Heliyon 10 (2024) e30074

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Opt-in or out? Public perspectives on forensic DNA kinship investigations within the Dutch-speaking community

Sofie Claerhout [a,b,c,*], Hanna Noppe [d], Betty Cohn [e], Pascal Borry [f]

[a] *Laboratory for Forensic Genetics, Forensic Biomedical Sciences, KU Leuven, Leuven, Belgium*
[b] *Interdisciplinary Research Facility, KU Leuven Kulak, Kortrijk, Belgium*
[c] *Centre for Sociological Research, KU Leuven, Leuven, Belgium*
[d] *Biomedical Forensic Sciences, KU Leuven, Leuven, Belgium*
[e] *Institute of Public Health Genetics, University of Washington, Seattle, USA*
[f] *Center of Biomedical Ethics and Law, Department of Public Health, KU Leuven, Leuven, Belgium*

ARTICLE INFO

Keywords:
Forensic DNA kinship investigation
Cold cases
Familial DNA searching
Genetic genealogy
Y-chromosome
Ethics and privacy

ABSTRACT

Forensic DNA kinship investigation involves analyzing genetic relationships between individuals to offer new leads for solving (cold) cases. Familial DNA matching has become a valuable asset in criminal case investigations, especially when traditional DNA methods hit dead ends. However, concerns surrounding ethical and privacy implications raised questions about its implementation and acceptance among the general public. The present study investigated the public perspectives regarding forensic DNA kinship investigations among 1710 Dutch-speaking Belgians using an online cross-sectional survey. The questionnaire consisted of three categories, including personal information, DNA knowledge, and their opinion on several familial DNA searching and investigative genetic genealogy related questions. The participants' average DNA knowledge score was 71 %, indicating a relatively high level of understanding of DNA-related concepts. Remarkably, the study revealed that 92 % of the participants expressed willingness to cooperate as a volunteer in a forensic DNA kinship investigation, irrespective of their scientific background or educational level. Key factors influencing participation included assurance of painless sampling and robust privacy safeguards. Participants lacking familiarity with DNA hesitated more towards participating in forensic DNA analysis, referring to "the fear of the unknown". Despite ethical and privacy concerns, the highly positive attitude towards forensic DNA analysis reflects a level of empathy and willingness to contribute to the pursuit of justice. Nearly all participants (95 %) agreed to use online DNA databases for resolving violent crimes with forensic genetic genealogy, but half emphasized the need for prior informed consent, referring to the current "opt-in" system. The results underscore the need for stringent regulations and ethical oversight to ensure the responsible use of genetic data while striking a balance between public safety and the protection of individuals' privacy rights. These findings add to the growing body of evidence regarding the potential benefits of forensic DNA kinship matching as a tool in criminal investigations, suggesting its potential future utilization and legalization.

* Corresponding author. Laboratory for Forensic Genetics, Forensic Biomedical Sciences, KU Leuven, Leuven, Belgium.
E-mail address: sofie.claerhout@kuleuven.be (S. Claerhout).

https://doi.org/10.1016/j.heliyon.2024.e30074
Received 15 August 2023; Received in revised form 15 April 2024; Accepted 18 April 2024
Available online 24 April 2024

1. Introduction

In the world of modern forensic science, few concepts are as iconic as Locard's principle: every contact leaves a trace [1]. Biological traces on a crime scene can take many forms, but they almost all share one critical characteristic: the presence of DNA as a unique identifier [2–4]. After generating a DNA profile of the unknown source, it can be compared against all available suspects and profiles in national DNA databases to find a direct match and provide a likelihood ratio. In Belgium, three separate national DNA databases are currently in operation for legal purposes: one with DNA profiles from crime scene traces and suspects involved in ongoing cases, a second containing DNA profiles of convicted individuals, and a third dedicated to profiles of missing persons [5]. Clear policies outline the permitted categories to conduct searches against each other. In cases where national and international DNA database comparisons fail to provide a direct match, and other available traces are insufficient to clarify the case, further investigative actions are required to prevent the case becoming cold. In such cases, forensic DNA kinship matching represents a promising next step to identify biological family members based on similar DNA profiles [2]. It relies on the shared genetic markers between the perpetrator and their relatives.

'Forensic DNA kinship investigation' is an umbrella term including a variety of searching techniques, each characterized by unique kinship searching methods. In the present study we include three types of DNA kinship matching: Familial DNA searching (FDS), Crime Scene Y-DNA investigation (CSY) and Forensic Investigative Genetic Genealogy (FIGG or IGG). FDS involves searching national DNA databases for autosomal DNA profiles that closely match the unknown sample, identifying potential relatives who may share autosomal DNA. CSY focuses on the Y-chromosome, which is almost entirely passed on from fathers to sons. By searching for Y-chromosomal profiles similar to the unknown sample in national DNA databases or exploring surrounding communities, investigators can potentially identify paternal relatives. FIGG employs autosomal DNA searches within online commercial DNA databases, leveraging genetic matches to construct family trees and trace common ancestors, ultimately pinpointing potential relatives of the unknown sample. Each method offers unique advantages and considerations, contributing to the diverse toolkit available for forensic DNA kinship investigations.

A familial search using autosomal DNA to identify close relatives of the perpetrator requires screening a large number of people, as the amount of shared DNA decreases with each subsequent generation. The largest law enforcement regulated national DNA database is the United Kingdom (UK) National DNA Database (NDNAD) with an estimated 6 million individuals as of May 2023 [6]. Such large databases are a gold mine of information for the forensic DNA kinship method 'FDS' to identify close relatives of the perpetrator through autosomal DNA profiles. For that reason, the UK was the first to introduce FDS. However, the UK stands as an exception as most countries have limited sizes for their national DNA databases. For these countries, the DNA kinship investigation method 'FIGG' could be implemented relying on massive public DNA databases that are not government-regulated and thus not subject to the same legal regulations. One massive public DNA database is GEDmatch, which is an online platform that allows individuals to upload their DNA profile results from various genetic testing companies and compare their genetic data with others [7]. This platform provides tools for genealogical research and DNA analysis, including the ability to search for potential relatives and explore genetic connections. Therefore, GEDmatch serves as a valuable resource for screening a large number of individuals to identify close or distant relatives of the perpetrator. In 2018, American law enforcement made history as the first worldwide to use the GEDmatch platform in forensic investigation, leading to the identification of the Golden State Killer [8]. In response to the Golden State Killer case, the opt-in and -out arrangements of GEDmatch were implemented. This means that users must actively agree (opt-in) or decline (opt-out) to have their DNA profiles included for forensic DNA kinship matching. It is noteworthy that uploading your genetic data to GEDmatch automatically aids law enforcement in providing answers to families with missing loved ones. The opt-in option is specifically geared towards assisting law enforcement in solving violent crimes. While the company does not provide explicit figures on opt-in selections, genetic genealogy experts estimated that 700,000 out of the 1.8 million profiles have opted in as of August 2023 [9]. [8] According to the website of GEDmatch, the opt-in DNA profiles have played a crucial role in resolving over 400 investigations [10]. [6].

As the forensic kinship matching methods 'FDS' and 'FIGG' are based on partial autosomal DNA matches and probabilistic estimations, it may generate false hits, potentially increasing the number of individuals for investigation. Fortunately, there is another key part of the DNA which could open the doors of cold cases: Y-chromosomal DNA [11]. The Y-chromosome is a unique part of the DNA found exclusively in males that is almost entirely inherited from father to son, as 95 % of it does not recombine with the X-chromosome. Therefore, the Y-DNA can facilitate the identification of even far distant relatives of the unknown perpetrator [12], ultimately leading to the tracing of his identity. This makes the application of kinship matching or crime scene investigation using the Y-chromosome (CSY) to be a valuable tool to assist forensic (cold) case investigations [13–15]. The benefit of CSY is that it does not require a large national (FDS) or online (FIGG) DNA database as is needed for autosomal DNA matching because the Y-chromosome can match even distant relatives 40 generations apart [12,16] Additionally, Y-chromosomal DNA can be strongly correlated with the surname [17–19], narrowing down the search to a family tree. However, due to the absence or low number of Y-chromosome profiles in most national DNA databases [15], CSY today heavily relies on voluntary participation for screening purposes, particularly in close proximity to the location of the crime.

The first European CSY success was for the murder case of Marianne Vaatstra, a 16-year-old girl from the Netherlands who was brutally murdered in 1999. The case remained unsolved for more than a decade. However, the Dutch legislation was amended in 2012 to permit the search for close or distant autosomal and Y-chromosomal DNA matches. A large-scale campaign was launched to encourage men in the vicinity of the crime scene to voluntarily donate their DNA. Over 6600 men participated, accounting for 87 % of invited men within a 5 km radius of the crime scene [15]. By comparing Y-chromosomes from 81 individuals to the crime scene profile, two potential relatives of the perpetrator were identified. Further investigation led to the arrest and conviction of the perpetrator. This case serves as a pioneering example of the power of familial searching and CSY in helping to solve crimes and delivering justice. Therefore, it is crucial to understand public perspectives on forensic kinship DNA matching due to the role of public participation.

A few studies have already explored people's perspectives on the ethical dilemmas associated with forensic DNA kinship investigations. The study by Granja et al. [20] highlighted controversies in Poland and the UK, particularly in regard to its implications for social risks, public goods and accountability. The risks and benefits of DNA kinship matching can vary significantly for those involved. Guerrini et al. conducted a survey to specifically explore the public's opinion in the United States (US) on police access to genetic genealogy websites in order to assist crimes like the "Golden State Killer" case [7]. The survey, which involved 1587 respondents from the US, revealed that 91 % of participants would support the use of a genetic genealogy database to identify relatives of perpetrators of violent crimes. Moreover, 46 % of the participants even approve the use of these online databases for non-violent crimes.

The study presented here delves into public perceptions of Dutch-speaking Belgians regarding the different forensic DNA kinship matching methods. A web-based questionnaire was created, aiming to assess DNA knowledge and understand public perception on kinship matching in forensic investigations, considering ethical and privacy concerns. These findings can be used to inform the development of a framework for implementing forensic DNA kinship investigations.

2. Materials and methods

To gather data on the public opinion towards the use of forensic DNA kinship investigations, an online cross-sectional public survey was conducted. Participants were informed that the survey aimed to gather public knowledge and opinions on forensic DNA kinship analysis. The survey minimized technical jargon (e.g. abbreviations such as FDS, FIGG and CSY) and primarily offered expanded explanations of these various techniques, ensuring participants' comprehensive understanding of the referenced methods. No further preliminary background information was provided regarding genetics or forensic DNA analysis. The survey was in Dutch and required approximately 10–15 min to complete. People participated anonymously and voluntarily without receiving any form of compensation. Participants were requested to answer the survey honestly and without the assistance of external sources such as the internet, scientific literature or consulting with others. The questions were structured into three distinct categories and contained 44 questions in total. The purpose of each part of the survey was described at the beginning of the section. The questionnaire and possible answers are available in Supplementary Table S1.

The first category consisted of questions related to personal information, such as participants' biological sex, age, country of residence, level of education and whether their educational background pertained to a scientific discipline or a non-scientific field. For the latter, scientific disciplines were defined as exact sciences, referring to subjects such as Physics, Chemistry, and Biology. The candidates were ensured that this information would solely be used anonymously for additional population data analysis within the current study to compare this with the outcome of the next sections concerning DNA knowledge and forensic DNA opinions. The second category focused on participants' knowledge of DNA and genetics, and included eight theoretical questions with the option to answer with "no idea" to discourage guessing. The participants were informed that the purpose of this phase was to assess their general knowledge on the subject of DNA. The final category, which comprised 32 questions, focused on gathering participants' opinions on forensic DNA analysis and forensic DNA kinship investigations.

To ensure broad representation, the questionnaire was distributed through multiple channels, including diverse social media platforms and the CSY-website [14]. Efforts were made to engage various organizations and groups in Belgium through personalized emails. Anonymity of participants was ensured as no private information was collected and stored. The survey remained accessible for seven weeks to allow thoughtful responses. The ethics committee of UZ/KU Leuven has affirmed that according to our privacy laws, GDPR regulations do not apply to anonymous population surveys. Consequently, there was no requirement to submit documentation for this survey to the Research Ethics Committee.

The present study examines the differences between categorical variables such as age, education, DNA knowledge and the forensic DNA kinship questions. Statistical chi-square analysis was conducted to test whether there is a significant relationship between obtained categorical variables. Answers concerning the enthusiasm for familial searching are measured categorically (e.g. "yes" vs "no"), as well as the participants' DNA knowledge ("fail" or "<50 % score" vs "100 % score"), educational background ("low" vs "high"), age ("below 30" vs "above 50") and background information ("scientific" vs "non-scientific"). For instance, the responses to a yes-or-no question like ForGen_Q21 "Should a national DNA database include every newborn?" were examined in detail to determine if there were significant differences between individuals who scored below 50 % on the DNA test and those who scored 100 %. This way, it could be determined whether the observed differences were due to chance or if there was a correlation between the variables.

3. Results

The results of the survey provide insight into the Flemish population's perspectives towards who to include in the national DNA database, the use of online databases for criminal investigation, their willingness to participate in a large DNA-dragnet, the factors that influence their decision to opt-in or -out, and the extent to which they trust the authorities to protect their privacy.

3.1. Participant characteristics

The conclusion of the seven-week survey period yielded a substantial sample size of 1710 participants who actively finished the questionnaire. Since the survey was conducted in Dutch, inhabitants from the Netherlands also responded to the questionnaire. 92 % of respondents were Belgians, while 7 % had Dutch descent, and the remaining 1 % (n = 14) of the participants were currently living in other countries. The small sample size from the Netherlands is insufficient to make meaningful comparisons between the two Dutch-speaking countries as this was not the primary objective of this survey. Age groups were divided into three categories: '18–30', '31–50', and '51–91', as illustrated in Fig. 1A. The age distribution of the participants was slightly different from the overall Belgian population ratio of 2:3:5. Specifically, the 18–30 age group consisted of a little, yet not significantly, higher proportion of participants. In total, 40.6 % of respondents have a scientific educational background (Fig. 1A). Educational level was categorized as high (67 %; professional or academic bachelor, master or PhD), medium (29 %; high school), or low (5 %; primary school).

3.2. DNA knowledge results

Participants' knowledge of genetics was assessed through a DNA knowledge test, resulting in an average score of 72 %. Of the participants, 17 % failed the test (final score below 50 %), while 16 % achieved a perfect score. Participants with a test score below 50 % were more likely to lack a scientific background (90 %), have a lower level of education (58 %), and be older adults (54 %). The average score for each question, categorized by age, scientific background, and level of education, is visualized in Fig. 1B. The most challenging questions pertained to the location of DNA in the body (Q1), the building blocks of DNA (Q3), and the number of chromosome pairs in humans (Q4). Participants without a scientific background made 49 % false guesses instead of admitting "I do not know," whereas scientific participants made 71 % false guesses. This suggests that scientists are more prone to taking educated guesses, while nonscientists are more aware of their knowledge limitations.

Notably, the average score significantly increased with the level of education. Highly educated individuals scored an average of 76 %, while medium and low-educated participants scored an average of 65 % and 58 % respectively ($p = 7.46 \times 10^{-28}$). With this, again a significant difference was observed in the test scores between those with a scientific background and those without (85 % vs. 63 %, $p = 5.82 \times 10^{-184}$). Additionally, an inverse correlation was observed between the DNA knowledge score and the age of the participants ($p = 5.57 \times 10^{-61}$), with individuals between the ages of 18 and 30 obtaining an average score of 81 %, while those between the ages of 31 and 50 scored 71 %, and those over 50 scored 62 %. No significant difference in DNA knowledge scores was observed between participants from Belgium and the Netherlands, with both groups averaging 72 %. Males and females had minimal score differences, with females slightly more likely to answer correctly. These knowledge results were then compared to participants' willingness to engage in forensic DNA investigations.

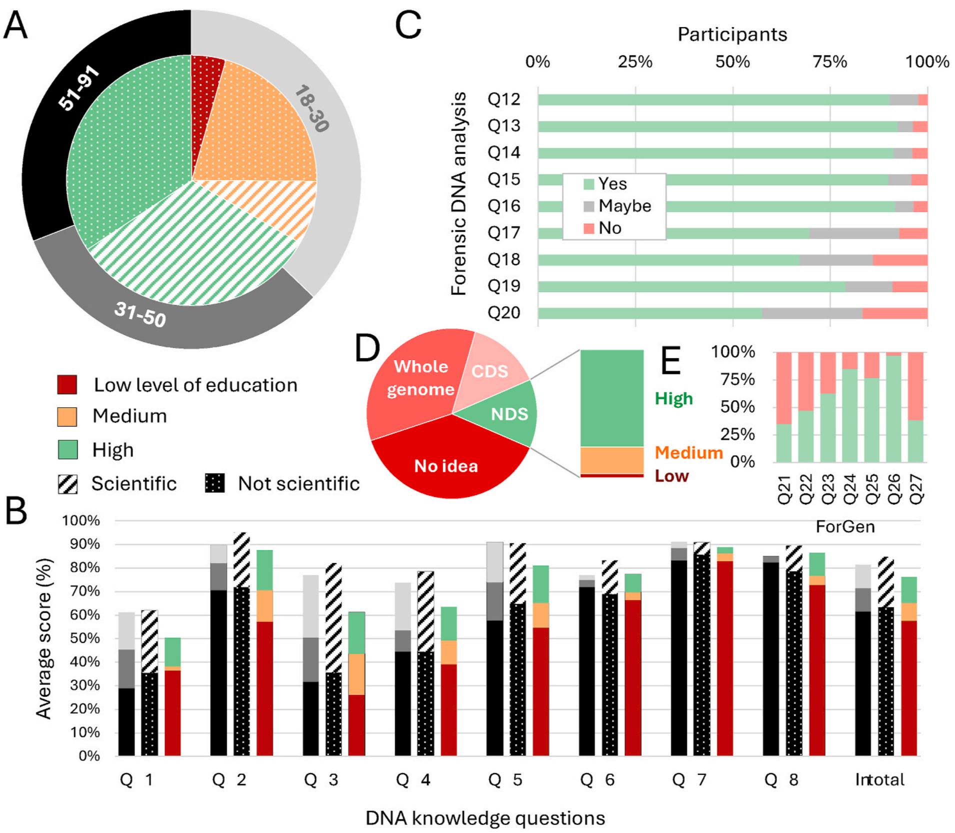

Fig. 1. Population survey results (n = 1710). (A) Participant distribution of education and scientific background (inner circle) and age (outer circle). (B) Average score for all DNA knowledge questions. (C) ForGen_Q12-20 concerning participation in a familial search. (D) ForGen_Q10 concerning the Belgian legislation on forensic DNA typing. CDS = coding DNA sequence; NDS = non-coding DNA sequence; subdivision level of education. (E) ForGen_Q21-27 concerning type of people to include in the national DNA database.

3.3. Perception towards using forensic DNA kinship investigations

When participants were asked if they would randomly give their DNA to someone, without giving any further context, approximately one fifth of the participants were initially very cautious or thought about the “worst case scenario”. However, this decreased to 17 % in the context of helping forensic DNA research and to only 8 % when asked if they would participate in a kinship search to help murder investigations. In other words, the overwhelming majority of the participants (92 %) expressed willingness to cooperate in a forensic DNA kinship investigation. The analysis of the responses to questions ForGen_Q12-20, as shown in Fig. 1C, concerned willingness to participate in forensic DNA kinship investigations dependent on different factors. This revealed that initially 90 % of the respondents were willing to voluntarily provide a DNA sample if it could assist murder investigations. This number increased slightly, yet not significantly, to 92 % when participants received the information that sampling was painless, and - in the context of CSY - their sample would be destroyed, their profile would not be kept in a database and their privacy was going to be secured. After detailed analysis it was clear that ‘painless sampling’ (Q13) and ‘privacy and security’ (Q16) were the two most important factors in deciding whether to participate in such investigations. Approximately 3 % of the participants held the belief that DNA samples could only be collected through invasive means such as blood sampling, rather than through the painless and non-invasive method of a buccal swab (ForGen_Q2).

Further, certain scenarios seemed to significantly impact participants’ willingness to participate. For instance, when there was a possibility that a family member could be identified as a perpetrator (Q17), or if a false biological kinship with their parents could be revealed (Q18), or if the police could identify them as a family member of a convict (Q20); participants were hesitant (3 %, 10 % and 13 % respectively) or even declined to participate (17 %, 13 % and 20 % respectively). ForGen_Q10 revealed that 87 % of participants did not know what forensic DNA researchers are permitted to genotype, and 34 % of them believed that it was allowed to sequence the entire genome revealing all their personal information (Fig. 1D). Interestingly, 13 % of the people who correctly answered that Belgian forensic geneticists are limited to only genotype non-coding parts of the DNA sequence (NDS), scored significantly higher on the DNA knowledge test from the second part of the survey (80 % vs. 71 %, $p = 3.42 \times 10{-}19$). Also, 76 % of them had a high educational level and 60 % had a scientific background. Additionally, we also wanted to examine in more detail whether people were more willing to donate their DNA for medical research, which has a more personal benefit, or for forensic research, which may have a societal benefit. Fig. 2A demonstrates that a large majority of participants, regardless of their level of education or scientific background, expressed willingness to donate their DNA for both medical (83 %) and forensic (82 %) research purposes.

Individuals from Belgium were slightly but not significantly more willing to donate DNA samples for the purpose of solving a murder compared to participants from the Netherlands (90 % vs 87 %), as depicted in panel Fig. 2D. The values in the graph were weighted since the number of Flemish participants (n = 1571) was almost ten times higher than the number of Dutch people (n = 125).

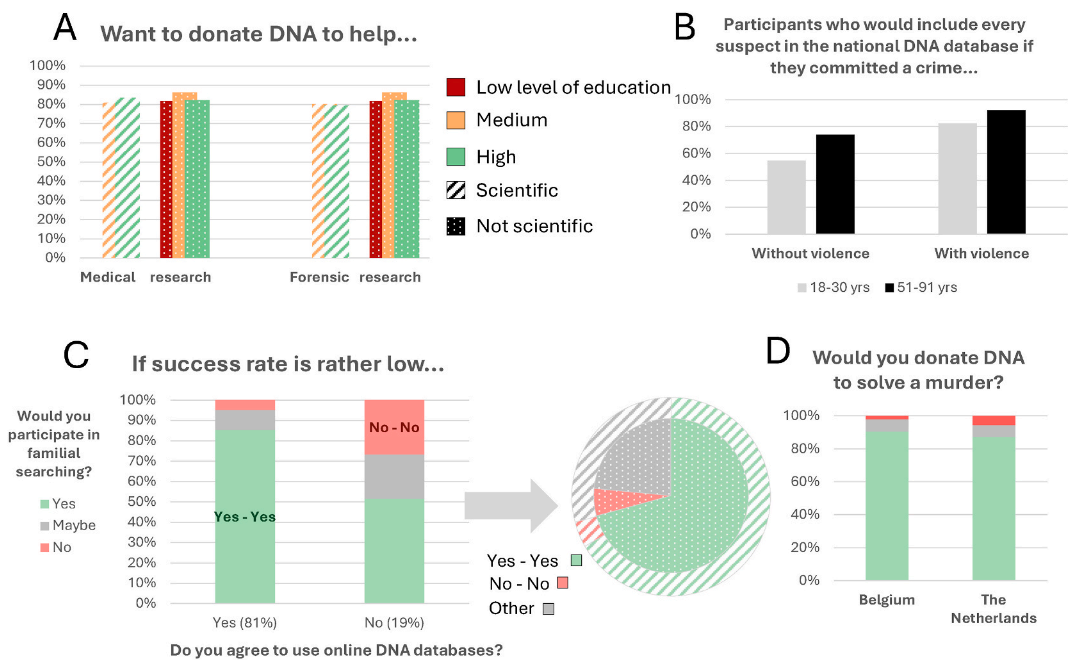

Fig. 2. Population survey in-depth results (n = 1710). (A) ForGen_Q8-9 providing DNA for medical (left) or forensic (right) research. (B) ForGen_Q23-24 including suspects in a national DNA database after committing a crime without violence (left) or with violence (right). (C) ForGen_Q19 participation in forensic kinship investigation such as CSY if success rate is rather low (= if chances are small that it will help the case) and ForGen_Q32 concerning the use of online DNA databases if the success rate is rather low. Circle diagram represents the combination of answers of the participants with (outer circle) and without (inner circle) scientific background. (D) ForGen_Q12 willingness to donate DNA to assist murder investigations, grouped per origin. Data used to make this graph was being weight.

To ensure a more robust and reliable comparison, it is necessary to include a larger number of participants from the Netherlands.

Peoples' responses towards which individuals need to be included in the national DNA database (ForGen_Q21-27) provided valuable insights. As indicated in Fig. 1E, almost all participants (97 %) were in favor of including all suspects and perpetrators of violent crimes in the database (Q26). However, it is noteworthy that a substantial proportion of the participants (35 %) agreed with the systematic inclusion of all newborns in the national DNA database. The percentage of participants in favor of including all adults in a national DNA database increased to 47 %.

The findings in Fig. 2B shed more detailed light on the participants' opinion towards including suspects in national DNA databases after committing crimes whether or not they are violent. The absence of a national DNA database with suspect DNA profiles in some countries makes this a particularly pertinent issue. The present survey included both non-violent crimes like theft and drug offenses, as well as violent crimes such as sexual assault and murder. Interestingly, the majority of participants were in favor of including suspects in the database, with slightly more support for violent crimes. The data reveals a significant difference in opinions between age groups. For instance, 55 % of 18–30 year olds would include every suspect from a non-violent crime, whereas 74 % of the 51–91 year olds would do so ($p = 7.73 \times 10^{-12}$). This is also the case for violent crimes (82 % vs 92 %, $p = 7.02 \times 10^{-7}$).

The results for the questions focusing on including the perpetrator of the crime in the database (ForGen_Q25-26), were consistent with those of the suspect inclusion in Fig. 2B. The younger age group again showed slightly less support for inclusion, with 75 % in favor of including the perpetrator for non-violent crimes and 97 % for violent crimes. The older age group showed slightly higher levels of support, with 80 % in favor of inclusion for non-violent crimes and 98 % for violent crimes.

The last few questions in the survey addressed the use of online DNA databases for forensic investigative genetic genealogy (FIGG). The majority of the participants (95 %) agreed to use these online DNA databases to assist forensic investigations for violent crimes, but about half of them (52 %) felt that informed consent should be obtained from the database members prior to the search, indicating to be in favor of the 'opt-in' system. Even with lower success rates, 81 % of the people are in favor of using online DNA databases (ForGen_Q32), visualized in Fig. 2C. This means that 326 out of 1710 participants do not approve its use in forensic investigation when there is only a small chance that it could help the investigators identify a suspect. In total, 85 % of the respondents in support of online DNA databases, are willing to volunteer in a forensic DNA kinship search even if success rates are rather low (ForGen_Q19), while 10 % are unsure. This means that 5 % of the participants that approve FIGG, would not participate themselves in a voluntarily setting such as CSY. There is no significant difference based on level of education, age nor scientific background of the people saying "yes" to both questions (use of online DNA database even with small chance of success; and willing to cooperate in CSY. However, it is important to note that half of those who said "no" to the use of online databases when success is rather low, would cooperate in a voluntarily CSY investigation, while 22 % of them are unsure. The second part of Fig. 2C reveals that a similar percentage of participants (4 % and 6 % respectively) responded negatively to both questions, irrespective of whether they had a scientific background or not.

Overall, there is a positive attitude towards forensic DNA kinship investigations and donating DNA to help finding an unknown perpetrator of a serious crime.

4. Discussion

The present study collected empirical data on public perspectives towards the use of DNA and kinship matches to assist in forensic cold case investigations. This provided valuable insights into the factors that affect participants' willingness to volunteer in forensic DNA kinship investigations.

The widespread distribution of the questionnaire and efforts to engage with a diverse range of organizations and groups resulted in a high response rate of 1710 individuals, which is slightly more than the US study conducted by Guerrini et al. [7]. Our study showed that a significant majority (92 %) of the participants displayed a strong willingness to volunteer and cooperate in a forensic kinship search. This enthusiastic response is attributed to their assurance that the sampling process would be painless, with an emphasis on ensuring participant comfort. Furthermore, participants were informed that their collected samples would be securely and permanently destroyed to address any concerns related to data retention. This approach mirrors the protocol used by large DNA dragnets like CSY, which is currently implemented in the Netherlands. Another key factor contributing to their positive disposition was the commitment to preserving their privacy, assuring them that only non-coding regions were analyzed and Y-chromosomal data does not reveal their medical or phenotypical background information. Interestingly, the success rate of forensic DNA kinship investigation had only a minor impact on participants' decision to participate. This suggests that participants were less concerned about the potential success rate compared to their own privacy and confidentiality concerns. This overwhelming support signifies a noteworthy willingness among individuals to embrace forensic kinship searches, underscoring the potential and promise of this innovative investigative approach.

These results are a positive sign for the effectiveness of CSY as a crime-solving tool, as this forensic identification method relies on voluntary participation from family members who are probably not involved in the crime themselves. This resembles the high number of volunteers in the Dutch murder case of Marianne Vaatstra, which accounted for 87 % of the men invited to participate [15] and is equal to the 91 % of participants willing to cooperate in forensic DNA kinship investigation according to a population survey in the US [7]. The present survey results also revealed that participants distinguish between different types of DNA research and are more willing to cooperate in cases where the research is conducted for a specific cause or purpose, such as solving a murder. Perhaps this opinion is due to participants' moral obligation to help society by way of contributing to solving a murder, which also benefits their own safety. This is true for participants even at the expense of donating their DNA for forensic research. The high number (92 %) of the participants suggests that individuals are aware of the potential impact that DNA evidence can have in identifying perpetrators and achieving justice.

However, it is important to note that the current legal framework in most European countries does not specifically include the engagement of volunteers in forensic investigations (large DNA-dragnet), nor actively searching for a close DNA match to the unidentified genetic lead recovered from the crime scene [21]. In the pursuit of justice, the Belgian authorities have taken some significant steps throughout the last couple of years. More precisely, the updated DNA law from begin 2024 includes forensic DNA kinship investigation, introducing new prospects for both forensic genetics, the judicial system and notably for those who are victim of serious crime [22].

4.1. National DNA databases

97 % of the participants were in favor of including all perpetrators of violent crimes in the law enforcement DNA database, while 85 % wanted to include suspects as well. This indicates a preference for expanding the national DNA database and taking extra measures to ensure safety and prevent future crimes. The personal nature of violent crimes may contribute to higher levels of support. Factors such as age, awareness of data storage and experiences of violence influence opinions. Younger individuals show slightly less support, possibly due to increased awareness of privacy concerns and the digital age [23]. These considerations are crucial when developing national DNA database policies for crime investigation. It is interesting to note that this is similar to the system in place in the UK, where any interaction with law enforcement could lead to DNA collection and thus profile-storing in their national DNA database [20]. This expanded DNA collection, however, raised concerns regarding genetic privacy and the establishment of a permanent "suspect list" [24]. In 2008, the European Court of Human Rights decided that DNA from innocent people should be removed from the NDNAD. Four years later, the Protection of Freedoms Act confirmed that over a million DNA profiles from innocent adults and children were removed [25]. In total, the NDNAD currently consists of 11.4 million DNA profiles (without duplicates) as of April 2023 [26].

Almost half of the respondents expressed a desire to include all individuals above 18 years in the national DNA database, with 35 % supporting inclusion from birth. This unexpected finding demonstrates a widespread belief of potential benefits of extensive screenings for forensic DNA kinship investigations, aligning with previous research highlighting the efficacy of larger databases [15,27]. The participants' willingness to embrace a larger database reflects their understanding of its crucial role in enhancing forensic DNA kinship investigation.

The majority of the participants (95 %) agreed to use online DNA databases to help violent crime investigations, which has gained widespread attention following the identification of the "Golden State Killer" in the US [3,7,27]. However, about half of these participants (52 %) felt that informed consent should be obtained from the database members prior to the search, indicating being in favor of the 'opt-in' system. It is noteworthy to mention that these results are consistent with the population survey conducted in Texas after the identification of the "Golden State Killer", where 79 % of the participants supported police searches of genetic genealogy websites to identify relatives. These findings suggest that the general public is open to the use of online genetic genealogy DNA databases in forensic investigations but also values the privacy rights of individuals whose genetic data are stored in these databases. However, ensuring the security of personal information against unauthorized access remains a challenge for online DNA databases. This concern is illustrated by the frequent data breaches experienced by GEDmatch in the US, highlighting the vulnerability of these databases to hacking attempts [28,29]. In total, 85 % of the people in support of online databases (FIGG), are willing to volunteer in CSY even if success rates are rather low. This is fascinating because nowadays people have to consent before their DNA can be used for legal purposes, which was not initially the case when using a commercial online database in the US. Half of the people who answered "no" to the use of online DNA databases for forensic genetic genealogy would volunteer in CSY for forensic kinship matching. This is probably because they assume that they will have to give consent to participate in a large DNA dragnet while the online DNA databases could be used without a person's knowledge and therefore against someone's wishes.

4.2. Fear of the unknown

The commonly used term 'fear of the unknown' refers to the anxiety individuals may experience when faced with unfamiliar aspects [30]. In forensic genetics this highlights the need for effective communication, education, and transparency to address concerns of genetic analysis and its implications and foster informed decision-making among individuals involved in or affected by forensic genetic processes [7]. Participants with lower DNA knowledge had higher privacy concerns and anxiety, leading to hesitancy in providing their DNA without context, compared to those with higher knowledge (58 % versus 28 %, $p = 1.31 \times 10^{-3}$). However, when assured of privacy protection and DNA profile destruction (CSY), 85 % of participants with low DNA knowledge expressed willingness to volunteer, increasing to 93 % for those with high knowledge. The inverse correlation between DNA knowledge score and age may be attributed to genetics education in Belgian high schools [23]. Approximately 3 % believed DNA samples required invasive blood sampling instead of the painless and non-invasive buccal swab method, highlighting the importance of providing adequate information about the process to guide decision-making. Effective educational campaigns are needed to increase public awareness, understand forensic DNA analysis, help address concerns, dismiss misconceptions, and foster a sense of trust and confidence in the utilization of DNA as a tool for justice and public safety. Promoting informed decision-making and engaging the public in discussions surrounding DNA analysis, will contribute to increased participation and cooperation, ultimately advancing the effectiveness and integrity of forensic DNA kinship investigations.

4.3. Ethics and privacy concerns

Forensic DNA kinship investigations are a powerful tool offering a valuable opportunity in criminal cold cases where a dead end was reached despite conventional investigative efforts. Its implementation has proven to be successful in resolving long-standing investigations in various countries, providing closure to affected families and victims [15,27]. Nevertheless, despite its efficacy, we must use it carefully as ethical and privacy concerns have been raised, primarily in terms of familial and personal privacy [31]. Balancing the pursuit of justice with the preservation of privacy and the protection of individuals' rights is crucial in navigating the ethical complexities of forensic cold case investigations.

First, the privacy of a relative of the perpetrator could be violated with a search in the national DNA database since it could reveal his or her hidden criminal record [32]. While lawyers have observed a low impact of kinship searching on an individual's sense of privacy as most relatives remain unaware that they are under police inspection until law enforcement officials need further interrogation [33]. However, it is important to approach this finding with caution as the lack of awareness among individuals regarding the impact on their privacy and liberty does not negate the actual impact itself.

Second, kinship searching can reveal hidden genetic relationships, including unknown paternity and hidden adoption [34]. Our previous research found a nonpaternity rate of 1–2% per generation in Belgium and the Netherlands, highlighting the potential for uncovering unexpected familial connections and genetic discrepancies [35]. These revelations can have significant ethical and psychological implications, potentially disrupting family dynamics and challenging personal identities [36]. Disclosure of paternity secrets can lead to emotional distress, strained relationships, and the need for identity reevaluation [37,38]. The potential for harm and unintended consequences should be addressed to protect individuals' well-being.

Third, certain groups within the population are overrepresented in national DNA databases which could lead to discrimination based on race and social inequality [39]. In the context of commercial DNA databases and biobanks, the majority of participants are of European descent. Conversely, in criminal databases a significant disparity exists, leading to an overwhelming majority of non-European participants [40]. Overrepresentation in the DNA database can reinforce biases and perpetuate social inequalities, disproportionately impacting marginalized communities and exacerbating disparities in the criminal justice system. Conversations regarding disparities in racial composition within law enforcement DNA databases are ongoing. However, the precise "racial" composition of these databases remains uncertain. Race is a social construct, and in the cases of databases, it is often extrapolated from populations that may be presumed to be known, highlighting a notable gap in available data.

Fourth, DNA information from a large group of innocent individuals can always be susceptible to misuse, making forensic DNA kinship searching on large DNA databases (FIGG) more delicate [34]. There is the potential for unauthorized access to the database by individuals with malicious intent. In 2018, hackers breached 92 million accounts of MyHeritage DNA testing service, gaining access to encrypted emails and passwords but not the actual genetic data [41]. In a 2021 cyberattack, hackers gained access to personal information from an Ohio DNA testing company, but genetic data remained secure. In 2023, a security breach at 23andMe in early October revealed the DNA ancestry information of nearly 7 million users [42]. While security measures are in place, human error and unauthorized access can still risk data exposure, leading to potential misuse and harm [43]. [21]One notable advantage of CSY stems from the Y-chromosome's classification as "the genetic wasteland" [44],referring to the perception that the Y-chromosome contains fewer genes compared to other chromosomes and is therefore less biologically significant [44]. Yet, recent research has shown that the Y-chromosome could still play a role in certain biological processes and disease susceptibility, albeit to a lesser extent than other chromosomes [45]. The concept of the Y-chromosome as a "genetic wasteland" may still hold true in terms of overall gene content, but specific genes could still have important effects on health and disease. Nonetheless, the Y-chromosome remains unable to provide details about an individual's overall health status or susceptibility to specific diseases, nor does it offer insights into physical characteristics like hair, eye and skin color. This feature ensures the safeguarding of personal data in the event of a CSY data breach [41].

Finally, DNA kinship searching carries the inherent risk of implicating innocent family members who have not provided explicit consent to be included in criminal investigations. However, it is important to clarify that law enforcement uses kinship searching only to generate leads and not to directly arrest a relative solely based on genetic information [8]. Privacy concerns require thoughtful delibration of the implications and safeguards surrounding forensic DNA kinship searching investigations. Some participants (8 %) were hesitant once informed about the possibility of being identified as a relative of the perpetrator, reflecting concerns and perceived stigma associated with familial connections to criminal activities. This underscores the importance of addressing privacy concerns and engaging in open ethical debates. While the majority (92 %) are willing to participate in forensic DNA kinship investigations, there is a need for open debate regarding ethical concerns and individual choice to refrain from participation should be respected.

4.4. Weighing the benefits and the risks

The potential risks and benefits of participating in forensic DNA kinship investigations must be carefully weighed. However, the potential benefits may outweigh the associated risks. First, it offers a possible breakthrough in cold cases where DNA from the perpetrator is available, but cannot be matched to any suspect. Second, forensic DNA kinship research provides a bigger pool of possible suspects as the relatives of close or distant DNA matches can also be tracked down. Third, studies show that relatives of convicted individuals are more likely to be convicted themselves, which increases the success rate of familial searching on national DNA databases and suggests a correlation between the socio-economic circumstances under which someone grows up [46,47]. For online database searches (FIGG), Erlich et al. revealed that once the number of participants in law enforcement databases exceed 3 million, a milestone currently exceeded by GEDmatch, over 99 % of individuals of European ancestry can be identified [48]. And lastly, forensic DNA kinship investigations could offer closure to all relatives of the victim by resolving unanswered questions and bringing clarity to the circumstances surrounding the case.

Although the benefits are strong, 'fit for purpose' regulations are required to address the ethical and privacy issues. For instance, policy recommendations regarding the use of personal information in forensic kinship searching have to be created to reduce the personal harm and provide the best social protection for the relatives. The results of the survey revealed that a significant majority of participants (95 %) expressed their agreement to use an online DNA database (FIGG). However, when the scenario of conducting FIGG without obtaining prior consent from the participants was introduced, the percentage decreased to 52 %. These findings suggest that obtaining consent plays a crucial role in shaping public support for the implementation of FIGG. In places such as China, apparently consent is not needed to collect blood samples from men across the country to have a massive national DNA database for their high-tech surveillance system [49]. In 2020, they already included 68 million DNA profiles into their national DNA database [50]. Men who refuse to provide their DNA are listed as a 'black household', which means that they could lose the right to travel or go to a hospital [51]. This method is widely criticized worldwide [50,52].

Kinship between a relative and the perpetrator must be kept confidential to protect the privacy and reputation of innocent relatives. Confidentiality minimizes the risk of harm, such as stigmatization or discrimination. Forensic DNA kinship searching should only be used when no match is found in the national and international DNA databases and no other leads are available. Implementation should be limited to cold cases with significant prison sentences. Adhering to these guidelines helps to manage and balance the ethical and legal implications of forensic DNA kinship investigations [53]. Further, it is crucial to have tactical elements which indicate that the biological trace recovered from the crime scene belongs specifically to the perpetrator or an accomplice and that these stains provide a distinct and unambiguous autosomal DNA profile. This ensures a reliable basis for court proceedings and effectively minimizes the risk of false positive matches. Finally, some suggest that the profile should ideally be highly unique within the population, thereby increasing the likelihood ratio and match probability. Following this, a well-advised deliberation must be made for each crime individually, and only used when the advantages of forensic DNA kinship investigations outweigh the potential harms.

Given the significant influence of public opinion on the adoption and effectiveness of CSY and FIGG, it is encouraging to report that the substantial majority of the Dutch-speaking Belgian population supports the implementation of this investigative technique.

4.5. Survey challenges and limitations

Although these results can help inform future policy decisions in developing a framework to implement forensic DNA kinship investigations that respects individual rights and privacy while ensuring public safety, some results need to be interpreted with caution. First, it is worth noting that the use of the internet, while convenient, may limit the sample size to individuals with access to the internet and could potentially bias the results towards certain demographics. Second, the survey design did not specifically inquire about the number of participants who desired the destruction or storage of their DNA sample or profile in a database. Third, it is possible that the age group of the principal investigators (below 30 years) was the reason why slightly more younger people participated in the study (37 % below 30 years, 32 % between 31 and 50 years and 31 % above 50 years old). It may have been more effective to reach a younger demographic through the choice of social media platforms and advertising strategies. Fourth, it is important to note that using participants' level of education warrants careful consideration and interpretation. While higher levels of education may imply a certain degree of knowledge and proficiency, it is crucial to avoid making assumptions that individuals with lower educational backgrounds are less intelligent or incapable of providing valuable insights. On the other hand, the study of Ritchie et al. (2018) suggests that there is a positive relationship between education and intelligence [54]. They observed that additional years of education have beneficial effects on cognitive abilities, resulting in an increase of approximately 1–5 IQ points. These effects are observed across different age groups and cognitive domains. The findings indicate that education is a reliable and effective method for enhancing intelligence. Yet, categorizing participants solely based on their last obtained diploma still may present limitations. For instance, individuals who are currently enrolled in high school would be classified as having a lower educational level, despite potentially possessing considerable knowledge in certain domains. Furthermore, participants may have acquired substantial expertise through practical experience or self-directed learning, even in the absence of a formal degree. Thus, it is imperative to exercise caution when interpreting these educational categories, recognizing that they may not consistently align with participants' actual knowledge or expertise. Instead, we used a more nuanced approach involving the presence of a scientific background and the participants' knowledge to specific DNA questions of the second part of the survey. This provided a more accurate gauge of their understanding and comprehension of the subject matter at hand.

Despite these challenges, the present survey results allow us - for the first time - to analyze various forensic DNA research questions in the Dutch-speaking population of Belgium in relation to participants' age, country of origin, level of education, scientific background as well as DNA knowledge. This provided valuable insights into public attitudes towards the use of DNA in forensic investigations and its ethical concerns.

5. Conclusion

The findings of this study indicate that despite the absence of a legal framework for forensic kinship DNA investigations in Belgium, 92 % of the Dutch-speaking society demonstrates a willingness to contribute DNA samples for the purpose of serving justice. This inclination is observed across participants with varying levels of scientific background and education, emphasizing the broad support for forensic DNA kinship investigation. Notably, the majority of the participants wanted to include DNA profiles of suspects in the national DNA database, highlighting their commitment to aiding criminal investigations. The decision to participate in a forensic DNA kinship search was found to be influenced by factors such as the painless nature of sampling and the assurance of privacy protection.

Participants showed some reservations when informed about the potential risks, such as the possibility of family members being implicated or the revelation of false kinship with their parents. These concerns were particularly evident among participants with lower scores on the DNA knowledge test, suggesting that “fear of the unknown” played a role in their decision-making process. Consequently, effective communication and information provision are crucial in ensuring informed participation and addressing fears surrounding forensic DNA kinship investigations.

It is important to recognize that the practice of DNA kinship searching raises ethical considerations. Striking a delicate balance between public safety and the preservation of individuals’ privacy rights is essential. This highlights the need for robust regulations and oversight to ensure responsible use of genetic data in forensic investigations, while safeguarding privacy and minimizing the risk of genetic discrimination. Overall, the overwhelmingly positive response from the Dutch-speaking Belgian population, with 92 % willing to provide a DNA sample to assist in the case of a violent crime, underscores the potential for forensic DNA kinship searches as a valuable tool in criminal investigations. This marks a hopeful start for the forensic DNA kinship investigation methods FDS and CSY, now available for implementation in Belgium due to the long-awaited and crucial legal updates.

Data availability statement

The raw and detailed data concerning answers per participant cannot be shared publicly as this data contains potentially identifying participant information. Nevertheless, data will be made available upon request to the Ethics Committee Research UZ/KU Leuven (www.uzleuven.be/ethische-commissie/onderzoek).

CRediT authorship contribution statement

Sofie Claerhout: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hanna Noppe:** Writing – review & editing, Visualization, Investigation, Data curation. **Betty Cohn:** Writing – review & editing. **Pascal Borry:** Writing – review & editing.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT-3.5 to ensure the use of proficient English. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We would like to express our sincere appreciation to all anonymous participants who dedicated their time to complete our DNA survey. Additionally, we extend our gratitude to Barbara Claerhout and Ann Blanckaert for their valuable contributions in the creation, refinement, and validation of the survey. Furthermore, we are thankful for the valuable input provided by Prof. Bruce Weir. Funding for this research was provided by FWO (SC; 1265622N).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30074.

References

[1] D.O. Jaquet-Chiffelle, E. Casey, A formalized model of the Trace, Forensic Sci. Int. 327 (2021), https://doi.org/10.1016/J.FORSCIINT.2021.110941.
[2] R.M. Mateen, M.F. Sabar, S. Hussain, R. Parveen, M. Hussain, Familial DNA analysis and criminal investigation: usage, downsides and privacy concerns, Forensic Sci. Int. 318 (2021), https://doi.org/10.1016/j.forsciint.2020.110576.
[3] R.A. Wickenheiser, Forensic genealogy, bioethics and the golden state killer case. https://doi.org/10.1016/j.fsisyn.2019.07.003, 2019.
[4] P. Roffey, N. Scudder, Privacy implications of the new “omic” technologies in law enforcement, WIREs Forensic Science 4 (2022), https://doi.org/10.1002/wfs2.1445.
[5] Nationale DNA-databanken | NICC, (n.d.). https://nicc.fgov.be/nationale-dna-databanken (accessed June 12, 2023).
[6] A.O. Amankwaa, C. McCartney, The effectiveness of the UK national DNA database, Forensic Sci. Int. 1 (2019) 45–55, https://doi.org/10.1016/J.FSISYN.2019.03.004.
[7] C.J. Guerrini Id, J.O. Robinson, D. Petersen, A.L. Mcguire, Should police have access to genetic genealogy databases? Capturing the Golden State Killer and other criminals using a controversial new forensic technique. https://doi.org/10.1371/journal.pbio.2006906, 2018.

[8] C.J. Guerrini, R.A. Wickenheiser, B. Bettinger, A.L. McGuire, S.M. Fullerton, Four misconceptions about investigative genetic genealogy, J Law Biosci 8 (2021), https://doi.org/10.1093/jlb/lsab001.
[9] GEDmatch Loophole Gave Police Access to Private DNA Data, (n.d.). https://theintercept.com/2023/08/18/gedmatch-dna-police-forensic-genetic-genealogy/ (accessed February 16, 2024).
[10] Community Safety | GEDmatch, (n.d.). https://www.gedmatch.com/community-safety/ (accessed February 16, 2024).
[11] R.A. Wickenheiser, Expanding DNA database effectiveness, Forensic Sci. Int. 4 (2022) 100226, https://doi.org/10.1016/J.FSISYN.2022.100226.
[12] S. Claerhout, M. Vandenbosch, K. Nivelle, L. Gruyters, A. Peeters, M.H.D. Larmuseau, R. Decorte, Determining Y-STR mutation rates in deep-routing genealogies: identification of haplogroup differences, Forensic Sci Int Genet 34 (2018) 1–10, https://doi.org/10.1016/j.fsigen.2018.01.005.
[13] Sofie. Claerhout, Dader Onbekend : Het Y-Chromosoom Als Sleutel Tot Onopgeloste Moordzaken, 2022.
[14] S. Claerhout, CSY-leuven, (n.d.). https://www.csy-leuven.be/ (accessed June 12, 2023).
[15] M. Kayser, Forensic use of Y-chromosome DNA: a general overview, Hum. Genet. 136 (2017) 621–635, https://doi.org/10.1007/s00439-017-1776-9.
[16] S. Claerhout, M. Van Der Haegen, L. Vangeel, M.H.D. Larmuseau, R. Decorte, A game of hide and seq : identification of parallel Y-STR evolution in deep-rooting pedigrees, Eur. J. Hum. Genet. 27 (2018) 637–646, https://doi.org/10.1038/s41431-018-0312-2.
[17] S. Claerhout, J. Roelens, M. Van der Haegen, P. Verstraete, M.H.D. Larmuseau, R. Decorte, Ysurnames? The patrilineal Y-chromosome and surname correlation for DNA kinship research, Forensic Sci Int Genet 44 (2020), https://doi.org/10.1016/j.fsigen.2019.102204.
[18] T.E. King, M.A. Jobling, What's in a name? Y chromosomes, surnames and the genetic genealogy revolution, Trends Genet. 25 (2009) 351–360, https://doi.org/10.1016/j.tig.2009.06.003.
[19] N. Solé-Morata, J. Bertranpetit, D. Comas, F. Calafell, Y-chromosome diversity in Catalan suRNAme samples: insights into suRNAme origin and frequency, Eur. J. Hum. Genet. 23 (2015) 1549–1557, https://doi.org/10.1038/ejhg.2015.14.
[20] R. Granja, H. Machado, Ethical controversies of familial searching: the views of stakeholders in the United Kingdom and in Poland, Sci Technol Human Values 44 (2019) 1068–1092, https://doi.org/10.1177/0162243919828219.
[21] ministerie van justitie, Wet van 22/03/1999 betreffende de identificatieprocedure via dna-analyse in strafzaken, Etaamb.Openjustice.Be. https://etaamb.openjustice.be/nl/wet-van-22-maart-1999_n1999009419.html, 1999. (Accessed 17 July 2023).
[22] De Belgische Kamer van volksvertegenwoordigers, (n.d.). https://www.dekamer.be/kvvcr/showpage.cfm?section=/flwb&language=nl&cfm=/site/wwwcfm/flwb/flwbn.cfm?legislist=legisnr&dossierID=3620 (accessed February 16, 2024).
[23] A.F. Kaiser, Privacy and Security Perceptions between Different Age Groups while Searching Online, 2016.
[24] H. Wallace, The UK National DNA Database Balancing crime detection, human rights and privacy, EMBO Rep. 7 (2006).
[25] Protection of Freedoms Act implementation and National DNA Database annual report 2012 to 2013 - GOV.UK, (n.d.). https://www.gov.uk/government/speeches/protection-of-freedoms-act-implementation-and-national-dna-database-annual-report-2012-to-2013 (accessed July 11, 2023).
[26] National DNA Database documents - GOV.UK, (n.d.). https://www.gov.uk/government/collections/dna-database-documents#statistics (accessed July 11, 2023).
[27] C. Phillips, The Golden State Killer investigation and the nascent field of forensic genealogy, Forensic Sci Int Genet 36 (2018) 186–188, https://doi.org/10.1016/J.FSIGEN.2018.07.010.
[28] GEDmatch confirms data breach after users' DNA profile data made available to police | TechCrunch, (n.d.). https://techcrunch.com/2020/07/22/gedmatch-investigating-dna-profile-law-enforcement/ (accessed July 10, 2023).
[29] Why a Data Breach at a Genealogy Site Has Privacy Experts Worried - The New York Times, (n.d.). https://www.nytimes.com/2020/08/01/technology/gedmatch-breach-privacy.html (accessed July 10, 2023).
[30] R.N. Carleton, Fear of the unknown: one fear to rule them all? J. Anxiety Disord. 41 (2016) 5–21, https://doi.org/10.1016/j.janxdis.2016.03.011.
[31] Ó. García, M. Crespillo, I. Yurrebaso, Suspects identification through "familial searching" in DNA databases of criminal interest. Social, ethical and scientific implications, Spanish Journal of Legal Medicine 43 (2017) 26–34, https://doi.org/10.1016/j.remle.2017.02.002.
[32] J. Kim, D. Mammo, M.B. Siegel, S.H. Katsanis, Policy implications for familial searching, Investig Genet 2 (2011) 1–9, https://doi.org/10.1186/2041-2223-2-22.
[33] J. Epstein, "Genetic surveillance" - the bogeyman response to familial DNA investigations, SSRN Electron. J. 2009 (2009) 141–173, https://doi.org/10.2139/ssrn.1129306.
[34] E. Haimes, Social and ethical issues in the use of familial searching in forensic investigations: insights from family and kinship studies, J. Law Med. Ethics 34 (2006) 263–276, https://doi.org/10.1111/j.1748-720X.2006.00032.x.
[35] M.H.D. Larmuseau, S. Claerhout, L. Gruyters, K. Nivelle, M. Vandenbosch, A. Peeters, P. van den Berg, T. Wenseleers, R. Decorte, Genetic-genealogy approach reveals low rate of extrapair paternity in historical Dutch populations, Am. J. Hum. Biol. 29 (2017) 1–9, https://doi.org/10.1002/ajhb.23046.
[36] C. Avni, D. Sinai, U. Blasbalg, P. Toren, Discovering your presumed father is not your biological father: psychiatric ramifications of independently uncovered non-paternity events resulting from direct-to-consumer DNA testing, Psychiatry Res 323 (2023), https://doi.org/10.1016/j.psychres.2023.115142.
[37] B. Cohn, DIRECT-TO-CONSUMER GENETIC ANCESTRY TESTING: A MORALLY OBJECTIONABLE PRACTICE, 2020.
[38] M. Grethel, J. Lewis, R. Freeman, C. Stone, Discovery of unexpected paternity after direct-to-consumer DNA testing and its impact on identity, Fam. Relat. (2022), https://doi.org/10.1111/fare.12752.
[39] F.R. Bieber, C.H. Brenner, D. Lazer, Finding criminals through DNA of their relatives, Science 312 (1979) 1315–1316, https://doi.org/10.1126/science.1122655, 2006.
[40] P.A. Chow-White, T. Duster, Do health and forensic DNA databases increase racial disparities? PLoS Med. 8 (2011) https://doi.org/10.1371/journal.pmed.1001100.
[41] Why a DNA data breach is much worse than a credit card leak - The Verge, (n.d.). https://www.theverge.com/2018/6/6/17435166/myheritage-dna-breach-genetic-privacy-bioethics (accessed July 17, 2023).
[42] Genetic testing firm 23andMe admits hackers accessed DNA data of 7m users | Hacking | The Guardian, (n.d.). https://www.theguardian.com/technology/2023/dec/05/23andme-hack-data-breach (accessed February 16, 2024).
[43] R. Daviet, G. Nave, J. Wind, Genetic data: potential uses and misuses in marketing, J Mark 86 (2022) 7–26, https://doi.org/10.1177/0022242920980767.
[44] L. Quintana-Murci, M. Fellous, The human Y chromosome: the biological role of a "functional wasteland,", J. Biomed. Biotechnol. 1 (2001) 18–24, https://doi.org/10.1155/S1110724301000080.
[45] R. Heydari, Z. Jangravi, S. Maleknia, M. Seresht-Ahmadi, Z. Bahari, G. Hosseini Salekdeh, A. Meyfour, Y chromosome is moving out of sex determination shadow, Cell Biosci. 12 (2022) 4, https://doi.org/10.1186/s13578-021-00741-y.
[46] M. van de Rakt, P. Nieuwbeerta, N.D. de Graaf, Like father, like son: the relationships between conviction trajectories of fathers and their sons and daughters, Br. J. Criminol. 48 (2008) 538–556.
[47] M. Stevens, Preventing at-risk children from developing antisocial and criminal behaviour: a longitudinal study examining the role of parenting, community and societal factors in middle childhood, BMC Psychol 6 (2018) 1–12, https://doi.org/10.1186/s40359-018-0254-z.
[48] Y. Erlich, T. Shor, I. Pe'er, S. Carmi, Identity inference of genomic data using long-range familial searches, Science 362 (1979) 690–694, https://doi.org/10.1126/SCIENCE.AAU4832, 2018.
[49] S.-L. Wee, China puts all its men in DNA surveillance net, N. Y. Times (2020) 1. https://www.nytimes.com/2020/06/17/world/asia/China-DNA-surveillance.html.
[50] A. Bernotaite, Building of the World's Largest DNA Database: The China Case, Forensic DNA Typing: Principles, Applications and Advancements (2020) 639–658, https://doi.org/10.1007/978-981-15-6655-4_33/FIGURES/4.
[51] China Is Collecting DNA From Tens of Millions of Men and Boys, Using U.S. Equipment - The New York Times, (n.d.). https://www.nytimes.com/2020/06/17/world/asia/China-DNA-surveillance.html (accessed July 10, 2023).

[52] D. Cyranoski, China's massive effort to collect its people's DNA concerns scientists, Nature (2020), https://doi.org/10.1038/D41586-020-01984-4.
[53] A.J. Meulenbroek, K. Slooten, D.J.C. Aben, C. van Kooten, A.J. Kal, DNA-verwantschapsonderzoek in de strafrechtpraktijk, Expertise En Recht 2 (2012) 1–28.
[54] S.J. Ritchie, E.M. Tucker-Drob, How much does education improve intelligence? A meta-analysis, Psychol. Sci. 29 (2018) 1358–1369, https://doi.org/10.1177/0956797618774253.