent in the 10-year period from Jan. 1, 1990 to Jan. 1, 2000 (Kestenbaum, Ferguson, 2005). Yet, factors predicting exceptional longevity and its time trends remain to be fully understood. Thorough and comprehensive studies of survival at advanced ages require searching for new data sources in addition to careful re-evaluation of already known ones.

Our previous search for additional data resources (see Gavrilov, Gavrilova, 1998; Gavrilova, Gavrilov, 1999) revealed an enormous amount of new family lifespan data that could be made readily available for subsequent full-scale studies. Millions of genealogical records are already computerized and after strict data validation could be used for the study of familial and other predictors of human longevity. Most of these genealogies are a product of family reconstitution, carried out both by professional genealogists and by family members tracing their ancestry back to the founder who brought their surname to America or even to their European family roots. The compilers of genealogies aided this time-consuming task by using many different sources: genealogical libraries, The Church of Jesus Christ Latter-day Saints (Mormon) family history centers, genealogical search engines available on the Internet, computer CDs with census, marriage, land and probate records, and many other resources for genealogical research.

Computerized genealogies provide the most complete information on the lifespan of centenarians' relatives, compared to other data sources, such as death certificates, census data and the Medicare database. Census records provide information on birth years of parents and siblings, but no information on death dates is available. The Medicare database allows identification of spouses (see Iwashyna et al., 1998), but no information on parents and other relatives is available. The Social Security Administration NUMIDENT file contains information on the names of parent/child pairs for Medicare beneficiaries (65 years and older). In the latter case, however, one cannot obtain information on distant ancestors (e.g., grandparents) as well as other relatives (e.g., first cousins), so there is no opportunity for reconstruction of pedigrees. Thus, computerized genealogies provide unique opportunities to greatly expand the scope of biodemographic studies of human longevity, and they cannot be adequately substituted by other data resources.

The first goal of this exploratory project is to identify and validate new data resources for biodemographic studies of predictors of exceptional human longevity, and to ensure feasibility of a subsequent large-scale research program on related topics (by developing unique datasets, new computer techniques and new substantive hypotheses on determinants of human longevity supported by preliminary studies of this project).

Specifically, this study is aimed to develop a high-quality, family-linked database on American centenarians, rich in the scope of individual predictor variables (including both early-life and life-course characteristics as well as a familial history of longevity), and complete for each predictor variable (without missing observations).

In this study we describe our experience in the identification, collection, verification and analysis of data taken from computerized genealogies for long-lived individuals born in the United States. The process of data quality evaluation and centenarians' age verification is described in detail because it appears to be the first attempt in systematic assessment of quality for this new and potentially promising data source on family factors of longevity. We also test several hypotheses on the effects of early-life living conditions and family factors affecting lifespan.

The idea of fetal origins of adult degenerative diseases and early-life programming of late-life health and survival is being actively discussed in the scientific literature (Lucas, 1991; Gavrilov, Gavrilova, 1991; 2003a; Barker, 1998; Kuh, Ben-Shlomo, 1997; Lucas *et al*., 1999; Costa, Lahey, 2003). The historical improvement in early-life conditions may be responsible for the observed significant increase in human longevity through the process called "technophysio evolution" (Fogel, Costa, 1997). Additional arguments suggesting the importance of early-life conditions in later-life health outcomes are coming from the reliability theory of aging and longevity (Gavrilov, Gavrilova, 1991; 2001a; 2003a). According to this theory, biological species (including humans) are starting their lives with an extremely high initial load of damage, and, therefore, they should be sensitive to early-life living conditions affecting the level of initial damage (Gavrilov, Gavrilova, 1991; 2001a; 2004).

The concept of high initial damage load also predicts that early life events may affect survival in later adult life through the level of initial damage. This prediction appears to be confirmed for such early-life indicators as the parental age at a person's conception (Gavrilov, Gavrilova, 1997, 2000, 2003b; Gavrilova et al., 2003) and the month of person's birth (Gavrilov, Gavrilova, 1999, 2003b, Gavrilova et al., 2003; Doblhammer, 1999; Doblhammer, Vaupel, 2001; Costa, Lahey, 2003). There is mounting evidence now in support of the idea of fetal origins of adult degenerative diseases (Barker, 1998; Kuh, Ben-Shlomo, 1997; Lucas, Fewtrell, Cole, 1999), and early-life programming of aging and longevity (Gavrilov, Gavrilova, 1991, 2001, 2003a; Gavrilova et al., 2003).

COMPUTERIZED GENEALOGIES AS A POTENTIALLY USEFUL DATA RESOURCE

Survey of the existing computerized genealogies

At the first stage of the study, we made a survey of the relevant data resources and identified computerized family histories for over 75 million deceased individuals using collections of online genealogies identified in our previous studies (Gavrilov, Gavrilova, 1998; Gavrilova, Gavrilov, 1999). Centenarian family histories were drawn from computerized family trees using the following selection criteria: (a) persons should have both the birth and death date information and have lifespans of 100 years and over, (b) persons should be born in the United States after 1875 and (c) persons should have pedigree information for at least three generations of ancestry (on both the paternal and maternal sides) as well as information on birth date and death date of parents.

The decision to exclude foreign-born centenarians from our study was conditioned by the difficulties of their age verification. The main obstacle here is that for persons born in the study window of 1890-1900 it may be difficult to find many foreign-born persons in the available early U.S. censuses (1900 and 1910) used for birth date verification, because many of these persons could immigrate later. Also, in the case of foreign-born persons, the U.S. census data are useless in providing information about early-life conditions because foreign-born children spent a part of their childhood abroad in unknown living conditions. Therefore, because this particular study is focused on the role of childhood conditions in predicting exceptional human longevity, foreign-born persons are less informative than U.S.-born persons. In addition, it is particularly difficult to verify the quality of genealogical data for foreign-born centenarians. Thus, by excluding the genealogies for foreign-born centenarians, we excluded the most questionable part of the data, which are particularly difficult to cross-validate through early U.S. censuses. It should also be noted that foreign-born children comprised a small proportion (3 percent) of all children below age 10 enumerated in the 1900 census. We obtained this estimate from the Integrated Public Use Microdata Series (IPUMS) 1 percent random sample of the 1900 U.S. census population (For more details on the IPUMS project see Ruggles et al., 2004).

Using online genealogical data resources, we identified over 2,000 genealogies, which contained detailed information about long-lived persons as well as detailed information about their parents and grandparents. The obtained genealogies were recorded in the so-called GEDCOM data format, which is used for genealogical data exchange (Gavrilova, Gavrilov, 1999) and is described below. "GEDCOM" stands for the "GEnealogical Data COMmunication" standard proposed by the Family History Department of The Church of Jesus Christ of Latter-day Saints (LDS Church) and adopted by many developers and users of genealogical software (Family History Department, 1996). The purpose of GEDCOM is to simplify the exchange of computerized historical and genealogical information. GEDCOM files are created in ASCII (text) format with special tags at the beginning of each line related to specific family information (variables). The most common variables contain personal information (name, birth date and place, death date and place) and family information (links to spouses and children and links to parents and siblings). In many cases, GEDCOM files contain more detailed information (occupation, education, residence, title, religion, cause of death, burial place and special notes). Data on living individuals are eliminated in the majority of computerized genealogies (to protect their privacy) except for their names and family links.

Information contained in GEDCOM files cannot be immediately used in statistical analyses because it needs to be converted to a relational database for data cleaning and further analysis. Thus, after collecting data in the form of GEDCOM files, they were converted to the relational database (MySQL) for their further verification and analysis.

Database on the U.S. centenarians

We used the Entity-Relationship (ER) approach to database modeling (Bagui and Earp, 2003). The data model focuses on what data should be stored in the database. To put this in the context of a relational database, the data model is used to design the relational tables. To do this, we first created an entity-relationship diagram for our model, which represents the data structures in pictorial form. Genealogical data can be well represented by a two-entity design: persons and unions/marriages with one-to-many relationships (one person may have many unions while a particular union/marriage describes a unique pair of partners). This design was further extended by adding an entity reflecting the SSA DMF data and two entities for the early census data: households and household members. Physical realization of this model was made using a common set of software: Apache Web server, PHP program language for user interface and the MySQL database management system.

The collected GEDCOM files for centenarians were screened for long-lived individuals and converted to the MySQL database using specially developed program scripts. As a result, we obtained information for 2,004 long-lived individuals and their relatives (including parents and grandparents) in the form of a relational database. From these 2,004 records for long-lived individuals, we selected 991 records for centenarians born in the United States after 1875.

As with any new data resource, this data set has an uncertain quality, which requires additional efforts for data verification and quality control using several independent data sources. Our primary concern was the possibility of incorrect dates reported in genealogies. Previous studies found that age misreporting and age exaggeration in particular are more common among long-lived individuals (Hill et al., 2000; Rosenwaike, Stone, 2003; Shrestha, Preston, 1995). For this reason the focus of our study was on age verification for long-lived individuals rather than for other members of genealogy.

Verification of centenarian birth and death dates

Verification of centenarian birth and death dates was made in three stages. To verify the centenarian's birth date, we first compared the person's birth date with birth dates for the person's parents, as well as with birth and marriage dates for the person's spouses (data consistency test). This was the preliminary test followed by two more sophisticated tests for data quality as described later.

In this project we followed the approach of age verification and data linkage developed by a team of demographers at the University of Pennsylvania (Rosenwaike, Logue, 1983; Preston et al., 1996; Rosenwaike et al., 1998; Hill et al., 2000; Rosenwaike, Stone, 2003).

The verification of death dates is an important step in quality control because it eliminates cases with potential mistakes and misprints in death dates reported for alleged centenarians. The verification of death dates was accomplished through a linkage of genealogical data to the Social Security Administration Death Master File (SSA DMF). This is a publicly available data source that allows a search for individuals using various criteria: birth date, death date, first and last names, Social Security number and place of last residence. This resource covers deaths that occurred in the period 1937-2003 (see Faig, 2001, for more details). Many researchers suggest that the quality of SSA/Medicare data for older persons is superior to vital statistics records because of strict evidentiary requirements in applying for Medicare, while age reporting in death certificates is made by proxy informant (Kestenbaum, 1992; Kestenbaum, Ferguson, 2001; Rosenwaike et al., 1998; Rosenwaike, Stone, 2003). In this project we based the death date verification on linkage to the SSA DMF, which is publicly available at the Rootsweb Web site (Faig, 2001).

In order to verify centenarian birth dates, data for centenarians were checked against the early U.S. census records collected when the centenarian was a child or young adult. For validation purposes, the early U.S. censuses (1900, 1910 and 1920) are particularly important, because they provide information on future centenarians during their childhood and early adulthood years when age exaggeration is less common compared to claims of exceptional longevity made at old age. The preference was given to the 1900 census because it is more complete and detailed (in regard to age verification) compared to the 1910 and 1920 censuses. Specifically, the 1900 U.S. census provided year and month of birth, not just an age at enumeration date.

Information from the 1900 U.S. census was used not only for age verification, but also for a study of early-life factors and chances to survive to extreme old ages. The 1900 U.S. census provides the following information for household and its members: state, county, and township of residence; street and house number (where available); relationship to head-of-household; gender and ethnicity; month and year of birth and age at last birthday; marital status and, if married, length of marriage; for married women, number of children born and number living; birthplace of person and birthplaces of mother and father; for aliens or naturalized citizens, year of immigration and citizenship status; occupation of each person 10+ years and number of months not employed; information about school attendance and literacy; and information about home ownership or farm residence. An important advantage of the 1900 U.S. census is the availability of information about year and month of birth, providing an additional source for birth date verification.

In our study, the linkage of centenarian records to the early census data is facilitated by online availability of the entire indexed U.S. 1900, 1910 and 1920 censuses—a service provided by Genealogy.com and Ancestry.com. In this study we conducted a linkage of 534 centenarian records (for centenarians found in the SSA DMF with confirmed centenarian status and born after 1889) to the early U.S. censuses. If individuals were not found in the 1900 census, then attempts were made to locate them in the 1910, 1920 and 1930 censuses.

Description of the Verified Data Sample of Centenarians

Quality of centenarian genealogical data

The data consistency checks revealed a surprisingly small number of obvious data inconsistencies. In one case, an alleged centenarian had parents with incorrect birth dates (parents born later than the person himself). This case was dropped from the database. In another case, the centenarian's father was rather old (62 years) when the centenarian was born. This is not an impossible situation, so this case was left for further validation (this case was later confirmed through the SSA DMF but not found in early censuses and therefore not included in final analyses). All other records did not reveal obvious inconsistencies in event dates, so 990 records were left for further verification.

The overwhelming majority of genealogical records, when linked to the SSA DMF, had revealed an identical birth and death year as well as birth and death month in both databases (687 out of 764 cases, or 89.9 percent). These matched records were additionally verified using information about first and last names (or last names of spouses for women), places of death (in the genealogy database) and places of last residence (in the DMF). When months of birth or death and years of birth or death did not match, then potential matches were established using information about place of death (in the genealogical file) and place of last residence (in the DMF). Thus, in addition to 687 (out of 990) persons having exactly the same birth and death dates in both databases, it was possible to add some records with birth or death dates that were not exactly identical in the genealogies and DMF. In most cases these differences were related only to minor disagreements in *exact month of birth or death* (not year), and in 731 cases (96 percent), the death year was the same both in the genealogy records and the DMF. One problem encountered for successful linkage to the DMF was surname changes by women after marriage. We resolved this problem by using surnames of spouses, which are available in the genealogical database, so that linkage success was approximately the same in both sexes. The number of successful links strongly depends on a centenarian's year of birth; persons born before 1890 were less likely to be found in the DMF. This result is consistent with previous reports that quality and coverage of the DMF database was lower for persons born before 1890 (Faig, 2001).

Thus, the proportion of successful links is 75 percent for males and 78 percent for females in total. For centenarians born after 1889, the percentage of successful links is higher (82 percent). Among the 767 persons found in the DMF, centenarian status was confirmed in 744 of the cases. 734 centenarians had the same calendar year of *death* both in genealogy records and in the DMF. 714 centenarians had *both the birth and death years* identical in genealogy records and the DMF. Centenarian status could not be confirmed for only 23 alleged centenarians from the computerized genealogies (3.0 percent). The detailed breakdown of records found in the DMF is presented in Table 1.

Table 1 About Here

The overall linkage success rate to the SSA DMF was moderate at 75-78 percent. Also, in 17 cases (2 percent) the difference between the death year in the genealogy records and the DMF was expressed in round numbers (e.g., 10, 20 or 30 years), which seems to be caused by misprints in genealogies (see Table 1). Thus all cases of exceptional longevity in genealogies should be checked using the SSA data.

The lack of a match with the DMF could occur for a number of reasons: a misprint in genealogy, missing Social Security record (particularly if the person did not use Medicare benefits), difficulty in matching a person with a common name when the dates are not identical, etc. In addition, DMF covers about 90 percent of all deaths for which death certificates are issued (see Faig, 2001) and about 92-96 percent of deaths for persons older than 65 years (Hill, Rosenwaike, 2001). Further work with non-matched cases using additional data sources (obituaries, state collections of death certificates) revealed that about half of the non-matched cases are related to misprints in genealogies, and about 20 percent of the non-matched cases have correct death dates (as confirmed by linkage to the state death indexes) although are not recorded in the SSA DMF.

It should be noted that the linkage success rate to the DMF was substantially higher for persons born after 1889—at 82 percent. The 534 records for persons with confirmed centenarian status born after 1889 and matched to the DMF were used further in verification of centenarian birth dates through linkage to early censuses.

The overall success rate for linkage of centenarian records to early U.S. censuses was 91 percent (see Table 2).

Table 2 About Here

The agreement between years of birth recorded in computerized genealogies and years of birth reported by the 1900 census as well as age reported by the 1910 census was surprisingly good; there was complete agreement in birth year between genealogy records and census records in 92 percent of cases. In one case only, the centenarian's year of birth was three years less than in the genealogy record, i.e., the centenarian was in fact *older* than was reported in the genealogy file. In 4.5 percent of cases, the birth year of the centenarian in the U.S. census was one year less than the birth year indicated in the genealogy database and in 3.5 percent of cases the centenarian was one year younger than reported in genealogy records. Disagreements between birth years reported in the censuses and genealogies were more notable for parents (about 15 percent of all cases) than for children, but in the majority of cases the differences did not exceed one year.

As a result of this record linkage study, we could verify birth dates for 485 centenarians born after 1889. The steps of age verification for this group of centenarians are presented in Table 3.

Table 3 About Here

Thus, we obtained 485 records for centenarians with verified birth dates, confirmed centenarian status and detailed genealogies. We did not find many cases of significant age exaggeration among centenarians with known genealogies and verified death dates. In other words, the birth year is recorded more accurately in studied genealogies than the death year. The 25 cases of one-year discrepancy with the census records are more likely caused by inaccurate birth date reporting during census enumeration rather than inaccuracy of genealogical records. Most genealogical records provide a detailed date of birth (day, month and year) most likely taken from birth certificates or family bible records while census records are based on verbal reports during enumeration.

As a result of this validation study, a sample of 485 centenarians born in the United States in 1890-1900 was identified. A general overview of the data collection, verification and linkage used for identification of these 485 cases is presented in Figure 1.

Figure 1 About Here

All centenarians had verified dates of birth and death and known information for parents, siblings, spouses and other relatives. Table 4 shows the age and sex breakdown of centenarians with verified ages.

Table 4 About Here

This developed database on long-lived persons combines information on family characteristics with data on the early-life conditions taken from the 1900-1910 U.S. censuses. This database was used in testing hypotheses on the factors affecting exceptional longevity.

STUDY OF EARLY-LIFE CHILDHOOD CONDITIONS AND LONGEVITY

Using the U.S. Census of Population data to study early-life predictors of longevity

The resulting dataset of 1900 and 1910 households linked to centenarian genealogies allows us to make a comparison of these households to the general set of households enumerated in early censuses. We followed in part the methodological lines established by Preston et al., 1998, and used individual data from the 1900 U.S. census of population as a control group. The data are available as part of the IPUMS project from the University of Minnesota (Ruggles et al., 2004). The sample represents 1 percent of Caucasian households enumerated in 1900 (household where the head of household was Caucasian). The linkage to early U.S. censuses in our study found that most centenarians in our sample were Caucasian (with the exception of two American Indian families), so we used a sample of the Caucasian population from the IPUMS dataset as a control. At this initial stage of data analysis, we conducted a comparison of households that raised a future centenarian (linked to the 1900 census) to the general sample of Caucasian households enumerated by the 1900 census, which had children below age 10 (to make these households comparable to our set of centenarians who were born in 1890-1899 and hence were below age 10 in 1900).

We applied a method of multiple logistic regression (procedure 'logistic' in the Stata statistical package) in order to compare the two sets of households. The set of variables describing a household is similar to one applied by Preston et al. (1998). We did not use the variable describing the occupation of the father because this variable is strongly correlated with ownership and farm status variables and because of existing problems with the classification of diverse occupations. In fact, 63 percent of the fathers of centenarians in our sample were farmers by occupation, almost all white-collar fathers owned their house, and most low-skilled fathers were renters.

Our tested hypothesis is that if early childhood conditions are important for survival to age 100, then the households with children-future centenarians would be different from the general population. Tables 5 and 6 present results from multivariate logistic regression that estimate the odds for the household to be in the "centenarian" group. We conducted our analyses separately for male and female centenarians because our previous analyses demonstrated that men and women may respond differently to early-life living conditions (Gavrilov, Gavrilova, 1999; 2003a).

Table 5 About Here

Table 6 About Here

Data presented in Tables 5 and 6 demonstrate that both the region of childhood residence and the household property status are the two most significant variables that affect chances of a household to produce a future centenarian (for both sons and daughters). Thus, spending a childhood in the Mountain Pacific and West Pacific regions in the U.S. may highly increase chances of long life (by a factor of 3) compared to the Northeastern part of the country. Also farm (particularly owned farm) residence results in better survival to advanced ages. This result is consistent with studies of childhood conditions and survival to age 85+ (Preston et al., 1998; Hill et al., 2000). These earlier studies, also based on linkage to early censuses, demonstrated a significant advantage in survival for children living on farms for both African Americans (Preston et al., 1998) and native-born Caucasians (Hill et al., 2000). On the other hand, the Northeast and Midwest were found to be the best regions for survival to age 85+ (Hill et al., 2000).

Both of the above-mentioned studies of childhood conditions and later survival found that a father's illiteracy significantly diminishes the chances of survival to age 85+. We find no such relationship for survival to age 100 in our dataset.

Having a father immigrant decreases the chances to become a centenarian for males and females, although for females the effect is weaker. A similar negative effect of the father's immigrant status was found for native-born Caucasians, both sexes combined (Hill et al., 2000). Recently Costa and Lahey (2003) came to the same conclusion that immigration status is not related to better health.

Finally, we found that deaths of siblings early in life had no statistically significant effect on the chances of becoming a centenarian. A previous study found that death of siblings decreases chances to survive to age 85 among African Americans (Preston et al., 1998). That study used more sophisticated methods of child mortality estimates (child mortality index) and copy-pair controls. In our study we used a proportion of surviving children reported by the mother during census enumeration as a proxy for child mortality within the household, and compared households where centenarians were raised, with a general population.

Links between birth order and exceptional longevity

Information about birth order of centenarians allowed us to test whether the centenarians are distributed randomly within a sibship (brothers and sisters in the family) or not. If a centenarian's birth order is determined by chance only and is not linked to exceptional longevity, then the ratio of *[centenarian birth order/(sibship size + 1)]* should be equal to 0.5 on average. If centenarians are found more often among the older or among the younger siblings, then the observed ratio, named "centenarian birth order ratio" (CBOR), should demonstrate a statistically significant deviation from the expected value of 0.5.

To study the birth order effects, we have to remove non-informative cases where family size is equal to one and cases with less reliable information on family size (there are a few genealogies where family size was lower than that reported in the census). We found that the centenarian birth order ratio for female centenarians is lower (0.45 ± 0.01) than expected (0.5) and this effect is statistically significant (P<0.01). In other words, the birth order ratio of centenarian women is 12 percent lower on average than it would be expected by pure chance (random uniform distribution for cases of exceptional longevity by birth order). Thus, female centenarians can be found less likely among later-born siblings conceived to relatively old parents. In contrast to females, the birth order ratio for centenarian men (0.48 ± 0.02) is closer to the theoretically predicted value of 0.5, suggesting that birth order is less important for exceptional male longevity (see however, later results and discussion).

Similar results are obtained using another statistic named 'centenarian birth order difference': [*centenarian birth order - (sibship size + 1)/2*]. If centenarians are distributed randomly by birth order within a sibship (independently of their centenarian status), then this difference should be equal to zero on average. This is what we expect to find for centenarian males, while this birth order difference should be negative for centenarian women, if the tested hypothesis is correct. We found that the mean value of the centenarian birth order difference for females is lower (-0.50 ± 0.11) than zero, and this difference is statistically significant (P<0.01). In other words, the birth order of centenarian women is lower on average than it would be expected (if birth order is irrelevant for longevity), and this difference in absolute terms corresponds to the shift of 0.5 to lower birth order on average. Thus, there is a tendency for female centenarians to be born among the first half of siblings in the family. In contrast to centenarian women, the birth order difference for centenarian males (-0.13 ± 0.22) is close to the theoretically predicted zero value, suggesting that birth order is less important for exceptional male longevity (however, we will present more detailed analysis later).

The results we presented so far are based on summary statistics, which describe the overall shift in birth order ranking of centenarians relative to their siblings. Deeper analysis of the odds to become a centenarian as a function of birth order (with centenarian siblings born in the same time window (1890-1900) used as a control group) found that the best fit of the data both for males and females analyzed separately could be achieved with the following model:

$$\text{Logit (Longevity odds ratio)} = a\,x + b\,x^2 + c\,z + d,$$

where x is the birth order, z is family size, and a, b, c, and d are the parameters of the polynomial regression model. The choice of a quadratic model for birth order effect was made after studying all possible interactions between predictor variables. This study found that the quadratic effects of birth order are statistically significant, and therefore they cannot be ignored. On the other hand, the effects of higher order (cubic function) proved to be statistically insignificant, and they were dropped from the final model. Other interaction terms between predictor variables (birth order and family size) were found to be statistically insignificant and therefore were not included in the model.

The effect of family size, parameter c, was negative both for males (-0.11 ± 0.05, p = 0.028) and females (-0.07 ± 0.02, p = 0.002), which indicates that the odds of longevity are in fact decreasing in larger families. Further studies are required to find out whether this is a meaningful finding or a trivial consequence of ascertainment bias (the proportion of centenarians in a family is bound to decrease with increasing family size, because other siblings are likely not to be centenarians).

Figure 2 presents the results of data analysis in graphic form. It shows the dependence of the odds of living to age 100 as a function of a person's birth order (as predicted by the fitted polynomial logistic model). The graphs are computed for a fixed family size of 10 children (which is not particularly important, because family size influences only the vertical location of the curves rather than their shape because there is no interaction of family size with birth order).

Figure 2 About Here

Note that the odds of becoming a centenarian decrease with birth order for females, which is consistent with the results of earlier data analysis based on summary measures. First-born daughters are almost three times (2.7 times) more likely to survive to age 100 compared to later-born daughters of higher birth orders (8+). Note that the strongest effect of birth order is observed when it is relatively small - one to five (see Figure 2), and then the birth order effect fades out.

The picture is different for males; there is an unusual U-shaped curve for the odds of living to age 100 in relation to birth order. The chances for exceptional longevity are minimal for sons having a birth order of four to six compared to those born earlier or later. Thus the earlier studies based on summary measures, which found no birth order effect in males, seemed to overlook it, because of a complex U-shaped form of the birth order effects in males. In fact, first-born sons are twice (2.05) as likely to become centenarians compared to sons having a birth order of five (see Figure 2). However, the last-born sons (birth order 10+) also have more than twice (2.4 times) higher chances of surviving to 100 years compared to sons having a birth order of five. Further studies are required to test whether this is a robust finding or a result of a particular model selection.

Within-Family Analysis of Exceptional Longevity
Effects of Birth Order, Parental Age and the Month of Birth

To test whether the survival advantage of the first-born is indeed a true within-family phenomenon, rather than an artifact of mixing different families together, we compared the first-born children with their brothers and sisters born exactly in the same family. To achieve this, we applied a method of within-family comparison, known as a conditional logistic regression (procedure clogit in Stata). Method of conditional logistic regression allows us to compare centenarians with their siblings within the same family. This eliminates confounding caused by between-family variation. Using this method we found that the odds to become a centenarian are indeed 1.7 times higher for the first-born children compared to their later-born siblings (brothers and sisters) from exactly the same family (see Table 7).

Table 7 About Here

In order to conduct these analyses we selected 198 validated centenarians born in USA in 1890-1893 (from the centenarian database) and reconstructed their family histories using the US Censuses, the US Social Security Administration data, genealogical records and other supplementary data resources. All birth dates of centenarian siblings were reconstructed using information available in computerized genealogies and early censuses. Death dates were reconstructed for 85% of siblings using the Social Security Death Master File, state death indexes and online genealogies. Birth order of all first-born centenarians was verified using the data from early censuses.

Next question explored in this study was about the role of child mortality, which was very high a century ago, when the studied centenarians were born. So if the first-born children were more likely to survive to adult age, then simply because of this selective child survival, the centenarians might become more prevalent among the first-born. To test this hypothesis we re-analyzed the data including only those siblings who survived to adulthood (20 years and above). It was found that even for adult persons the odds to live to 100 are almost twice higher for the fist-born persons (Table 8).

Table 8 About Here

Moreover, even at age 75 it still helps to be a first-born person -- the odds to celebrate the 100th birthday are 1.6 times higher for the first-born rather than for later-born persons in the same family (odds ratio = 1.66, 95% CI = 1.02 - 2.69, P = 0.04, n=557).

Then we explored the role of the father's age as a potential explanation for the birth order effect. When the first child is born, the father is younger and can provide resources for this child for a longer period of time than for his later-born children. Therefore, we tested a hypothesis that it could be the younger age of the farther, which is responsible for the first-order effect. The collected data on father's age at birth for each studied person were included into the statistical analysis. It turned out that the young father's age was far less important than the fist-born status itself in predicting the chances of exceptional longevity. Thus, the hypothesis of young father as an explanation of the survival advantage of the first-born was rejected (Table 9).

Table 9 About Here

Finally, we included into analysis the mother's age, and it turned out that the young maternal age at childbirth was the most important predictor of exceptional survival, while the effect of the birth order itself has become statistically insignificant. These findings indicate that the protective effect of being first-born is driven mostly by the young maternal age at person's birth (being born to mother younger than 25 years). Being born to young mother is the major predictor of human longevity with odds ratio to live to 100 being 1.8 times higher than for later-born children, even when the effects of birth order are taken into account (Table 10).

Table 10 About Here

Moreover, even at age 75 it is still important to be born to young mother in order to survive to 100 years, because the odds of exceptional survival are 1.9 times higher than for later-born siblings (odds ratio = 1.87, 95% CI = 1.15 -3.05, P = 0.01, n=557).

What is really interesting is that the survival benefits of being born to young mother are observed only when the mother is younger than 25 years (data not shown). This may have important social implications, because so many women now decide to postpone childbearing due to career demands. Why being born to particularly young mother is so beneficial for long-term survival is not yet known, and we plan to test a number of competing social and biological explanations in the future. For example, if the best (most vigorous) maternal ova cells are used first, for the very early pregnancies, this could explain why particularly young mothers produce particularly longevous children. There is also another hypothesis, which may explain the observed findings and which may be interesting to test in the future. It may be reasonable to assume that some particularly young women may be initially free of many diseases and latent infections, interfering with optimal fetus development, but shortly after that most women become carries of latent pathogens and conditions simply because of accumulated lifetime exposure. Further testing of these and other related hypotheses is very important and may bring new fresh approaches for enhancing human health and longevity.

We have also studied the effects of the month of birth on exceptional survival using the matched sibling design. We found that the highest chances of exceptional longevity were observed for those persons who were born in March (odds ratio = 4.09, 95% CI = 1.50 - 11.13, P = 0.006), July (odds ratio = 3.40, 95% CI = 1.25 - 9.27, P = 0.02) and August (odds ratio = 3.02, 95% CI = 1.08 - 8.47, P = 0.04) compared to persons born in December (Figure 3).

Figure 3 About Here

This seasonal effect cannot be explained by seasonality of child mortality because it is also observed for adult persons who survived by age 20 (Figure 4).

Figure 4 About Here

To the best of our knowledge, this is for the first time when a within-family analysis of the month-of-birth effects on human longevity has been made. This approach has great advantages over other methods, because it is free of confounding caused by between-family differences. However, it remains to be seen whether the observed seasonal pattern could be reproduced in further studies.

DISCUSSION

Computerized genealogies contain important information about family and life-course events, which are otherwise difficult to collect: lifespan of parents and other relatives, number and sex of siblings, birth order, ages of parents when person was born, age at marriage, number of spouses and lifespan of spouses and other non-blood relatives, number and sex of children and timing of their birth, place of birth and information about residence during the life-course (derived using places of birth for siblings and children). Thus, computerized genealogies may be a valuable resource for studies of mortality and longevity. However, the reliability and quality of computerized genealogies are uncertain, resulting in underutilization of this data resource by researchers. In this study we developed a technique of genealogical data collection, verification and utilization in scientific analyses of longevity.

This study demonstrated that the ongoing revolution in information technologies created unique opportunities for conducting biodemographic studies of childhood predictors of exceptional longevity. In particular, the online availability of early censuses greatly accelerated and facilitated the process of record linkage used in the process of centenarian age verification. In our study the overall matching success rate of linkage to early U.S. censuses was 91 percent, which is significantly higher than in other studies on linkage to early censuses: 39-56 percent (Rosenwaike, Logue, 1983; Guest, 1987; Rosenwaike et al., 1998), 69 percent (Hill et al., 2000) and 54 percent overall and 69 percent for Caucasians (Rosenwaike, Stone, 2003).

The reasons for the relatively high success rate of linkage to the early censuses in our study can be explained by the availability of detailed supplemental information in genealogical records. The most important piece of information for successful searches in census records was information on *places of birth* for siblings born close to the census date. Thus, if the family moved to another state after the birth of the alleged centenarian, his/her family could be easily traced using information about the birthplaces of other siblings. This is an important advantage compared to the traditional studies of record linkage to the early U.S. censuses based on information taken from the Social Security SS-5 forms (Rosenwaike et al., 1998; Hill et al., 2000; Rosenwaike, Stone, 2003).

We had no need to apply the scoring system of match rating suggested in previous studies (Hill et al., 2000; Rosenwaike, Stone, 2003), because the availability of supplemental information in genealogy records made the judgment about match or non-match perfectly clear. If the names and years of birth for parents and siblings are in a good agreement in both the genealogy database and census, the match is considered to be very confident. On the other hand, if the names of parents are the same in the census and genealogy, but siblings have different names, it is quite clear that the match is not acceptable. In some rare cases of small families with one or two children, additional information about places of birth for parents and children was used to resolve the problem. Unlike previous studies of linkage to early censuses, we did not encounter problems with persons having common first and last names because detailed information about place of birth for the potential centenarian and his/her siblings (state, county, township) helped to identify the correct match among many potential matches. The detailed information about names, ages and places of birth for parents and siblings available in genealogies helped us to avoid ambiguous matches, which should be common in linkage studies based only on the information about parental names and places of birth and residence (Rosenwaike et al., 1998). The main difficulty we encountered in our search was related to rare and unusual first names, which were spelled in a variety of ways in census indexes.

During the centenarian birth date verification process, we also tested a suggestion that deceased elder siblings of the same name might be incorrectly cited as centenarians in genealogies. Such cases of "identity theft" are well known in centenarian studies. For example, Pierre Joubert, who appeared in the Guinness Book as a 113-year-old man, in reality died at 65 years, whereas his namesake—his son—died 48 years later (see Jeune, Vaupel, 1999). Such a scenario, however, is highly unlikely when detailed genealogies are available, and it was a Canadian genealogist and demographer, Hubert Charbonneau, who demystified the Pierre Joubert case using genealogical methods. In complete and detailed genealogies, this scenario of "identity theft" looks highly unlikely. Almost all genealogies with families having deceased children (88 percent) reported all children, including those who died in infancy. Only in two out of 198 such families the younger child was named after his or her elder sibling (and this younger sibling was not a centenarian in both cases). Thus, the appearance of a centenarian with a false identity in the genealogy should involve a combination of three relatively rare events: naming a child after a deceased elder sibling, non-reporting the deceased child in the genealogy and survival of a sibling to an advanced age (even a younger sibling should become at least an octogenarian or nonagenarian). Thus, it seems that "identity theft" by centenarians is not a likely phenomenon in detailed and complete genealogies.

This study demonstrated that quality of pre-selected computerized genealogies is good enough for conducting scientific research, if only the detailed and complete genealogies are selected. If birth dates and death dates of persons, as well as their parents, are available in the genealogy, then such genealogies might be considered to be a good starting point for further studies. We found that the quality of birth dates reporting in genealogies is particularly high. Frequency of serious misprints in death dates is higher, although even in this case it is close to 2 percent only. An internal consistency check is a good way to eliminate potential misprints in genealogies, and all cases of extreme longevity require validation.

Study of birth order effects demonstrated that women seem to be more likely to become centenarians if they are born earlier compared to other siblings, when their parents are relatively young. In contrast to women, the birth order of centenarian men initially seemed to be no different than what would be expected by pure chance. These observations corresponded well with earlier published findings obtained on European aristocratic families that daughters conceived to older fathers live shorter lives, while sons are not affected by the fact of their late conception (Gavrilov, Gavrilova, 2000; Gavrilov et al., 2003b; Gavrilova et al., 2003). Obviously the later-born children having a higher birth order are also the children conceived to older fathers (on average). Therefore, one can speculate that the birth order effects observed in this study may be related to paternal-age effects, which were already documented in scientific literature (cited earlier), and were speculated to be attributed to accumulation of deleterious mutations in parental germ (sperm) cells.

However a more detailed subsequent study on the effects of birth order revealed that the birth-order effects in males were simply overlooked because they proved to be not monotonic, as initially assumed, but rather U-shaped (see Figure 2).

For females, the birth order effects are high for low birth orders and then the birth order effects fade out. In other words, it is good for female longevity to be born among the first children, while for the last-born children the exact birth order is less important. It is obvious that these kinds of studies may have significant implications for population studies.

A large number of studies have demonstrated that children with high birth order tend to have a disadvantaged position during childhood years with regard to both health (Sears et al., 1957; Nixon & Pearn, 1978; Kaplan et al., 1992; Elliot, 1992) and educational achievement (Belmont & Marolla, 1973; Belmont et al., 1976; Breland 1973, 1974).

Even if birth order *per se* may not have a direct influence on survival, there are some childhood living conditions important to health and mortality that are related to birth order. An excellent review of the existing hypotheses and facts regarding birth order effects is provided by Modin (2002), which is briefly summarized here.

One hypothesis, called "resource theory," assumes that family resources (both material as well as human) may become diluted as the family grows larger (Blake, 1981, 1989). Thus, in contrast to most first- and earlier-born, children of high birth order are born into conditions characterized by more limited access to parental attention and supervision (Hanushek, 1992). Such limited access to parental care may also result in less attention being paid to the health and safety of these children during their first years of life. It was demonstrated that later born children in large families have a higher risk of accidents during early childhood (Nixon & Pearn, 1978; Bijur et al., 1988). Specifically, children of higher birth orders are more likely to experience accidents at ages between 1 and 5 years (Bijur et al., 1988). Also, among children who had experienced a non-fatal drowning accident, more than half were found to be last-born children of large sibships. The causes of these findings may be lack of time for parental supervision leading to an increased risk of accidents for later-born children of large sibships (Nixon & Pearn, 1978).

Lack of parental attention may result in less efforts invested in the health of the child and disease prevention. Earlier-born children receive more health care (Horwitz et al., 1985) than those of later birth order (Horwitz et al., 1985; Celik & Hotchkiss, 2000; Fergusson et al., 1984) including immunization against diphtheria, smallpox and polio (Kaplan et al., 1992). This relative lack of medical care early in life may have long-lasting consequences on health and mortality later in life.

Other factors that should be taken into account while studying the mortality and health of persons born in the late 19th and early 20th centuries are poverty and a high rate of infections at that time. In the early 20th century, later-born children living in poor families were more affected by the shortage of economic resources and crowded housing during early childhood than their earlier-born siblings. Higher-order children who were born into an already crowded household were at higher risk of infectious diseases, which were very common in the late 19th and early 20th centuries (Burnett, 1991). The higher mortality of later-born infants was found not only for historical data but also for contemporary data on Swedish and Norwegian infants born in 1985-88 (Espehaug et al., 1994).

Another hypothesis providing a possible explanation of birth-order effects is a hypothesis of the "biological depletion" of the mother, explaining the often-observed higher mortality of children born in the end of the mother’s reproductive life (Chidambaram et al., 1987; Majumder, 1988).

Interestingly, the recent Swedish study of birth-order effects on adult survival at ages 20-54 years (Modin, 2002) has produced results that are similar to the findings presented here. Specifically, this study also found a U-shaped dependence of survival chances as a function of birth order. This study of adult mortality revealed that "*a hump-shaped association appears to exist for both men and women, with first* *and very late borns having approximately the same mortality risk*" (see p. 1059, Modin, 2002), while individuals with intermediate birth orders (3-6) had the highest risk of death at adult age (Modin, 2002). Because of the inverse relationship between mortality and survival, this "hump-shaped association" for mortality corresponds to the U-shaped association for survival chances described in our study. No good theoretical explanation had been suggested so far for this puzzling observation, but a speculation was made that "*having a large number of [older] siblings may well be considered a resource in many respects. Older brothers and sisters may serve as role models for younger siblings, and they are often important sources of social support*" (see p. 1051-1052, Modin, 2002). Therefore, "*it is possible that, at adult and old age, having a large number of [older] siblings acts as a buffer against ill health and mortality by means of greater access to social support from the family of origin*" (see p. 1059, Modin, 2002). Later-born children are also heavier at birth, on average, which is considered to provide a survival advantage (Magnus et al., 1985; cited in Modin, 2002). Heavier newborn children are less prone to many diseases in adult life (Barker, 1998). Another interesting observation of this Swedish study, which corresponds well with our findings, is a stronger birth-order effect in women when compared to men (Modin, 2002). This Swedish study also found that the birth-order effects on human mortality and survival are qualitatively different in different age groups, which adds to the complexity of this problem (Modin, 2002).

We believe that further more detailed studies are necessary to explore the mechanisms of birth-order effects. The importance of this exploratory study is in (1) detection of significant birth-order effects on chances of survival to extreme old ages; (2) demonstration that these birth-order effects may have a complex U-shaped dependence, and, therefore, may be overlooked in previous studies assuming monotonic dependence.

Study of other early-life living conditions. Studies of exceptional longevity using genealogical data require a choice of an appropriate control group. One approach is to use a population-based control group. We applied this approach in studies of early-life conditions and survival to age 100 using a control group taken from IPUMS (see earlier). Our findings agree with previous reports on the effects of childhood conditions on survival to advanced ages (Preston et al., 1998; Hill et al., 2000). However, we should admit certain limitations of our study. Comparison with population samples assumes that differential survival is the only cause of differences between cases and controls. However, in our case computerized genealogies of good quality may not represent a random representative population sample. The absence of African American centenarians is one obvious bias of our sample, which can be explained by difficulties in genealogy compiling because of the paucity of historical information for African Americans, lower popularity of this genealogical activity among African Americans and less attention to date and age recording (see Hill et al., 1995), which selected out potential African American genealogies during our initial screening. For other studied variables, the possibility of bias is not so certain. The proportion of genealogies compiled for families originating from the New England and Middle Atlantic regions is by no means lower than for families originating from the Western region, because of the much longer documented history of New England and East Coast families. There is no reason to believe that household characteristics are different for families covered by genealogies and the general Caucasian population. The definite answer to this question could be obtained by comparing computerized genealogies for "normal" (non-centenarian) individuals with population characteristics drawn from the IPUMS database, a study that we hope will be conducted in the future.

Data from early censuses linked to computerized genealogies add additional important information about conditions during a person's childhood. In this study we compared data for centenarians with population-based controls. This approach allowed us to study the effect of early place of residence on the chances of survival to advanced ages. In addition, there might be other approaches for the choice of control group. One approach is to select a family of neighbors enumerated on the same or adjacent page of an early census, which has a child of the same age, and use this family as a control. Another approach is to take a control group from the genealogy (e.g., sisters- or brothers-in-law) and link these individuals to early censuses as well. In both cases we can alleviate a problem with potential bias caused by selection of genealogies, but lose an opportunity to study the geographical effects of early residence (cases and controls have the same or almost the same place of residence).

In general, our results support the idea that early childhood conditions might be important for survival to advanced ages (Gavrilova et al., 2003; Costa, Lahey, 2003). Possible mechanisms of these early-life effects were discussed at the international symposium, "Living to 100 and Beyond" where the earlier version of this study was presented. In particular, Thomas Edwalds, the President of the Chicago Actuarial Association, has suggested the following useful comments, now published in the "Living to 100" monograph: "*The first [comment] concerns the Gavrilov study and [parental] farm ownership being a significant factor [for a child to survive to 100]. Without the type of food processing that's currently available, living on a farm 100 years ago meant fresher food with more nutrient value. It very well might correlate to prenatal and perinatal nutrition to have that as one of your significant factors predicting the mortality at advanced ages.*" (published online, see page 5 at: http://library.soa.org/library-pdf/m-li05-1_tr4.pdf).

Indeed, our findings are consistent with hypothesis that the chances of becoming a centenarian are inversely related to the level of the sickness burden in early life (measured through the level of child mortality) in compared groups of U.S. populations. This conjecture follows from comparison of the results of an earlier study by Preston and Haines (1991) on child mortality in the 1900 U.S. population with the results of our study on longevity chances in the same groups of the U.S. population. Specifically, families of farm owners had lower child mortality (see p.113 in Preston and Haines, 1991), and more long-lived children (our study, see Tables 5 and 6) than families renting a home.

Also, children born in the North Atlantic region of the United States had higher child mortality in the 1900s compared to the Western region (see p.112 in Preston and Haines, 1991). These findings correspond well with our observation that children born in the Western region of the United States in the same time period are more likely to become centenarians later when compared to children born in the North Atlantic region (see Tables 5 and 6).

It is also interesting to mention that the highest body weight among the World War I recruits was observed among those U.S. recruits who were born in the Western United States (see p.114 in Preston and Haines, 1991). In other words, the heaviest recruits came from the West, and there was a significant negative correlation ($r = -0.65$) between recruits' body weight and levels of child mortality in the regions where recruits were born (see p.114 in Preston and Haines, 1991). These observations suggest that there were indeed large regional differences in the sickness burden, which in disadvantaged regions, led to higher mortality of children, their impaired growth (reflected in lower weights of recruits), and, as we found in this study, lower chances of surviving to 100 years. Obviously, this historical correlation between child mortality and weight attained by young adults may not be applicable to modern populations of industrialized countries because of growing obesity problems.

CONCLUSIONS

This exploratory study has a number of new and interesting implications for demographic research. In general, this study has demonstrated that an ongoing revolution in information technology and computer science has created new opportunities for biodemographic studies on human longevity. Millions of individual records on human lifespans are now computerized and are available online (Social Security Administration Death Master File, genealogical records, etc.). Moreover, detailed information for each member of the entire population of the United States has become available online in the form of images of the early U.S. censuses, including the most recent publicly available 1930 U.S. census.

This study has demonstrated the opportunities of using these rich information resources for developing a reliable database for biodemographic studies on human longevity. In this exploratory study, we found that the best way to start human longevity database development is to first use the family-linked data available in computerized genealogies.

We found that contrary to the common belief in the poor quality of genealogical data, this information resource is highly valuable if we follow certain methodological guidelines uncovered in this study.

These methodological guidelines are:

1. To use only those genealogical records that contain complete, exact and detailed dates of birth and death, places of birth and information on parental names and lifespans.
2. To use this genealogical data as a starting point only, subject to subsequent external validation with the Social Security Administration Death Master File and the early U.S. censuses.

Perhaps most important, a particular procedure of data matching and cross-checking has been applied in practice, which produced a reliable dataset with several hundred family-linked records for individuals with exceptional longevity.

Other implications of this study are related to the identified putative predictors of human longevity. It came as a surprise to us that the geography of a birth place (or factors associated with it) within the United States seems to be an important determinant of human longevity. Our preliminary findings suggest that there may be a threefold difference in chances of survival to age 100, depending on the location of childhood residence. Two kinds of implications are important here. The methodological implication is that future studies should not be limited to a common practice of using a geographically matched control group for comparison purposes, because this study design overlooks the importance of geographic factors. A substantive implication is that the mechanisms of this early-life location effect on human longevity need to be studied and understood, and the alternative trivial explanations (like selection bias) need to be excluded in future studies. Another interesting observation of this study is a very strong effect of farm background on survival to advanced ages, particularly for men.

This study has developed a methodology of using online genealogical, historical and demographic data resources for longevity studies. It also tested some hypotheses on predictors of human longevity and identified determinants of survival to advanced ages. This study has demonstrated the feasibility of subsequent large-scale studies on predictors of human longevity, and provided both a preliminary estimate of the magnitude of the effects of these longevity predictors, and a number of new research ideas that can be pursued as testable hypotheses in future biodemographic studies.

Finally, a method of within-family analysis has been applied to investigate the occurrence patterns for centenarians among siblings, which allows researchers to avoid confounding caused by between-family variation. This approach was implemented using conditional logistic regression with a binary outcome variable describing either a centenarian, or non-centenarian survival outcome. For this in-depth analysis the 198 validated centenarians born in USA in 1890-1893 were identified, and their family histories were reconstructed using the US Censuses, the US Social Security Administration database, genealogical records and other supplementary data resources. The following predictor variables were explored: sex, birth order, paternal age at person's birth, maternal age at person's birth, and the season of birth.

The study found that first-born siblings are more likely to become centenarians when compared to later-born siblings. This protective effect of first-born status can not be simply explained by differences in child mortality, because it persists when a comparison is made with those siblings only who survived to adulthood (age 20). Moreover, even at age 75 it still helps to be a first-born child in order to become a centenarian.

In order to find out the mechanism of the birth-order effect, a multivariate analysis with included parental age variables was performed. This multivariate analysis found that the protective effect of being first-born is driven mostly by the young maternal age at person's birth (being born to mother younger than 25 years). Being born to young mother is the major predictor of human longevity. Moreover, even at age 75 it is still important to be born to young mother in order to survive to 100 years.

The results of this study demonstrate that childhood conditions are indeed very important in determining the chances of exceptional longevity and justify the feasibility of the subsequent large-scale research efforts in this direction.

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Table 1. Comparison of death year reporting in genealogal records and the Social Security Administration Death Master File (SSA DMF)

Age at death reported in genealogy	Number of cases	Difference between the death year reported in genealogy and SSA DMF
100	1	-1
	216	0
	1	1
	6	10
	1	20
101	4	-1
	241	0
	4	1
	2	10
	3	20
102	2	-1
	154	0
	1	2
	1	20
103	73	0
	1	1
	1	22
104	23	0
105	9	0
106	12	0
	2	20
107	5	0
	1	17
109	1	0
110	1	30
114	1	30

Table 2. Number and percentage of genealogical records that were successfully linked to early U.S. census records (for records already confirmed through linking to the Social Security Administration Death Master File, SSA DMF).

U.S. census	Males		Females		Both sexes	
	Number linked to early census record	Percentage linked to early census record	Number linked to early census record	Percentage linked to early census record	Number linked to early census record	Percentage linked to early census record
1900	90	78%	292	79%	382	79%
1910	24	21%	76	20%	100	20%
1920	1	1%	2	1%	3	1%
Total	**115**	**100%**	**370**	**100%**	**485**	**100%**

Table 3. Summary of results of genealogy records' linkage first to the Social Security Administration Death Master File (DMF) and then to the early U.S. censuses

Steps of data verification	Number of records for centenarians born after 1889		
	Males	Females	Both sexes
Initial number of records	160 (100%)	511 (100%)	671 (100%)
Found in the DMF	130 (81%)	421 (82%)	551 (82%)
Found in the early censuses	115 (72%)	370 (72%)	485 (72%)

Table 4. Distribution of centenarians confirmed through linkage to the Social Security Administration Death Master File and early U.S. censuses, by age and sex.

Age at death reported in genealogy	Males	Females
100	40	102
101	34	134
102	28	83
103	9	37
104	2	7
105	1	0
106	1	6
107	0	1
Total	115	370

Table 5. Odds for household to be in the "centenarian" group for selected characteristics in the 1900 U.S. census. Female centenarians.

Characteristic	Odds ratio	p-value	95% confidence interval	
Census region:				
New England and Middle Atlantic	1.00 – reference level			
Mountain West and Pacific West	3.16	0.000	1.81	5.52
South (Southeast and Southwest)	2.05	0.002	1.30	3.23
North Central	2.42	0.000	1.58	3.70
Characteristics of father				
Immigration status				
Father immigrated	0.70	0.035	0.50	0.98
Father native-born	1.00 – reference level			
Literacy				
Father literate (can write)	1.29	0.352	0.76	2.19
Father illiterate	1.00 – reference level			
Survival of siblings in childhood:				
All mother's children survived	1.02	0.917	0.75	1.37
71-99% of children survived	1.00 – reference level			
Less than 70% of children survived	0.85	0.434	0.57	1.27
Household properties:				
Owned farm	1.00 – reference level			
Rented farm	0.63	0.007	0.45	0.88
Owned house	0.62	0.003	0.45	0.85
Rented house	0.26	0.000	0.18	0.37

Table 6. Odds for household to be in the "centenarian" group for selected characteristics in the U.S. 1900 census. Male centenarians.

Characteristic	Odds ratio	p-value	95% confidence interval	
Census region:				
New England and Middle Atlantic	1.00 – reference level			
Mountain and Pacific West	2.68	0.041	1.04	6.90
South (Southeast and Southwest)	1.11	0.797	0.51	2.41
North Central	1.39	0.372	0.67	2.89
Characteristics of father:				
Immigration status				
Father immigrated	0.40	0.019	0.19	0.86
Father native-born	1.00 – reference level			
Literacy				
Father literate (can write)	1.39	0.579	0.50	3.87
Father illiterate	1.00 – reference level			
Survival of siblings in childhood:				
All mother's children survived	0.91	0.734	0.51	1.54
71-99% of children survived	1.00 – reference level			
Less than 70% of children survived	0.93	0.848	0.45	1.91
Household properties:				
Owned farm	1.00 – reference level			
Rented farm	0.60	0.193	0.33	1.11
Owned house	0.28	0.001	0.13	0.58
Rented house	0.20	0.000	0.10	0.40

Table 7. First-born status and exceptional longevity.
The of odds to become a centenarian as predicted by conditional logistic regression (fixed effects).

Variable	Odds ratio	P>|z|	95% Conf. Interval	
First-born status	**1.772**	**0.006**	**1.180**	**2.663**
Male sex	0.404	0.000	0.284	0.576

Number of observations: 950; LR chi2 = 33.75; Prob. > chi2 = 0.0000

Table 8. First-born status of adult persons (20+ years) and exceptional longevity.
The of odds to become a centenarian for those survived to age 20 as predicted by conditional logistic regression (fixed effects).

Variable	Odds ratio	P>|z|	95% Conf. Interval	
First-born status	**1.949**	**0.003**	**1.261**	**3.010**
Male sex	0.458	0.000	0.318	0.658

Number of observations: 797; LR chi2 = 27.54; Prob. > chi2 = 0.0000

Table 9. Father's age, first-born status and exceptional longevity.
The of odds to become a centenarian as a function of birth order and paternal age as predicted by conditional logistic regression (fixed effects).

Variable	Odds ratio	P>|z|	95% Conf. Interval	
First-born status	**1.635**	**0.039**	**1.025**	**2.607**
Born to young father (<25)	1.294	0.484	0.628	2.668
Male sex	0.407	0.000	0.285	0.580

Number of observations: 950; LR chi2 = 34.24; Prob. > chi2 = 0.0000

Table 10. Mother's age, first-born status and exceptional longevity.
The of odds to become a centenarian as a function of birth order and maternal age as predicted by conditional logistic regression (fixed effects).

Variable	Odds ratio	P>|z|	95% Conf. Interval	
First-born status	1.360	0.189	0.859	2.153
Born to young mother (<25)	**1.760**	**0.021**	**1.089**	**2.846**
Male sex	0.407	0.000	0.285	0.580

Number of observations: 950; LR chi2 = 39.05; Prob. > chi2 = 0.0000

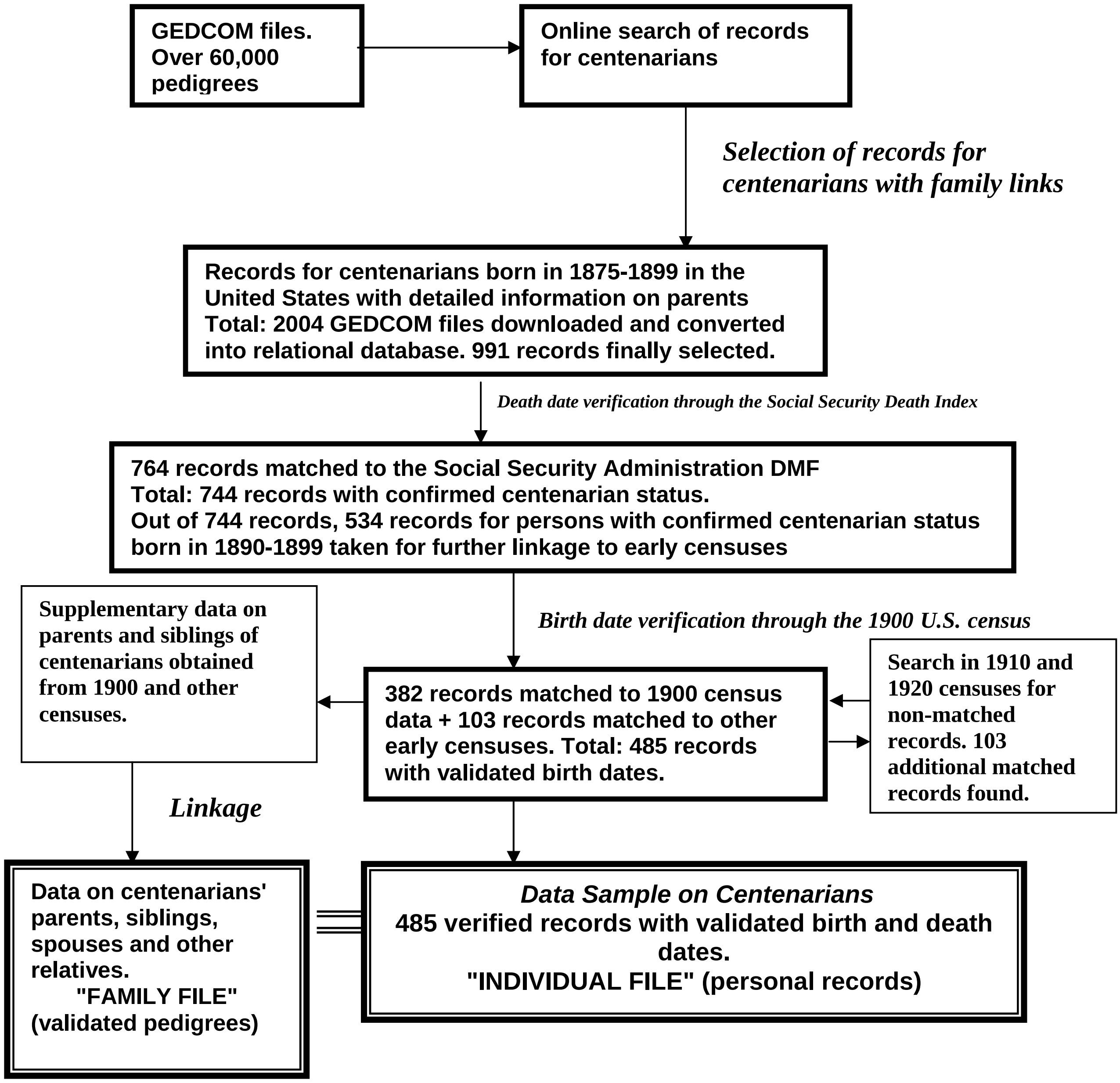

Figure 1. General overview of data collection and data processing protocol.

Beginning in the upper left, we searched the genealogical database Ancestry.com. Then, records for centenarian individuals born in 1875-99 in the United States with detailed information on both parents and grandparents were selected for further verification and analysis.

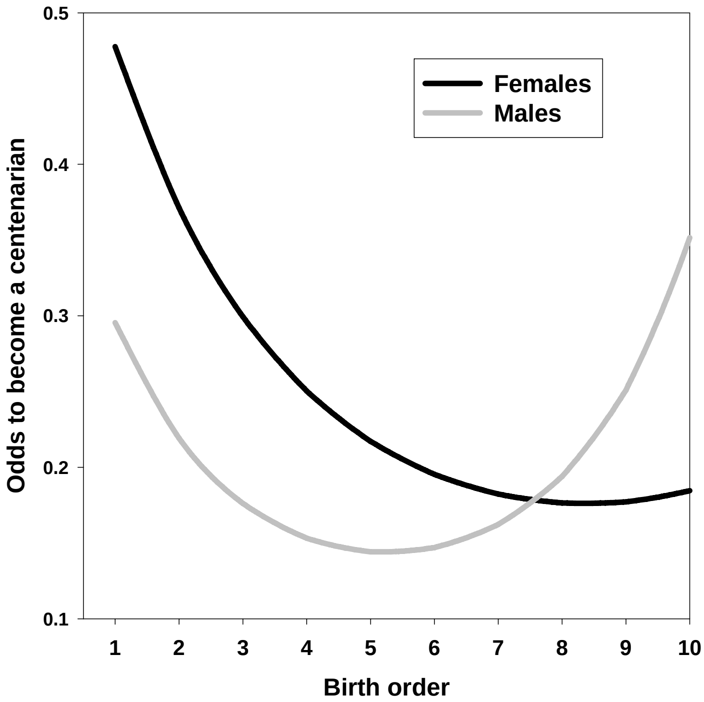

Figure 2.
The dependence of odds to become a centenarian on person's birth order as predicted by the fitted polynomial logistic model.

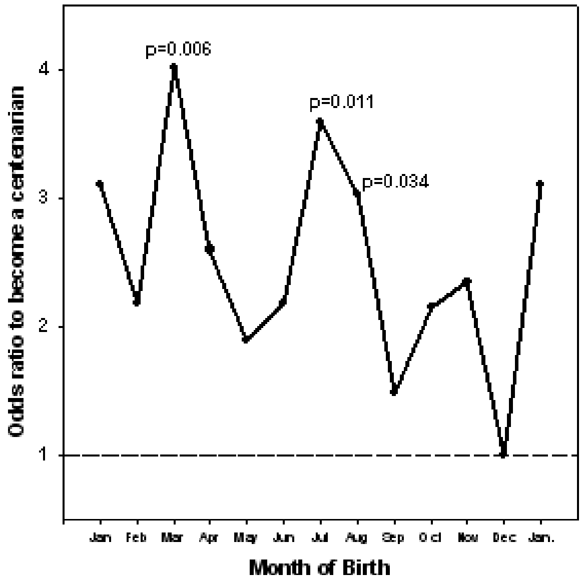

Figure 3. Month of birth and the likelihood to become a centenarian.
The estimates of within-family effects are obtained by conditional logistic regression.

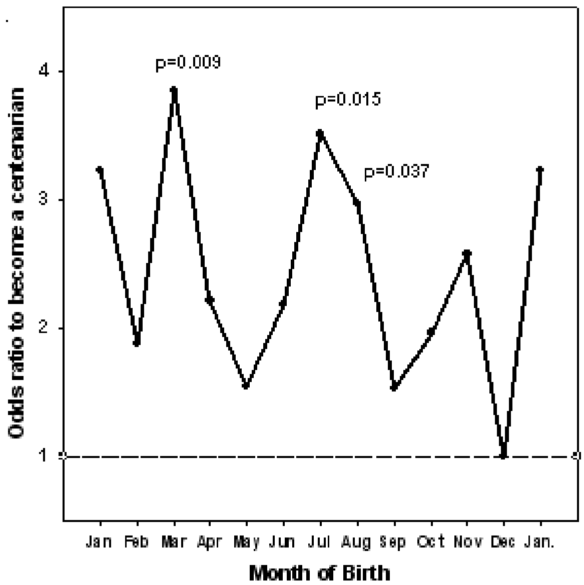

Figure 4. Month of birth and the likelihood to become a centenarian for adult persons (20+ years).
The estimates of within-family effects are obtained by conditional logistic regression.