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Healthy Longevity 2019: Research Article

The Real Facts Supporting Jeanne Calment as the Oldest Ever Human

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Abstract

Background: The 122 years and 164 days age claim of Jeanne Calment, the world oldest person who died in 1997, is the most thoroughly validated age claim. Recently the claim that families Calment and Billot organized a conspiracy concerning tax fraud based on identity fraud between mother and daughter gained international media attention.

Methods: Here, we reference the original components of the validation as well as additional documentation to address various claims of the conspiracy theory and provide evidence for why these claims are based on inaccurate facts or unrelated to the death of Yvonne Billot-Calment, the daughter of Jeanne Calment, in 1934.

Results: Also, countering the contention that the occurrence of a 122 year old person is statistically impossible, mathematical models are presented which also supports the hypothesis that though extremely rare, as would be expected for the oldest person ever, Jeanne Calment's age claim is plausible.

Conclusions: In total, the quality of the investigation supporting the claim of conspiracy as well as the mathematical analysis aiming to back it do not reach the level expected for a scientific publication.

Keywords: Centenarian, Supercentenarian, Demography, Age validation, Mathematical simulation

Since she died at the age of 122 in 1997, Jeanne Calment (JC) has been recognized as the record-holder for longevity of the human species. Though a few researchers have been skeptical based on statistical arguments, most researchers in the field have been convinced by the thorough documentation and validation carried out and published by French researchers, Michel Allard (MA) and Jean-Marie Robine (JMR) with the help of her Doctor Victor Lèbre (1–6). She was at that time and still is among the best documented supercentenarians, that is, people over 110 years old (5,7–9).

However, in December 2018, JC's record of longevity was contested by the gerontologist Valery Novoselov in an interview published on a website (10) and by the laboratory technician Nikolay Zak in a manuscript posted on ResearchGate.net (11). Based upon

inaccurate or unrelated facts, they propose a conspiracy theory, claiming that JC died in 1934 and that her daughter, Yvonne Billot (YB), committed an identity fraud in order to avoid paying inheritance taxes. Novoselov and Zak accused the Calment and Billot families having conspired to commit this identity fraud. Eventually, Zak revised his preprint and it was accepted for publication by Aubrey De Grey, for the journal *Rejuvenation Research* (12).

Most of age claims 115 years and older are false, either intentionally or unintentionally, and thus, it is particularly important to compile multiple forms of proof that agree with one another in order to sufficiently substantiate such claims (13–16). This is even more so the case when a claim would establish a new record for the world's ever-oldest person. JMR and MA therefore compiled and described

multiple pieces of intraconsistent evidence supporting the age of death of JC at 122 years (1,2,4).

In the process of validating the claim, particularly one as rare as the oldest person ever, one must carefully rule out all the possible causes of a false positive. It is particularly helpful, as was the case with JC, for the claimant to be alive at the time of the validation and to be able to ask them questions to both rule in a true positive and rule out a false positive. During the 3 years, from 1993 to 1995, JMR and MA regularly visited and interviewed JC and despite few small inconsistencies not once did these conversations produce a suspicion of fraud and especially not a possibility of an identity switch between mother and daughter.

The hypothesis of an identity switch between mother and daughter is not new. It was already considered in 1995 when the epidemiologist Bernard Jeune (BJ) and demographers Väinö Kannisto (VK) and James W. Vaupel (JWV) went to visit JC the day after her 120 years anniversary and went through all the 30 documents that the French researchers had found in the archives of Arles. In their book about her (1), MA and JMR had included a photo of JC and her daughter Yvonne with the following caption in French "*Quelle est l'une, quelle est l'autre?*", meaning "*Who is who?*" The purpose of the photo was to show just how young JC appeared for her age and thus how slowly she was aging. However, in 1995 when BJ, VK, and JWV were working in the archives of Arles, they focused on any possible confusion of birth records among family members particularly between siblings, but also JC and YB. They found a fraud improbable given the position and the life circumstances of the Calment family in this relatively small city of Arles where many people knew JC and her daughter. BJ, VK, and JWV were more looking for an identity switch with a younger sister than one between mother and daughter.

In this current paper, we are more specifically focused on the switch hypothesis between daughter and mother raised by Zak and Novoselov. After a summary of the steps taken to validate JC's age in the 1990s, we specifically address Zak's contention with new facts of the case. Finally, we discuss why his belief that her claim is mathematically too improbable is incorrect.

Summary of the Validation of JC's Age

Several publications provide the details of the validation of JC's age at death of 122 years. Much of these validation efforts occurred while JC was alive, once she surpassed the age of 117 years. The first step to validate her age claim was to look up her birth record. Since the 16th century and the French Revolution and in the case of Catholics, there are usually two birth registrations, one civil and one religious. In the case of JC, we located both the civil birth record and the baptism record and they exactly corresponded with one another. At that time, the civil vital events were noted in sequential individually bound books, with a new book created for each year. We located her civil birth record in the 1875 book on the correct page of the book corresponding to her birthdate.

Familial Reconstitution Method

Familial reconstitution is a critical part of the validation process, in which one determines that all the relative's ages make reproductive sense (13–16). For example, a case would not be valid if a mother appeared to have a child before the age of 10 or if one sibling was 60 years older than another. In the case of JC's pedigree, all of the ages make sense. Beginning with her birth documents and

the information she provided, we constructed a family pedigree that included JC's parents, siblings, and descendants. All of the birthdates made sense. Her parents married at the age of 23 years. They had four children born in 1862, 1863, 1865, and 1875. The two oldest siblings, Antoine and Marie died in infancy. Her brother, François was born 10 years before her (1,2,4–6).

Regarding the family pedigree, Zak argues that a case such as JC should demonstrate familial evidence of exceptional longevity. Indeed, about 50% of current centenarians have a history of an ancestor living into their nineties or older, but the other half do not, and in the case of supercentenarians (those ages 110+ years), the frequency appears to be even less (Thomas Perls, personal communication). Many potential centenarians died as infants when infant mortality was so high. Also, many adults who had a familial predisposition for longevity did not achieve such ages because of what today would be a readily reversible cause of death (eg, infection, trauma). Still, in the case of JC, JMR and MA have disclosed an exceptional concentration of long-living ancestors. Indeed, JC had a Total Immediate Ancestral Longevity (TIAL) of 477 compared with 289 for the sum of the ages at death of the six immediate controls of the reference family (6).

Multiple Documents from Throughout the Person's Life That Are Consistent in Their Documentation of the Claimant's Age

One of the most important tenets of age validation is that the claimant should have been known within the local community well before the age of 100 years, thus not appearing suddenly at a claimed extraordinary age. Thus, JMR and MA searched for proofs of the existence of JC well before she surpassed the age of 100 years. The general census of the French population, administered by each municipality, offered such proofs. From 1801 to 1946, the census was conducted every 5 years except for 1916 and 1941 because of the wars. Since 1946, the census was carried out irregularly in 1954, 1962, 1968, 1975, 1982, and 1990.

The details of the comprehensive multiple forms of written proof of JC's ages throughout her life, including the above, are noted in reference (4). In the discussion of that article, the gathered evidence was summarized as:

...seven direct civil status documents (i) bear witness to the identity of Jeanne Louise Calment from her birth date to her death. (ii) They are complemented by numerous indirect civil status documents which confirm the sequence of the information (iii) by 14 direct documents from censuses that confirm the age or the birth date of Jeanne Calment [1876, 1881, 1886, 1901, 1906, 1911, 1921, 1926, 1936, 1946, 1954, 1962, 1968, 1975], (iv) and by direct or indirect parish documents, (v) by notarial documents (marriage contracts, sale of a house), (vi) by a medical doctorate dissertation, (vii) and by newspaper articles.

Links to copies of these censuses are provided in the [Supplementary Material \(SOM, A1\)](#).

Though we discuss Zak's arguments below regarding what he views as inconsistencies in the JC age claim, we point out here one issue that he asserts, which is the lack of mention of JC's 100th birthday in the local newspaper. However, this is clearly countered by the 1975 census indicating her date of birth and the fact that many centenarians do not have their birthdays celebrated in the news for a range of reasons. Furthermore, Zak's coinvestigator, Novoselov, in a published interview, indicated that JC was visited by the Mayor of Arles on the occasion of her 100th birthday (10).

Zak also believed that JC's apparent absence from the 1931 census was supportive of his accusation of identity fraud. 1931 was a difficult year for the census since hand-written entries were replaced with typewritten entries and that year's entries are well known for many mistakes; so much so that census officials returned to hand-written entries in 1936 and did not begin to use typed entries until 1962. Some of the many incorrect entries in the 1931 census are shown in the SOM (see SOM, A2)

Claimant Interviews

From their 1993 and 1994 interviews with JC (ages 117 and 118 years), JMR and MA listed the following facts stated by JC who provided these details from memory (Table 1) (4):

Again, regarding Zak's hypotheses, he posited that JC's daughter, Yvonne, could have provided facts to JMR and MA by perhaps access to a diary or other set of records previously in the possession of her mother. In considering this hypothesis, note that had she not died in 1934, at the age of 36, in 1993 YB would have been 95 years old. It is not reasonable to claim that she could provide, for example, the names of JC's godparents based upon her recollection of what she might have read many years previously in an attempt to maintain a fraud.

Additionally, Zak indicated that there was a family move in 1888, when JC was 13, that was not mentioned by JC in the interviews of her by JMR and MA and thus this oversight is an important inconsistency that supports an assertion of a conspiracy to commit fraud. Indeed, we did not learn about this move during our interviews with JC, but we have since determined that the move was only 150 m away in the same neighborhood in 1884 or 1885 when JC was 9 or 10 (not 13) years old (see SOM B). We do not feel it is

remarkable that a minor move such as this at the age of ten would not be mentioned.

The Conspiracy Theory of an Identity Switch

According to a published interview, Novoselov asserted that JC did not look frail enough to be a supercentenarian (10). He referred to the surprise of the Mayor, who made it a habit to visit centenarians on their birthdays, that at age 100 years, JC appeared so spry. Actually, such spryness is exactly what one would expect from a 100-year-old destined to live another 22 years, to the age of 122 years.

In their study of people living to supercentenarians, New England Centenarian Study (NECS) investigators noted that the morbidity and disability profiles of these individuals support James Fries compression of morbidity hypothesis (17,18). That is at the limit of human life span, aging-related diseases and syndromes that increase mortality risk must be delayed towards the time of death. The NECS found that supercentenarians generally require minimal or no assistance with their activities of daily living or clinically manifest any of the major aging-related diseases (heart disease, stroke, diabetes, hypertension, cancer, or chronic obstructive pulmonary disease) at the mean age of 106 years (17).

Photos of both JC and Sarah Knauss, who died at the age of 119 years in 1999, are examples of how supercentenarians have a history of aging so remarkably slowly. Supercentenarians are typically characterized as having delayed or escaped major diseases and compressed the time they experience severe decline towards the end of their extremely long lives, and it is not until the relatively short time at the end of their lives that they demonstrate frailty (Figure 1).

Nonetheless, Novoselov approached Zak to analyze available mortality data to determine whether mathematically, JC was an impossible outlier (10). From his preprint uploaded on Researchgate.

Table 1. Facts Provided by Jeanne Calment to Jean Marie Robine and Michel Allard During Their 1993 and 1994 Interviews with Her

(i)	She was born on February 21st, 1875 in Arles;
(ii)	Her father, Nicolas Calment, was a shipbuilder;
(iii)	Her mother, Marguerite Gilles, was from a family of millers;
(iv)	Her godfather was named Louis Pages [or Paget];
(v)	Her godmother was Jeanne Gilles, her maternal aunt;
(vi)	She had a brother, François Calment, who was ten years older than her and who died at 97 years of age;
(vii)	She married her cousin, Fernand Calment;
(viii)	They lived for some time with Mrs. Maria Calment, [maiden name Felix], her mother-in-law;
(ix)	Ever since, she lived in the same house in Gambetta Street [at the corner of St-Estève Street, next to Rue de la République], in an apartment located above their department store named "Grand Magasin Calment";
(x)	She left this house when she was 110 years old to live in a nursing home, "La Maison du Lac" where we met her;
(xi)	She gave birth to one child, a daughter, Yvonne, [Calment], born in Arles;
(xii)	Her daughter married [Captain] Joseph Billot;
(xiii)	They had one son, Frédéric [born Billot];
(xiv)	Her daughter Yvonne died when she was 36 years old;
(xv)	Her grandson, Frédéric Billot, also died at 36 years old;
(xvi)	She mentioned Marthe Fousson, one of the first servants she had in her service, when she was newly married [Marthe was noted in the 1906 and 1911 censuses as living with the family].

Note: Annotations from JMR are provided in brackets (5).



Figure 1. Photos of Sarah Knauss, ages 99 years and 119 years (the latter by Theo Westenberger) and Jeanne Calment at 116 years and 122 years.

net, it appears that Zak concludes that it was mathematically impossible for a person to reach the age of 122 years. He then researched what had been written about JC and subsequently constructed a story that he believes supports a case of fraud (11,12).

In the preprint, Zak devotes just a few paragraphs to his mathematical refutation of JC's age claim. He bases his conclusion on two assumptions in both the preprint and later in his article, that "the force of mortality is almost constant after 105 years" thus half of supercentenarians die "during any year of follow up," and that it "does not vary much with sex, country and year of birth" (11,12). Initial studies argued for an exponential increase in the mortality rate at older age but then a deceleration at extreme ages. In fact, it is difficult to assess if mortality rates keep increasing with age or tend towards some mortality plateau. Data quality issues combine with small numbers to render these issues to be quite complex and thus approaching the problem with one possible model is incorrect. Zak declined to investigate multiple possible models of mortality. Also, given that generally 85% of centenarians and 90% of supercentenarians are female, considering that there are no differences in sex is grossly incorrect. We formally address the statistical plausibility of a person living to age 122 years later in this paper.

To support the hypothesis of an identity switch one must have a motive justifying such a fraud, and then show that such a substitution was practically possible. As for a motive for why the Calment and Billot families would conspire to commit fraud, Zak wrote,

"Perhaps the Calment family suffered from taxation after the death of Maria Felix (widow of the founder of the store, Jacques Calment) and especially after the death of Jeanne's father Nicolas Calment, the owner of land and real estate in the surrounding villages in 1931. The inheritance tax for the farm in Saint Martin de Crau could amount to hundreds of thousands of dollars in modern money. It is not hard to imagine that the family had neither desire nor ability to pay the tax, especially twice in a row (here, one should recall that Jeanne hated socialists)." (12)

This motive is not only speculation, it has no basis. In actuality, French real estate transactions have resulted in notarial deeds for centuries. These documents are publicly available after 70 years and in the case of JC a dozen transactions established before 1949 are available (see SOM B). Zak is negligent in not noting that Nicolas Calment (NC) had given all his property to his children on March 15, 1926 in exchange for an annual life annuity of 5,000 francs that his children had to pay him until his death. The only financial consequence upon the death of NC in 1931 is the extinction of the life annuity.

According to Zak, another motive could be an annuity contract presumably signed before 1934 and still in operation at the time of her death in 1997 (12). This second motive seems also to have no basis as it is not reported in the declaration of assets that JC made in 1946 on the occasion of the national solidarity tax in application of the Ordinance of August 15, 1945 (see SOM B).

An important argument against Zak's conspiracy theory is the fact that the Calment family was a well-known family in Arles. Her father-in-law had established the local and prominent department store, Grand Magasin Calment, and her father was a city councilman. Yvonne's husband was a member of the French Legion of Honor. Novoselov, in his interview (10) stated that the community would not have noticed a switch because Arles is actually based in a large county and that JC and her daughter spent some of their time in a homestead 16 km away from Arles. Zak himself negates this notion in his preprint stating that "Jeanne Louise Calment had been alive for 12 years and 164 days after her 110th anniversary and was under close (and with growing age) scrutiny from the general public and scientific community" (12).

Since Zak's accusations of fraud and conspiracy, at least four relatives have released photos showing that Yvonne was, before her marriage in 1926, active and well-integrated within her social group of young women (See SOM C). Of course, this social circle of friends would have been deceived into believing that it was JC who lived beyond 1934, rather than her daughter, YB. According to the local press, at the funeral of YB in 1934, "A huge crowd drove last Saturday to her last home, Mrs. Billot Calment died at the age of 36 years." (see SOM C). The death notice of YB has been sent on behalf of 34 people and their children, the staff of the House Calment and 13 different families (see SOM C for the notice). People were invited to gather at the family house and we can guess that many of them attended the funeral wake. In these circumstances, unless we accept the idea of the complicity of dozens of people, a substitution between the bodies of JC and YB was virtually impossible.

Also, such a substitution would have led to an incestuous family configuration. Frédéric Billot, the son of YB, was 7 years old when his mother died in 1934 and Fernand Calment, the husband of JC was still alive for several years beyond Yvonne's death. Therefore, according to Zak, YB took the place of her mother and therefore Fernand and Yvonne would have had to act as if they were married. Frédéric, at the age of seven would have had to act as if his mother had died and pretend that Yvonne was really his grandmother, rather than mother. His own father, Captain Joseph Billot, the husband of Yvonne, would have had to be complicit with the ruse. A conspiracy to commit identity fraud would have required the participation of many people.

Zak also asserted that Yvonne's absence from the 1931 census was evidence of fraudulent behavior. In fact, the reason she is not listed is because at the time, she was staying in Leysin, Switzerland, being possibly treated for tuberculosis (Figure 2). Leysin was home to a number of sanatoriums for the treatment of tuberculosis, and a famous one in particular, the Sanatorium Universitaire (19).



Figure 2. Photo of Yvonne in 1931, staying in Leysin, likely at one of its numerous sanatoriums for treatment of tuberculosis.

Yvonne's stay in Leysin, 3 years before her death underlies that she was an ill woman at the time and speaks to the authenticity of her death at the age of 36 in 1934. JC had told MA and JMR that her daughter's illness had started after the birth of Frédéric. At the end of this conversation, JC turned to Victor Lèbre, her doctor, saying, "When they put me in the coffin, put the photo of my grandson at my right, and the one of my daughter at my left, and they will be buried with me. Oh, that will only be an imaginary burial, they are both in the ground already, but that way, they will be beside me." (1,2)

A military file of Joseph Billot, YB's husband, indicates a granted leave on personal grounds for 5 years from June 10, 1928 and then renewed for another 5 years on June 10, 1933 (See SOM C). A 1928 letter written by Joseph Billot's superior, indicates the reasons for the requested leave; namely the poor health of his wife. He wrote "Captain Billot made an application on March 30, 1928, to be admitted for a granted leave. It is with regret that he leaves the army, but his interests and the health of his wife oblige him to go to live in the South, near Arles." (see SOM C). The new documents consulted since Zak's story are consistent with the fact that Yvonne was sick, presumably suffering from tuberculosis, a major cause of death at the time (20).

The paragraph of Zak on a possible fibroma is another weakness "In one of the few photographs of the young Yvonne that exist, one can see a small fibroma on the nose (it could be a scan defect, but it is also visible on different scans). A similar fibroma can be seen in one of the photos of the old Calment. Interestingly, it is absent from later photos, indicating that it was removed. If Yvonne removed it more than once, that could explain its slightly different locations in Figure 3A and B and also the fact that the fibroma appears smaller in the older woman, even though fibromas grow over time." None of the photos of the young YB (see SOM D) and the many photos of JC taken after 1936 (see SOM D) shows a fibroma. In Figure 3B, of the Zak paper, JC is 114 years old. Zak suggests that the fibroma has been removed when JC was a resident of the nursing home Maison du Lac. Of course, there is no mention of such intervention in the dissertation of Catherine Levraud (21) where she summarizes, with great detail, the medical history of JC after her arrival in the nursing home, between the ages of 111 and 118. Other weaknesses of his arguments, for instance about JC's size and JC's eye color have already been pointed out by the publication by Le Bourg (22).

The Statistical Plausibility of a Human Surviving to Age 122 Years

Zak's interest in the sociodemographic aspects of the JC age claim began with his contention that JC's ability to survive to age 122+ years is mathematically impossible. Thus, here we also refute his mathematical argument.

In the broadest sense, the statistical universe of JC is composed of all the lifetimes of human beings throughout the world. Of course, the ages of survival for the vast majority of these lives are unknown.

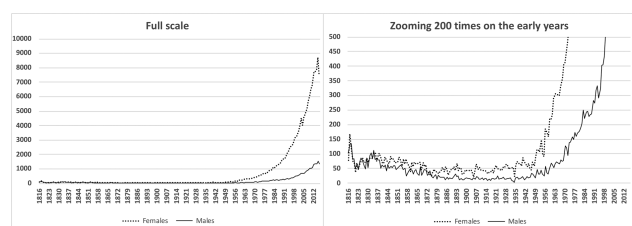


Figure 3. Number of deaths at aged 100 years and older, France 1818–2016, according to the Human Mortality Database. Source: <https://www.mortality.org>.

Therefore, we consider a subset within a defined period of time where we have some degree of confidence in its completeness and a substantial similarity in terms of sociodemographic and culture to JC. Thus, we chose France where JC was born and where she lived, and for which we have continuous information on the ages at death since 1816. These data, assembled by the General Statistics of France, and then by the National Institute of Statistics and Economic Studies are available at the Human Mortality Database (HMD, <https://www.mortality.org>). In this database, approximately 142 million deaths were recorded in France between 1816 and 2016 and are segregated by sex, by single age from age 0 to an open-ended age group "110+," by year of birth from 1706 to 2016 and by year of death. Figure 3 displays the changes over time in the number of deaths recorded at aged 100 years and older for both males and females.

Overall, the number of deaths of centenarians did not increase in France until the post WW II period for women and the 1990s for men. The zoomed in view on the right panel shows that the number of centenarians decreased during the initial period, from 1816 to 1880, probably due to the improvement in the quality of the statistics and then remains stable during a second period, from 1880 to the end of the WWII. In 1975, when JC turned 100 years old, 684 deaths of centenarian women were registered, and in 1997, the year of her death, there were 2,727 deaths recorded. As the HMD data are censored beyond the age of 109, we have supplemented them with data from the International Database on Longevity – IDL (<https://www.supercentenarians.org>), compiling lifetimes greater than 105 years. These data relate to 9,466 individual records of people who died between 1982 and 2017 in France. Although virtually no one died at age 105 or older in the 1980s, there are several 100 deaths recorded above this age in the most recent years. They are mostly women.

The Exceptional Case of JC

Figure 4 depicts the age at death of JC (1997, age 122 years) in the context of the above described data. Over the long term, changes in the Maximum Reported Age at Death (MRAD) demonstrated large fluctuations and much smoother changes were observed with the measure Highest Age Providing at Least 30 deaths (HAPaL_30). Thus, we chose HAPaL_30 to assess the limits of longevity without its extreme fluctuations. The 122-year lifetime of JC is not only quite far from the value of HAPaL_30 which reached 106 years in 1997 when JC died but also from the values of the MRAD in the

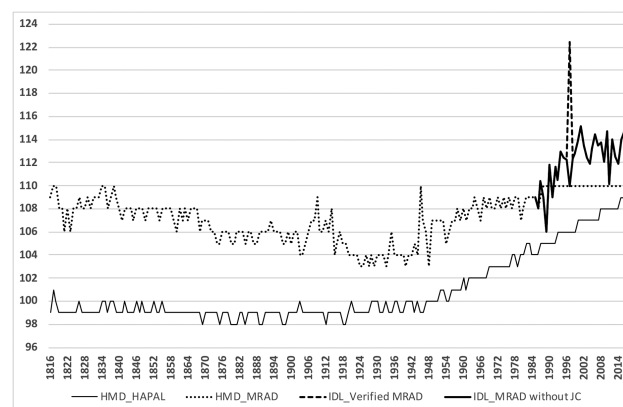


Figure 4. Individual observations and statistical indicator of Maximum Life Span (MLS): Maximum Reported Age at Death (MRAD) and Highest Age Providing at Least 30 deaths (HAPaL_30), females, France, 1818–2016. Source: <https://www.mortality.org> and <https://www.supercentenarians.org>.

neighboring years, that is, 112 years. Obviously, 122 years appears as an outlier, even among the extreme values measured by the MRAD.

Cohort Reconstruction and Modeling

Using the death data described above, organized by single age, period, and cohort of birth (Lexis triangles), we reconstructed the cohorts born in 1875 as in the case of JC and in 1903, the most recent extinct cohort, and computed the probability (q_x) that someone aged $A_{[x]}$ will die before reaching age $A_{[x+1]}$. Then, we plotted the mortality risk expressed as the line plots of q_x over age and modeled it using three usual functions: three-parameter exponential ($b_0 + b_1 b_2^{Age}$), four-parameter Gompertz function = $b_0 + b_1 \exp(-\exp(-b_2 (age - b_3)))$, and four-parameter logistic function = $b_0 + b_1 / (1 + \exp(-b_2 (age - b_3)))$ (equations 1–3).

Equation 1: Exponential

$$q_x = b_0 + b_1 b_2^{Age}$$

Equation 2: Logistic

$$q_x = b_0 + \frac{b_1}{1 + e^{-b_2 (Age - b_3)}}$$

Equation 3: Gompertz

$$q_x = b_0 + b_1 e^{-e^{-b_2 (Age - b_3)}}$$

Modeling of the mortality risk of the 1875 and 1903 birth cohorts using exponential (short dash line), Gompertz (plain line), and logistic (long dash line) functions are shown in Figure 5. The open dots correspond to the one used to compute the models. The plain dots correspond to ages above (HAPaL_30), those with less than 30 deaths occurrence and excluded from the models. The parameters of the models are given in Table 2 along with their coefficient of determination, which exceeds 99%.

For determining the probability of reaching JC's age, we used the fitted parameters to generate three sets of simulations. The exponential function diverging too quickly was not used here.

Simulations set 1: starting with a sample of 10 centenarians, we applied at each age the mortality risk of the logistic and Gompertz functions with a pseudo-random number generator determining the death or living status of each virtual centenarian until the extinction of the whole sample. The simulations were run 500,000 times to determine the maximum age that could be reached and the probability of reaching it with its binomial exact 95% confidence interval.

Simulations set 2: same as above but starting with 500 centenarians and 100,000 runs.

Simulations set 3: same as above but starting with 100,000 centenarians and 500 runs. All computations were performed with the

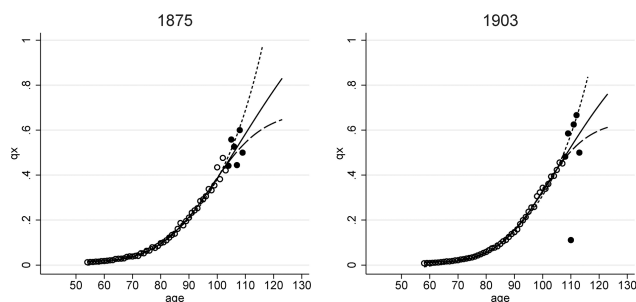


Figure 5. Modeling of the mortality risk of the 1875 and 1903 birth cohorts.

Stata software release 15.1. Results of the 12 sets of simulations (3 samples size \times 2 models \times 2 cohorts) are given in Table 3.

With samples of 500 and 100,000 centenarians, the maximum age ranged from 120 to 123. The Logistic and Gompertz models yield similar results, with the Logistic 1903 outperforming the others by a small margin. It must be underlined that these maximum ages were observed even when extrapolation of the functions leads to q_x exceeding 0.6 that is a probability of dying above 60%. Thus, in silico, JC's age can be reached and even exceeded, even though the probability remains very low.

In the best simulation set (set 3 and Logistic 1903), this event occurs on average once every 10 million centenarians. Such a result is compatible with previous estimations (23,24) including a first estimation proposed by Väinö Kannisto and Roger Thatcher (unpublished in 1993, available on request).

Based on these data, the survival of JC to 122 years is possible. Considering that the world has experienced somewhere between 8 and 10 million centenarians since at least the 1700s, then a person age 122 years by around the late 1900s is reasonable. According to the Population Division of the United Nations, by 2100, the global number of centenarians within a single year could be as high as 25 millions (25) and so the observance of yet another person age 122 or perhaps even a little older is also reasonable.

Conclusion

Jeanne Calment claim as the record-holder for longevity for the human species, at the 122 years and 165 days, remains valid. The material gathered in favor of its accuracy far outweighs Zak's hypothesis of identity fraud. Our mathematical models show that a person achieving the age of 122 years by the late 1990's would be possible. Empirically though, the only way to assess that it is an accurate observation is to examine the evidence supporting and challenging the age claim.

Zak never mentioned the existence of well-validated extreme cases of longevity. Sarah Knauss, who passed away at age 119 in 1999, and Marie-Louise Meilleur, who died at age 117 years in 1998, make JC appears less exceptional than if, for example, the next oldest person was 115 years old. Since 2015, five other women have reached the age of 117 years: three of them in 2017 (the Japanese woman Misao Okawa (26), the Italian woman Emma Morano (27) and Violet Brown from Jamaica) and two of them in 2018 (the Japanese women Nabi Tajima and Chiyo Miyako (26)). The cases of Violet Brown and Nabi Tajima have not yet been thoroughly validated.

Should Zak and his colleagues wish to contest Sarah Knauss' age, they should keep in mind that not only was her age also well validated with multiple documents throughout her life, the age of her daughter Kitty, who lived to 101 years, was also validated (correspondence with the New England Centenarian Study).

Table 2. Parameters of the Mortality Models with Their Coefficient of Determination

(R^2) Model	b_0	b_1	b_2	b_3	R^2
Logistic 1875	0.0071	0.6819	0.1078	97.8033	0.9921
Logistic 1903	0.0062	0.6403	0.1241	99.7883	0.9986
Gompertz 1875	0.0160	1.4365	0.0379	108.0642	0.9917
Gompertz 1903	0.0138	1.1814	0.0463	106.1697	0.9979

Table 3. Maximum Age Reached According to 12 Simulations Sets with Varying Sample Size and Resampling

Model	Simulations Set 1	Simulations Set 2	Simulations Set 3
Sample size (number of centenarian)	10	500	100,000
Number of resampling	500,000	100,000	500
Logistic 1875			
Maximum age	119	121	121
Probability of maximum age or 122+	3/50,000,000	4/50,000,000	3/50,000,000
Lower bound 95% CI	0.000000124	0.000000218	0.000000124
Upper bound 95% CI	0.000001750	0.000002050	0.000001750
Logistic 1903			
Maximum age	121	123	123
Probability of maximum age or 122+	2/50,000,000	2/50,000,000	5/50,000,000
Lower bound 95% CI	0.000000005	0.000000005	0.000000325
Upper bound 95% CI	0.000001110	0.000001110	0.000002330
Gompertz 1875			
Maximum age	120	122	120
Probability of maximum age or 122+	1/50,000,000	1/50,000,000	1/50,000,000
Lower bound 95% CI	0.000000005	0.000000005	0.000000005
Upper bound 95% CI	0.000001110	0.000001110	0.000001110
Gompertz 1903			
Maximum age [year]	119	122	121
Probability of maximum age or 122+	1/50,000,000	1/50,000,000	2/50,000,000
Lower bound 95% CI	0.000000005	0.000000005	0.000000005
Upper bound 95% CI	0.000001110	0.000001110	0.000001110

Note: CI = Confidence interval.

We have identified three main limitations of this study. First, time and space limitations to answer in this journal to the dozens of arguments challenging the reported age of JC gathered by Zak and Novoselov. Therefore, we only focused on the main arguments concerning the motive and the practicability of the identity fraud. However, we examined many other arguments and we discovered some errors which at least show great negligence in their work. Second, legal limitations as the most recent financial transactions concerning JC will not be publicly available before 2067, 70 years after her death. Third, ethical limitations as the most recent transactions involved people who are still alive. For instance, some allied families close to the Calment/Billot family informed us about the most recent financial transactions but asking us not to circulate this information. In other words, there is still many material to confirm the biography of JC.

As expected for the age of the oldest person in the world, the probability of her occurrence is extremely small. In his published interview in leafscience.com, Novoselov requests a revalidation of the case of Jeanne Calment. In a way, it is what we have provided with this paper showing that JC remains the oldest human whose age is well-documented.

In conclusion and coming back to the paper published by Zak, we would like to stress the unacceptability of publishing an article with such unfounded accusations claiming that members of the Calment and Billot families collectively committed fraud. How was it possible that a paper so full of unsubstantiated assertions could survive a responsible peer review and subsequently be published in *Rejuvenation Research*? Based on the evidence that we bring in this paper, we call for a retraction of Zak's article.

Supplementary Material

Supplementary data is available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

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Author Contributions

All authors, J.M.R., M.A., F.R.H., and B.J., equally contributed to the design of the study and the writing of the paper. J.M.R. and B.J. drafted the first version of the paper. F.R.H. and J.M.R. coordinated the mathematical part.

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Conflict of Interest

None reported.

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