

DNA PHENOTYPING IN FORENSIC INVESTIGATIONS: RESULTS FROM A SURVEY IN THE REPUBLIC OF SERBIA

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Abstract: DNA phenotyping aims to predict human observable physical and biochemical characteristics, age, biogeographic ancestry, internal characteristics and even behavior and lifestyle habits, using a set of techniques often reliant on single nucleotide polymorphisms and epigenetic markers. Forensic DNA phenotyping specifically intends to provide intelligence information to the law enforcement, with an idea of estimating different traits from unknown biological material uncovered during criminal and missing persons investigations. This promising and exciting approach is burdened by the consequences of technical errors, ethical issues (stigmatization, infringement of human rights, freedoms and individual privacies), as well as a lack of regulations and safeguards, thus stirring substantial scientific debate in the recent years. Given its impact on the entire society, the goal of this work is to stimulate a discussion with the public regarding forensic DNA phenotyping, by examining opinions among two distinct groups of citizens in the Republic of Serbia – lay public and senior students majoring in criminalistics and forensic sciences (future professional beneficiaries). Results demonstrate general acceptance of visible trait, age and ancestry prediction for forensic purposes, particularly for solving more serious crimes against life and limb, as well as sexual offences. Stronger overall support, contrasted with concerns regarding errors resulting from these probabilistic approaches, was particularly evident in the soon-to-be professional stakeholder category. I discuss the impact of these findings - the first from the Southeast Europe – which not only expand the international body of knowledge on the topic, but also contribute to developing operational and legal frameworks for responsible use and management of sensitive DNA data.

Keywords: forensic phenotyping, DNA database, EVC, discrimination, public opinion.

INTRODUCTION

DNA profiling is a routine method for human identification which has been used by the law enforcement and other security agencies for the past 35 years, in order to establish the identity of perpetrators, victims and other individuals of interest to criminal investigations. In addition to its integral role in establishing guilt, it has also played an immensely important part in proving innocence, including overturning wrongful convictions [1], and identifying mass disaster victims. However, this approach is comparative in nature, requiring comparison of the DNA profiles obtained from a biological trace and a reference sample (a suspect or a victim) or matching a DNA profile from a crime scene against a DNA database of known offenders. Therefore, in instances when first

time offenders leave their DNA at the scene of the crime, when there is no suspect, lead or eyewitnesses, and when DNA sample is obtained from anonymous bodies, DNA profiling is inadequate, making the investigative progress challenging. The limited options for overcoming these shortcomings include performing database searches with the unidentified DNA profile at a later point in time (in case the profile has been included in the database in the meantime) or creating DNA dragnets, both of which are limited by the legal framework (statute of limitations and national regulations, respectively). Scientific advances in the past decade have led to a proposal of a different solution - forensic DNA phenotyping (FDP). This set of techniques includes probabilistic inferences of externally visible characteristics (EVC), chronological age, biogeographic ancestry (BGA), internal

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characteristics (IC), medical conditions, lifestyle habits and behavioral traits based on DNA [2-11], with an idea of providing investigative intelligence to the police and security agencies. Clearly, the possible benefits of using this approach include creating investigative leads when no other data are available, thus narrowing the field of suspects [12], speeding up the investigative process, not wasting financial resources on less probable leads, preventing arrests of the innocent that do not fit the criteria and identification of unknown victims [13]; furthermore, missing person and mass disaster victim identifications could also be advanced with the FDP. For instance, 'DNAWhitness' technology (DNA Print Genomics Inc.) was used to predict the ancestry of a sought after serial rapist and murderer as 85% sub-Saharan African and 15% Native American, stirring the investigation into the direction which led to the arrest of the wanted perpetrator [14]. Similarly, the 34plex autosomal ancestry-informative-marker single nucleotide polymorphism (SNP) assay was used to predict North African origin of a suspect involved in the 2004 Madrid bombing, later confirmed to be of an Algerian origin [15].

The potential benefits of the new technologies have already motivated some countries to implement forensic DNA phenotyping into their legislation. For example, the Netherlands permits prediction of race at the moment, while other EVCs and sex could be added at a later time through an Order in Council; inference of disease-related information, however, is prohibited [3, 16, 17]. German state Bavaria has allowed estimation of age, ancestry, hair, eye and skin color in cases of "imminent danger"[18]. While Slovakia and some US states have also authorized the prediction of visible phenotypic traits (and disease-related markers in the case of the state of Texas, US) through explicit legal schemes, a few other countries (UK, France, Hungary and Canada) have done so implicitly, without a dedicated legislation [3, 16, 19]. On the other hand, Belgium has not only prohibited the use of FDP, but has also stipulated penalties for violating this regulation. The underlying reasons are numerous unresolved questions, concerns and risks associated with the practical applications of this technology, including errors. In fact, despite the technological progress and the development of prediction models based on the statistical approaches already employed in forensic DNA analysis (i.e. Random match probability - RMP and Likelihood ratio - LR) [20], potential consequences of the probabilistic nature of such inferences must always be considered. For instance, the prediction probabilities

for rare traits, which are the most useful in aiding criminal investigations, can decline below 50%, leading to over-representation of minorities (carrying rare characteristics) in police investigations [21]. Similarly, BGA testing is not as reliable in case of individuals with mixed ancestry or ancestry underrepresented in the reference databases. Additional apprehensions arise in relation to the more challenging approaches still in their developmental phases (such as the prediction of facial structure and generation of a modern version of a facial composite), which do not show sufficiently accurate predictions [22]. Further, despite the fact that EVCs are characteristics observable to everyone who has come into contact with the person and constitute integral components of identity documents, their exploitation through DNA phenotyping may breach human rights by pointing to a group of individuals who share the same characteristics, which may lead to stigmatization and discrimination of subpopulations (racial, ethnical, etc.) [23]. Other misinterpretations of FDP, missuses, misidentifications, associated privacy issues and regulatory challenges also pose a concern. In Germany, a murder of a college student by a refugee from Afghanistan stirred up a debate between different stakeholders. While the police, politicians and the media urged for the changes of the Criminal Procedure Code to include FDP and BGA, scientists questioned the current credibility of underlying science and insisted that more time should be given for the development of techniques before their implementation, which would allow the science to become more sound and for substantial debate among multi-disciplinary experts and the public [24, 25].

Republic of Serbia has passed the first Law on the National DNA Register in March 2018 and is currently in the process of establishing a national DNA database. For the past twenty years forensic genetic analyses have been carried out at one private and six public laboratories (at the Universities, Ministry of Interior and Security Information Agency), each operating their own database, which was made searchable by others *via* a court order. The legislated law stipulates merging of these individual databases into a national repository governed exclusively by the Ministry of Interior. This short and simple law, comprising of a total of 11 articles, has been passed without an opinion-forming process, a prior consultation with the other stakeholders (forensic geneticists, prosecutors, judges, layers) and the lay public. It has been heavily criticized by forensic geneticists and the Commissioner for Information of Public Importance and Personal

Data Protection, based on the unconstitutionality, biosurveillance, infringement of human rights and civil liberties. Hence, there already exists a pressing need for in-depth revisions of the existing regulations. The current Law on the National DNA Register stipulates that the prediction of physical, biochemical, physiological and psychological characteristics, that is heritable traits, is not permitted (Articles 4), thus restricting the analysis to noncoding DNA regions. However, as the field of forensic genetics progresses and the international debate regarding FDP expands from academic to public and political circles [26], Serbia and other Southeast European countries will also be faced with considering these emerging topics when reevaluating their operational and legal crime-fighting models. In order to achieve a balance between the use of the up-to-date technologies to fight crime and protection of individual privacies and human rights, thorough examination of public knowledge, awareness, understanding, interpretation, misconceptions and beliefs regarding the technology will be essential. To the best of the author's knowledge, only three studies have researched this topic in the past among European professional [26] and civil society [27] stakeholders and Swiss residents [28].

Considering an importance of such discussions, here, the author conducted an initial study, the first in Southeast Europe, to explore social acceptance and public views on FDP use by the law enforcement. The idea behind this work was to survey the lay public, but also young people about to enter the police work who will soon become professional beneficiaries of the new technologies, and examine putative differences in outlooks between these sub-populations.

MATERIALS AND METHODS

Results presented in this manuscript were obtained from an anonymous survey conducted in the Republic of Serbia from May to September 2019. The questionnaire was designed by the author and comprised of 8 questions covering basic opinions regarding the use of DNA in police work to predict EVC, BGA, age and lifestyle habits, as well as socio-demographic characteristics (gender, age, educational level and professional field). The survey was administered to a total of 303 respondents. In order to examine putative differences in viewpoints between specific population groups, two sub-populations were interviewed – lay public (208 respondents) and senior students at the Forensic Science and Criminalistics Departments,

University of Criminal Investigation and Police Studies in Belgrade, Serbia, who consented to participation in the survey (95 respondents). Unlike students, the category of respondents labeled 'lay public' indicates a population subgroup without any known prior professional association with forensic DNA databases. While the second category of respondents was interviewed by direct contact, with equal representation of both genders, the general public was approached *via* the snowball sampling method. Each initial contact was asked to participate and extend the invitation to their contacts. Although this sampling method increases the number of participants, it also leads to the loss of control over the sample in terms of gender, age and educational level. Specifically, this recruitment method created a bias in the current sample structure, most notably towards the younger and more educated population, in comparison to the national average.

Out of 303 people surveyed, 156 (51.49%) were women and 147 (48.51%) men. Different age groups were represented in the dataset, ranging from 16 to 70 years of age. While all students were aged between 21 and 30, distribution by age in lay public was as follows: 16-30 years 40.87%, 31-50 years 34.13%, and 51-70 years 25.00%. Median age of respondents in the current sample was 32, compared to 43.7, the national median recorded in 2018. In terms of the level of education, 1.44% of respondents from the lay public reported completing elementary school, 34.62% high school, 22.60% currently studying, 28.37% university, and 12.98% post-university education. In a census conducted in 2018, 34.7% of the general population stated elementary school as the highest obtained education, 49% secondary education, and 16.2% higher education.

Quantitative analyses were performed using The Statistical Package for Social Sciences (SPSS) for Windows, Version 22.0 (IBM Corp., US). In order to check for the statistically significant differences between the two surveyed groups, chi square test of association was performed.

RESULTS AND DISCUSSION

The participants were first questioned about their approval of the FDP use by the law enforcement. When asked about the utilization of unidentified DNA for predicting EVC, BGA and lifestyle, vast majority of respondents (94.71% lay public, 92.62% students and 94.05% total) provided some form of support for this approach (Table 1). Only 16 (5.28%) participants opted

for restricting such use of DNA information to missing persons cases only. FDP and BGA can be of great help for uncovering the identity of missing persons and disaster victims, when no antemortem evidence or living relatives exist. For instance, a study conducted in Slovenia reported success in predicting eye and hair color based on pigmentation markers analyzed from 49 WW II bone and teeth samples [7]. It is important to consider such application of FDP and BGA independently from the identification of perpetrators of crime, primarily in the context of the consequences which could arise from wrongful estimations, such as stigmatization or harassment of the innocence suspects.

Application of DNA phenotyping in criminal investigations was supported in 88.77% of answers (Table 1). However, there was a significant difference

between the views of the lay public and future beneficiaries of FDP ($\chi^2=13.76, p<0.05$). While 57.89% of students provided support for unrestricted use of the proposed technology, 39.9% of the public responders agreed, while 54.1% were in favor of the use restricted only to specific cases (Table 1). This is concurrent with the previous findings indicating that professional beneficiaries of the DNA technology exhibit more permissive views compared to the general public or individuals whose DNA has been previously collected by the government [29]. Only 15 (4.95%) respondents opposed to the use of FDP. These results are comparable with 8.5% of Swiss residents who also objected to the prediction of physical traits from DNA as a crime-fighting tool [28]. Open-mindedness towards this new technology to such an extent in both countries, with very different socio-demographic predicaments, is peculiar and could be a consequence of insufficient knowledge and awareness regarding its efficiency and intrusiveness. The possible lack of awareness of the implications of these technologies among the majority is quite worrisome. Despite being explained in the questionnaire introduction, it is unreasonable to expect that non-experts will be able to think of and comprehend all aspects surrounding FDP. This poses a complex issue, given that lay public does not possess much knowledge about biometric characteristics, yet they must be involved in the decision making process regarding such personal and sensitive data and, ultimately, have a say in what kind of society they would prefer living in. It is reasonable to expect, thus, that the most caution about the use of the technology will come from the experts in the field. Indeed, in a study which

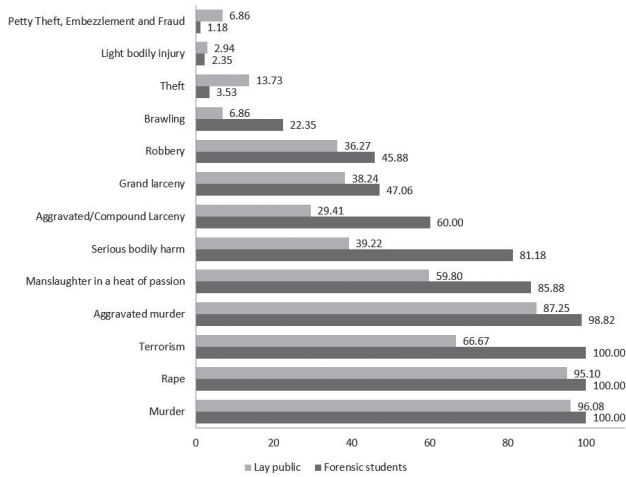


Figure 1. Types of crime for which the prediction of characteristics from DNA, by the police, is supported.

Table 1. “Do you support the use of anonymous DNA for predicting EVC and BGA by the police?”

		Yes	Yes, only for certain crime types	Yes, only for missing persons	Yes, only for certain crime types and missing persons	No	I do not know
Total respondents (n=303)		138 (45.54%)	125 (41.25%)	16 (5.28%)	6 (1.98%)	15 (4.95%)	3 (0.99%)
Profession	Lay public (n=208)	83 (39.90%)	98 (47.12%)	11 (5.29%)	5 (2.40%)	8 (3.85%)	3 (1.44%)
	Forensic students (n=95)	55 (57.89%)	27 (28.42%)	5 (5.26%)	1 (1.05%)	7 (7.37%)	0 (0.00%)
Sex	Female (n=156)	68 (43.59%)	68 (43.59%)	9 (5.77%)	3 (1.92%)	5 (3.21%)	3 (1.92%)
	Male (n=147)	70 (47.62%)	57 (38.78%)	7 (4.76%)	3 (2.04%)	10 (6.80%)	0 (0.00%)
Age	16-30 yo (n=180)	86 (47.78%)	67 (37.22%)	6 (3.33%)	8 (4.44%)	12 (6.67%)	1 (0.56%)
	31-50 yo (n=68)	27 (39.71%)	32 (47.06%)	3 (4.41%)	2 (2.94%)	2 (2.94%)	2 (2.94%)
	51-70 yo (n=55)	25 (45.45%)	26 (47.27%)	1 (1.82%)	2 (3.64%)	1 (1.82%)	0 (0.00%)
Educational level	Secondary and below (n=75)	29 (38.67%)	39 (52.00%)	2 (2.67%)	2 (2.67%)	2 (2.67%)	1 (1.33%)
	Students (n=142)	72 (50.70%)	50 (35.21%)	5 (3.52%)	6 (4.23%)	9 (6.34%)	0 (0.00%)
	Higher education (n=86)	37 (43.02%)	36 (41.86%)	3 (3.49%)	4 (4.65%)	4 (4.65%)	2 (2.33%)

examined the views of the professional stakeholders, STEM scientists exhibited reluctance towards the FDP implementation due to existing uncertainties about the methodology [26]. The current dataset, however, did not show differing views of individuals in the STEM area (40 respondents) or the law (10 respondents) compared to the other professions, likely due to the small sample size; this should be directly explored in more detail in the future. Similarly, overall educational level did not impact the views of the general public ($\chi^2=8.06, p>0.05$).

Views of the respondents who wished to limit the FDP to specific crime types only were next considered in further detail (Fig. 1). Offences against life and limb and sexual offences were, overall, the most supported, which is in line with the views of the Swiss respondents published recently [28]. The strongest support for FDP practical application, without notable differences between the subgroups, was obtained for the murder (97.86%), rape (97.33%) and aggravated murder (92.51%) cases. Convincing support was also evident for cases of terrorism (81.82%) and manslaughter in a heat of passion (71.66%), indicating that the seriousness of an offense was a determining factor for approving the employment of FDP. Serious bodily harm (58.29%) and offences against property - grand larceny (42.25%), robbery (40.64%) and aggravated/compound larceny (43.32%) - were moderately selected, but to a greater extent than in the Swiss sample [28]. The reason for such difference could lie in the fact that offences against property are by far the most common in the Republic of Serbia. For instance, statistical data from 2014-2018 showed that approximately a third of felons and about a half of minors were convicted for offences against property. It is important to note that there was an overall discrepancy in obtained answers between the two subgroups ($\chi^2=33.73, p<0.01$). These findings result from a significantly stronger support for the FDP use by the students, compared to the lay public, for virtually all crime types (for instance, 100.00% vs. 66.67% for terrorism, 81.18% vs. 39.22%, for serious bodily harm, 47.06% vs. 38.24% for grand larceny, 22.35 vs. 6.86% for brawling, etc.). In addition, students recommended including additional types of crimes, much more frequently compared to the general public (34.62% vs. 7.37% responders). These were sexual offences (sexual intercourse with a helpless person and sexual intercourse with a child), abduction, human trafficking, offences against human health and unlawful production and circulation of narcotics. Current findings support the notion of a more permissive outlook on FDP by the

future professional stakeholders.

While FDP is often contemplated and discussed as a single approach, it entails the prediction of an array of characteristics that may be regarded with different relevance in the public eye and which may bear distinct consequences. Thus, it is beneficial to examine public views on a trait-by-trait basis. The goal of this initial survey was to explore public outlook on a broad set of characteristics, ranging from EVC to propensity to certain lifestyle and habits, without discerning between the approaches that are currently feasible (i.e. eye, skin and hair color), the ones that are promising (i.e. boldness and age) and the ones that are technologically still far-fetched (i.e. face morphology) [22]. Results are shown in Fig. 2. Respondents' agreement with the use of DNA to infer proposed characteristics and habits ranged from 90.43% (biological age) to 52.81% (vegetarianism) [9]. In addition to the biological age, interviewed participants unequivocally opted for skin (85.48%), eye (83.83%) and hair (82.51%) color estimation, as well as face morphology (82.84%) and stature (78.88%) prediction. These results are interesting, particularly given that majority of students pointed out low permeance of eye and hair color, that is, that these characteristics can easily be purposefully altered and, thus, their usability can be called into question. Importantly, lay public and students, comparably, show significantly less support for testing propensity to lifestyle habits (such as smoking, alcoholism and vegetarianism), possibly because they perceive such analyses as privacy-invading to a greater extent (see below). Only two students and twelve lay respondents were against the prediction of all listed characteristics, while three students and 26 lay public participants opposed to using at least more than half of the proposed traits. In comparison, around 10% of the Swiss respondents rejected the use of geographic origin, hair, eye and skin color by the police [28]. It is interesting that these numbers are low in both studies, despite the subject matter being quite new to the respondents. Or perhaps, these low numbers are precisely a consequence of unfamiliarity with the FDP concept and the lack of awareness regarding the implications of practical applications. Only two people from the lay public category (and none among the students) in the current dataset declared being undecided regarding the use of all traits.

As with previous results, future professional stakeholders provided support more readily for virtually all EVC and BGA compared to the lay public (Fig. 2). These results corroborate the findings that the police officers, pressured to solve crimes, would be inclined to

implement in their work investigative approaches that are still not technologically sound, sufficiently accurate and validated, just in case they would be helpful [26, 28].

Arguments have been proposed that FDP and BGA can increase investigative intelligence, save time, money and resources, thus promising greater operational benefits, as well as adding a social value [2]. However, the question is whether achievement of tighter collective security comes at a cost for personal privacy for all. When asked about their biggest concerns, the majority of respondents (72.63% criminalistics students, 60.10% lay public, 64.03% total) expressed apprehensions about the possible errors (Table 2). These fears are quite justified from the scientific point of view, given the probabilistic nature and emerging status of the majority of approaches for discerning the EVCs, BGA, internal characteristics (ICs) and habits. The results are conditioned by the quality and quantity of samples, as well as the representation of the relevant genetic variants in the databases [25]. For instance, an assay based on 32 SNPs and one nanogram of DNA, demonstrated 77.7% ancestry prediction accuracy among the primary US populations and in 22.3% of cases inconclusively pointed to one of the two populations, one of which was correct [20]. There exist reports which emphasize accuracy and reproducibility of a six SNP IrisPlex system, a prediction model for brown and blue eye color [30-33], but also studies that

point out a much lower success in attempts to predict pigmentation phenotypes beyond “not blue”/“not brown” among different populations [30, 33], due to challenging intermediate phenotypes, putative role of gender [34, 35], etc. Similarly, it is reasonable to expect a dichotomous hair color prediction - “red”/“not red” [36-38], while more precise estimates are less reliable at the moment. In addition to issues with the predictability, majority of surveyed students pointed out that hair and eye color can be easily changed, and actually, that they would expect criminals to purposefully alter their appearance. This questions the future usability of the predictive tests from the criminalistics standpoint and the investment into the technology, given that it can direct the investigation into the wrong direction, risking new crimes to occur. Arguments have been made in the literature that these same concerns exist for eyewitness identification to an even greater extent, yet this method has been used in the court of law for decades. Yet, I believe that the case for the implementation of a new technology, such as FDP for investigative purposes, cannot be made based on the argument that it is a more modern version of a method known to be quite fallible [39]. Further, possible miscommunication and misinterpretation of obtained results must also be considered in the realm of errors. Predictive nature of FDP tests, due to SNP-SNP and gene-environment interactions, which cannot be surely determined for complex traits based on DNA alone, can easily be

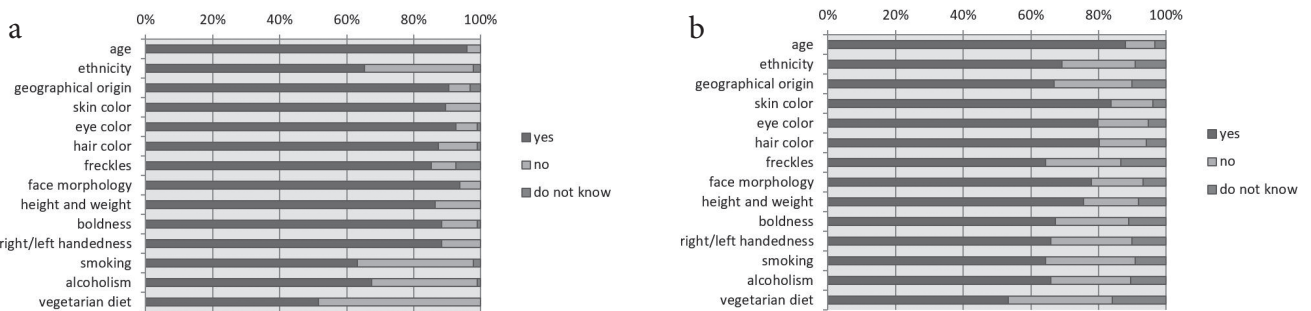


Figure 2. Support for the prediction of individual characteristics in the student population (a) and lay public (b).

Table 2. Major expressed concerns regarding FDP

	Public		Students		Total	
	Number of responses	Percent responders*	Number of responses	Percent responders*	Number of responses	Percent responders*
Errors	125	60.10	69	72.63	194	64.03
Privacy invasion	66	31.73	39	41.05	105	34.65
Discrimination	33	15.87	17	17.89	50	16.50
Nothing	41	19.71	7	7.37	48	15.84
Other	10	4.81	0	0.00	10	3.30
Total	275		132		407	

*Sum exceeds 100%, since multiple answers were allowed.

misinterpreted as deterministic and miscommunicated by non-experts or even experts. If prosecutor fallacy, an exaggerated likelihood of guilt assumed based on a routine method, has been documented in the court of law [40], why would it be unreasonable to expect misinterpretation of predictive tests? Further, instances of laboratory or crime scene sample contamination, as well as mixed deposition, would additionally complicate the interpretation of estimated results.

The second biggest concern expressed by the interviewed population (31.73% students, 41.05% lay public and 34.65% total) was the invasion of privacy by FDP. For instance, testing for a predisposition to a disease or a medical condition may breach the right not to know. Most countries are taking precaution in this matter and separating medical information from other FDP. Despite this, analyses of coding portions of DNA can include inferences about extremely sensitive internal characteristics, such as sexual orientation or gender identity [10]. These must also be considered bearing in mind 'not wanting to know' and 'not wanting others to know' such information, as their revelation could significantly impact one's life. The same is true for certain behavioral characteristics, such as propensity for impulsive and/or aggressive behavior.

The most common answers given by the respondents, particularly the lay public, when they were given space to discuss their concerns, were misuse and fraudulent use of obtained information by the police (including fabricating information and substitution of samples), corruption, distrust towards the governmental institutions, as well as the ability and preparedness of the government to implement advanced technologies and protocols. This is not surprising given previous reports on low confidence in state institutions among the Serbian public, perceptions that the government failed to provide constitutional rights to all and that the corruption is a leading social problem in Serbia [41-44]. On one hand, allowing FDP does not equate with placing the technology in the hands of the police, as proper interpretation of results (by an expert independent body) and well-defined guidelines for the law enforcement could ensure adequate use of the technology [2, 13]. However, this would be very difficult to imagine in practice in countries such as Serbia where all the power regarding establishing, maintaining and managing DNA databases has disproportionately been given to the police, without reviews by an external, independent body. In addition, transparent prosecution records for the employees of the Ministry of Interior or other government authorities do not exist in Serbia. One

study showed that in 2016, out of 201 criminal charges against Ministry of Interior employees, 21 convictions were ordered by the court (14 parole and seven lasting from six to eighteen months imprisonment), indicating that police officers are charged infrequently in the Republic of Serbia [45]. Thus, the voiced concerns regarding FDP misuses have merit, as they reflect hesitations regarding surrendering even more private data to the government, particularly in the environment in which the policy of 'no consequences' is present in the public eye.

In addition to being predictive in nature, another feature of FDP is that inferred information most often refers to group characteristics, which could lead to discrimination and stigmatization of a subpopulation. This poses a legitimate concern in virtually all societies. Specifically, in South European countries there has been a long tradition of poor position of Roma people, who are uneducated, under housed, and often stigmatized as lazy thieves and beggars [46-50]. During the author's class discussions throughout the years, police officers (who have come back to school to complete their studies) infrequently make remarks about being convinced that certain "Gypsy" people have committed a crime. "Why would I have to go to great lengths, wasting time and resources during an investigation, when I know he (referring to a Roma person) committed four crimes since he woke up this morning?", commented a student with many years of experience as a police officer. Having FDP at hand, particularly when ambiguous results are presented (for instance, DNA was left by a light skinned Roma female), could easily lead to wrongful interpretations (due to unreasonable expectations of the implemented technology) and unfounded allegations towards minority individuals, who could suffer harassment. Yet, less than a fifth of interviewed persons (15.87% lay public, 17.89% students and 16.50% total) expressed concerns regarding discrimination. Such results could be a consequence of the fact that virtually none of the respondents belonged to a minority group and they contemplated the application of FDP and BGA on someone else's DNA, as a useful crime-fighting tool. If, on the other hand, the participants were faced with the question of their own DNA being analyzed and the potential of, for instance, medical discrimination, perhaps their support would not be as convincing, but this would need to be tested directly in the future.

In conclusion, research advancements which create a shift enabling the use of biological data for investigative purposes, as seen with the iris recognition

technology [51], are exciting. Yet, the deliberation regarding sensitive data resulting from DNA phenotyping will involve a challenging balancing act between the arguments for collective security (i.e. effectiveness) and individual privacy (i.e. intrusiveness). Reaching a sensible position regarding the possible implementation of these technologies will require consideration and resolution of numerous remaining issues. Given the limited forensic sample, who would decide which traits would be estimated? What would occur with mixed depositions, when the person of interest was not the dominant donor? Where would the obtained data be physically stored? Would the approach be utilized only when other methods are unavailable or unreliable? Who would be granted access to the generated data, for what purpose, in which situations and for how long (during or after the investigation?)? What would happen if the authorizations are breached? Decisions regarding these unanswered questions, and the assessment of privacy impact [52], should come from deliberations of interdisciplinary panels of experts from life, social and legal sciences [5] on national and international levels. Importantly, reaching a balanced position also requires hearing the voice of the general public, given that the use of predictive markers in investigative intelligence is not the question of minorities [25], but will impact the entire society. This is why the current study was designed to initiate public consultation, which is particularly important in countries such as Serbia, where decisions regarding the use and management of DNA data have been made in the past without prior discussion with the professional stakeholders or the public (Teodorović S, Bošković A. Establishment of the National DNA Database in the Republic of Serbia: Legal Aspects and the Implications for the Future. *Medicine, Science and the Law*, in press). These baseline public perceptions will, along with further evaluations of public understanding, interpretations, misconceptions and beliefs regarding the benefits and risks of DNA phenotyping, be quite instrumental in developing strategies for raising awareness and education levels (through effective knowledge communication) and building operational and legal models for the responsible forensic use and management of sensitive DNA data.

Conflict of interest

The author declares that she has no conflict of interest.

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