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Forensic DNA Phenotyping: Examining knowledge and operational view from police officers

Audrée Gareau-Léonard [a,b,c,*], Vincent Mousseau [b,c,d], Frank Crispino [a,b,c], Emmanuel Milot [a,b,c,**]

[a] Université du Québec à Trois-Rivières (UQTR), 3351 boulevard des Forges, Trois-Rivières, Québec, G8Z 4M3, Canada
[b] Centre International de Criminologie Comparée (CICC), Université de Montréal, Pavillon Lionel Groulx, 3150 rue Jean-Brillant, Bureau C-4086, Montréal, Québec, H3T 1N8, Canada
[c] Groupe de Recherche en Science Forensique (GRSF), Université du Québec à Trois-Rivières, Pavillon CIPP, 3351 boulevard des Forges, Trois-Rivières, Québec, G8Z 4M3, Canada
[d] École de Criminologie - Université de Montréal, Pavillon Lionel Groulx, 3150 rue Jean-Brillant, Montréal, Québec, H3T 1N8, Canada

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ABSTRACT

Forensic DNA phenotyping (FDP) is a tool predicting physical characteristics from DNA to provide investigative leads. Research has mainly focused on the development and validation of molecular marker panels and associated statistical models to predict phenotypes. However, little is known about the operational value of DNA phenotyping, as perceived by the targeted users (i.e. police officers involved in criminal investigations). We used a questionnaire to survey 163 officers across Québec (Canada), and who are involved in major crime investigations, to better understand their knowledge and opinion regarding DNA phenotyping. Their responses show that a majority (63 %) are not yet familiar with DNA phenotyping. However, most respondents (58 %) support its use, especially for crimes against the person, if proven reliable. This research emphasizes the relevance of surveying police officers during the development and implementation of such operational forensic tools, as their expectations were not entirely in line with the current and anticipated possibilities of phenotyping, particularly with regard to the most useful traits to target. Respondents consider most useful predictions on eye colour, ethnicity, age and height, whereas it is biogeographical origin that is currently predicted (even if not a phenotype), and the last two traits are difficult to accurately predict. The perspective of police officers gathered here also argues in favor of involving other actors of the justice system to better delineate the scope of FDP in criminal cases and to improve its integration throughout the judicial process.

1. Introduction

Forensic DNA phenotyping (FDP) is a tool that has been the center of numerous discussions and research in the forensic field in the last few decades (e.g. Refs. [1–4]). This tool aims to predict physical characteristics (phenotypes) of individuals, such as their eye, hair and skin colour or their height, solely based on the analysis of their DNA [5]. In forensic science, it is particularly interesting in cases where a DNA trace left at a crime scene cannot be linked to an individual using standard identification genetic markers, and for which phenotyping could narrow down the list of persons of interest or help identify a victim based on physical characteristics [4]. Pigmentation traits (eye, hair and skin colour), phenotypes that correlate with biogeographical origin, age,[1] height and face are the most researched physical characteristics to date [6]. Pigmentary traits, especially eye colour, are the "easiest" to predict due to their greater "genetic simplicity" (one or a few genes with a major effect on the phenotype) [7], but on the other hand, phenotypes like height and face have proven to be much more difficult to predict [8–12]. In recent years, knowledge regarding these phenotypes has expanded and numerous phenotype prediction sets have been developed, some of

* Corresponding author. 3351 boulevard des Forges, 3160 CIPP, Trois-Rivières, QC, G8Z 4M3, Canada.
** Corresponding author. 3351 boulevard des Forges, 3160 CIPP, Trois-Rivières, QC, G8Z 4M3, Canada.
E-mail addresses: audree.gareau-leonard@uqtr.ca (A. Gareau-Léonard), vincent.mousseau.1@umontreal.ca (V. Mousseau), frank.crispino@uqtr.ca (F. Crispino), emmanuel.milot@uqtr.ca (E. Milot).

[1] We do not consider age and biogeographical origin as phenotypes, but since DNA predictions can be attempted on these characteristics as well, they are often treated in conjunction with phenotypic traits in articles on DNA phenotyping.

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which have been validated for forensic use [6,13]. Furthermore, other phenotypic traits are currently being researched, such as eyebrow colour, freckles, male hair loss and hair structure [6,14,15].

The tool has, however, reliability issues that could provide false leads (e.g. if it predicts that the person of interest has blue eyes and brown hair, it could potentially be misleading if the person has in reality brown eyes and black hair) [16]. This is in part due to the simplistic genetic models used to predict phenotypes, which do not incorporate all the major sources of phenotypic variance, for example, environmental effects [17,18]. DNA phenotyping has other limitations, such as not being able to accurately predict many physical traits to date or not being able to identify a person (which limits its scope). Moreover, its usefulness has not been thoroughly appraised by the targeted users, i.e. the police officers. To date, only one study has looked at DNA phenotyping at the police level and it has focused primarily on ethical, social and regulatory concerns [19]. Interestingly, this study showed that some police officers would be inclined to use tests even if a proper validation had not been carried out or if the predictive value was low, as long as they perceive their usefulness (e.g. if they believe the tests may provide a new lead). However, the number of police officers interviewed was small ($n = 6$), limiting the conclusions that can be drawn about the value of FDP from a police perspective. Previous studies [20–22] have also shown that police officers (in Québec and other parts of the world) have limited knowledge and understanding of the possibilities that forensic tools can provide. Furthermore, the majority of crime resolutions are not the result of the use of forensic science [23–25], which poses the question of whether police officers are ever asked about their intended use of forensic tools. Therefore, the question remains as to how familiar police forces are with DNA phenotyping and if they perceive this tool to be operationally valuable for their investigations.

This study aimed to address these issues by surveying a large sample of police officers across Québec, Canada, who are more likely to come into contact with DNA phenotyping because of their job titles and/or functions. Specifically, an online questionnaire was distributed to different categories of police officers of the *Sûreté du Québec* (SQ) (the largest police force, in terms of territorial jurisdiction and mandate of action, in the province of Québec) to assess their level of knowledge on the subject as well as their opinion regarding the use, reliability and issues of this approach. Our findings suggest that most police officers who participated in the study do not know, or only know the very basics (i.e. what it is), of DNA phenotyping, but still perceive an operational usefulness, particularly for crimes against the person, should the results be reliable.

2. Material and methods

2.1. Evaluation tool

In order to explore police officers' knowledge and opinion about DNA phenotyping in a forensic context, and the underlying sources on which they are based, an online questionnaire was chosen to collect the data. This method is suitable for our study because it provides a broad picture of the subject of interest [26]. The use of an online questionnaire also made it possible to circumvent limitations caused by public health measures during the COVID-19 pandemic. The questionnaire had three sections: the first one included socio-demographic questions about the respondent, the second included discrete-choice (yes/no, multiple-choice) and qualitative (textual) questions about their knowledge on DNA phenotyping, and the third included discrete-choice and qualitative questions about their opinion on DNA phenotyping (see Supplementary Data S1 for the full questionnaire). The questionnaire was pretested on a small number of police officers ($n = 14$) from the *École nationale de police du Québec (ENPQ)*[2] to evaluate its clarity and make adjustments whenever necessary [27]. Their answers were not included in the final sample.

2.2. Sample

In Québec, police services are categorized on a 6-level scale, according to the geographical extent and population size of their jurisdiction, as well as on their mandate, each increasing level being assigned supplemental police services, including some related to forensic science and major crimes. For example, investigation of murders without imminent arrest are handled by police level 3 and above [28]. The *Sûreté du Québec* (SQ) is the only organization of level 6 and was chosen for three reasons: 1) it investigates, or supports lower-level police organizations, in investigations related to major crimes (where DNA phenotyping seems to be mostly intended [29]); 2) since it plays a support role for all law enforcement agencies of lower levels, it is omnipresent in the province of Québec (it covers an area of 1 165 099 km^2 (data as of March 31, 2020) [30]); 3) it has the greatest scope of action and more financial resources than other levels, hence fewer constraints to use state-of-the-art technologies for its investigations, such as FDP. Following a presentation of the project in November 2019, the SQ agreed to collaborate by soliciting its police officers involved in criminal investigations (n° SQ-1234-2021-12). Investigators, police managers and crime scene examiners were specifically targeted due to their decision-making role at a crime scene and in requesting forensic analyses, thus excluding officers working in the organization's administration and patrol officers.

The surveyable population was estimated by the SQ to be 333 police officers and crime scene examiners. A total of 163 of them (48.9 %) participated in the questionnaire (134 sergeants-investigators, 11 lieutenants, 3 captains, 6 crime scene examiners and 9 others). Participants were aged between 29 and 62 years old (mean = 43, SD = ±7) and had between 6 and 31 years of working experience in the police (mean = 19, SD = ±6). At least 42 participants explicitely stated they were mainly involved in major crimes investigation in their routine work. All participants had a junior college diploma,[3] among which 83 also had a university degree (e.g. B.Sc. or shorter undergraduate certificate, M.Sc.) and one participant did a post-doctorate (Table 1).

2.3. Data collection

An internet link to the online questionnaire was sent to all police hierarchical levels of interest through an internal communique by the *Service de la coordination des enquêtes sur les crimes majeurs*[4] of the SQ. Participation to the study was voluntary, i.e. not a mandatory task asked by the police hierarchy, and relevant information to make an informed choice was provided to participants, who were also asked to sign a consent form beforehand. This project was approved by the Human Research Ethics Committee of the *Université du Québec à Trois-Rivères* on March 9, 2020 (n° CER-20-265-07.30) and has been carried out in compliance with Canadian laws and institutional guidelines of the *Université du Québec à Trois-Rivières*. Participants were asked to complete the questionnaire in once (which could not be verified), in a quiet

[2] The *École nationale de police du Québec (ENPQ)* is the only police academy in the province of Québec.

[3] In Québec, people wishing to become police officers generally obtain a junior college diploma in police technology (3 years) before completing their training at the ENPQ (15 weeks). However, candidates to the profession can also become police officers with a university degree or a vocational college diploma in another field (e.g. criminology or computer science) if followed by a 30-week Attestation of College Studies (ACS) in police technology and training at the ENPQ [31,32].

[4] Major Crime Investigation Coordination Department (our translation).

Table 1
Socio-demographic characteristics of the participants ($n = 163$).

Characteristic[a]	Count (%)
Declared sex	
Male	97 (59.5)
Female	64 (39.3)
NA	2 (1.2)
Age (years old)	
29-40	44 (27.0)
40-45	40 (24.5)
45-50	44 (27.0)
50+	22 (13.5)
NA	13 (8.0)
Highest level of education completed	
Junior college (CEGEP or certificate of collegial studies)[b]	63 (38.7)
Short undergraduate programmes (certificate or university microprogram)	78 (47.9)
Master, PhD or Post-doctorate	3 (1.8)
Other (CEGEP or graduate studies with additional training at the ENPQ or elsewhere)	19 (11.7)
Police job title	
Captain	3 (1.8)
Lieutenant	11 (6.7)
Sergeant-investigator	134 (82.2)
Crime scene examiners[c]	6 (3.7)
Other (e.g. polygraphist, analysts, CQEDS[d] specialist)	9 (5.5)
Policing experience (years)	
6-15	38 (23.3)
15-20	38 (23.3)
20-25	56 (34.4)
25-31	31 (19.0)
SQ police district	
North district	11 (6.7)
East district	28 (17.2)
South district	52 (31.9)
West district	8 (4.9)
Montreal and Laval	23 (14.1)
NA	41 (25.2)

[a] Choices with no respondents were not included in the table.
[b] CEGEP is a public institution of general and vocational education in Québec between high school and higher education.
[c] Crime scene examiners in Québec typically complete general police training before specializing in the discipline.
[d] CQEDS stands for *Centre québécois d'enregistrement des délinquants sexuels* (Québec Sex Offender Registration Center, our translation).

location, free from distractions. They were also asked not to consult any literature beforehand or other people regarding the research subject, and except for certain socio-demographic questions, they were not required to answer any questions if they did not wish to (which explains why certain results were only obtained for a part of the total sample). Their answers were collected between September 2020 and November 2021. Reminders to complete the questionnaire were given on three occasions between April and October 2021.

Data collection was based on the saturation criteria, which consists in analysing responses until no new data is discovered, increasing confidence that all major components have been identified [33–35]. Saturation was verified using the method presented in Ref. [36], which consists in counting the number of new codes in a given number of data collection events (i.e. questionnaires in this research) until a threshold is reached. Using a base size of six and a run length of four, the 0 % new information threshold aimed at was reached at 114^{+4} questionnaires, with a clear repetition of similar answers observed beyond this point, meaning the major themes have been gathered. Nevertheless, all questionnaires ($n = 163$) were analyzed to count the occurrences of each type of answer.

Participants took between 3 min and 5 h to complete the questionnaire, with an average of 40 min (SD = ±37). Those with some knowledge of DNA phenotyping took longer to answer the questionnaire than those without. As the questionnaire was completed online, we were unable to control whether some participants did not complete it all at once and left it temporarily open (e.g. because they were interrupted by other tasks), which could explain some longer response times.

2.4. Data analysis

Answers to qualitative questions were analyzed using an inductive approach [37]. First, they were curated following the same format (i.e. answers from each respondents were organized by section (knowledge or opinion on DNA phenotyping) in a distinct digital file, using the same font and font size). They were then read more carefully and repeatedly until the principal researcher (AGL) began to gain an overview of the data in the corpus. Once completed, the principal researcher (AGL) performed a vertical analysis by coding the information contained in each participant's questionnaire inductively. This step was accomplished using NVivo® (version release 1.2) and enabled the extracts from the corpus to be summarized using simple words that capture the main ideas emerging from each questionnaire [38]. Subsequently, horizontal analysis was used to group the codes assigned to each participant's responses into broader categories to identify themes and trends between all the responses obtained, thus generating a comprehensive picture of the subject matter [39]. Finally, a quantitative descriptive analysis was performed from an exploratory perspective by counting the occurrences of each code. Graphs of these counts were produced using Microsoft Excel® (version 15.0.5423.1000, 2013) and R software® (version 4.0.3, 2021) [40].

3. Results

3.1. Knowledge on DNA phenotyping in a forensic context

Most respondents answered that they had little to no knowledge of DNA phenotyping. Prior to participating in this project, 103/163 (63 %) had never heard about DNA phenotyping, 36/163 (22 %) had basic knowledge of what it was, and 24/163 (15 %) had a somewhat higher knowledge about the technology (e.g. names of companies offering phenotyping services, costs, etc.). It is interesting to note that a single company offering DNA phenotyping was mentioned by respondents, namely the USA-based Parabon NanoLabs.[5] Moreover, as Fig. 1 shows, a greater proportion (55 %) of senior police managers and specialized police officers (i.e. others in Fig. 1) seem to hold a basic or higher knowledge compared to sergeant-investigators (33 %).

Respondents' knowledge about DNA phenotyping seems to come from several sources. Among the 58 police officers who shared how they had heard of DNA phenotyping prior to this study, their prevalent sources were mainstream medias (e.g. newspapers, television, radio; 24/58; 41 %), training or courses (16/58; 28 %), colleagues (regarding a specific case or not; 15/58; 26 %) and/or the Internet (12/58; 21 %; Fig. 2). Note that absolute numbers above exceed 58 since participants could propose more than one source. A majority of participants mentioned only one (44/58; 76 %) or two (13/58; 22 %) different sources in their answer. One participant mentioned having attended a Parabon NanoLabs training on DNA phenotyping.

3.2. Opinion on DNA phenotyping in a forensic context

3.2.1. General reliability and reliability of DNA phenotyping

Scientific, legal, and practical aspects were identified as important

[5] Note that Parabon NanoLabs was the unique company selected in the few criminal cases across Québec for which a DNA phenotyping analysis was ever conducted (four cases, to our knowledge).

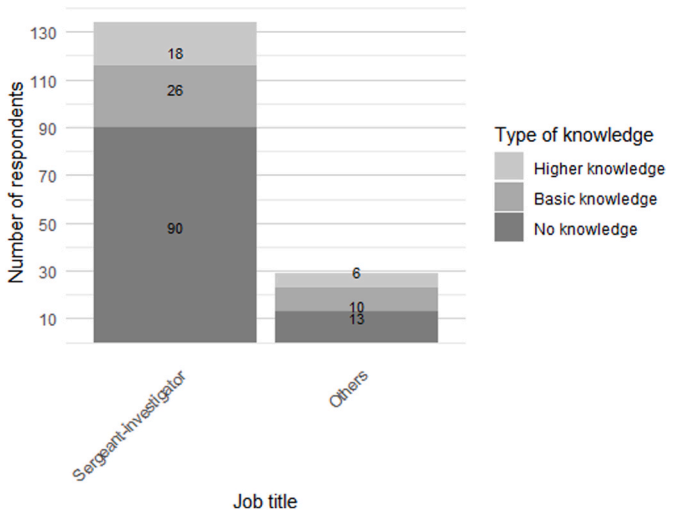

Fig. 1. Level of respondents' knowledge about DNA phenotyping prior to this study, according to their job title (n = 163). The category "Others" includes captains, lieutenants, crime scene technicians and others.

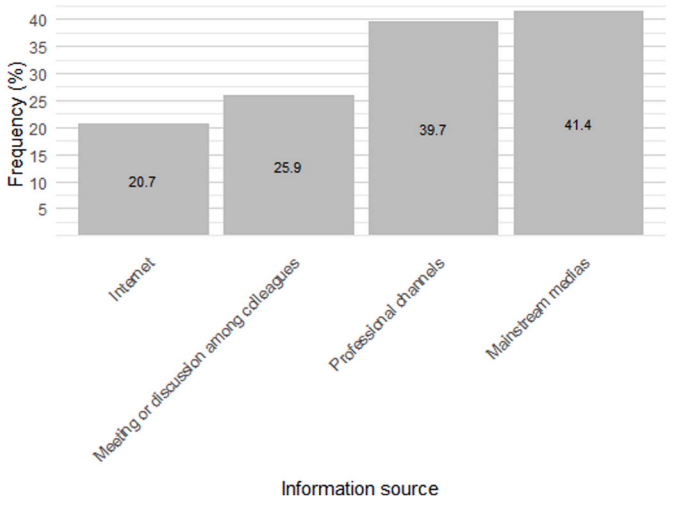

Fig. 2. Information sources mentioned by 58 police officers who already knew DNA phenotyping prior to this study. Professional channels include training or course, congress or conference, scientific papers and forensic press review. The sum of the columns is greater than 100 % because respondents could propose more than one source.

by police officers when asked what a reliable tool or technology meant to them in general, and not specifically in relation to DNA phenotyping. Of the 132 participants who answered the questions related to this topic, about half (62; 47 %) mentioned the need for the tool or technology to be scientifically tested and validated. This aspect is well summarized in two of the responses received, one from an investigator and the other from a crime scene examiner. The former explained that a reliable tool or technology is one that "has been tested and approved by laboratory experiments several times. Subsequently, the obtained observations are analyzed and the technology is judged reliable or not." (Participant 4059559; our translation[6]). The second shared that, for them, a tool or technology can be considered reliable after it had been submitted to "a well-established and respected quality control process. Several tests and studies have been done to verify the percentage of reliability and error. An exhaustive, objective, and neutral study on this technology [has been completed]." (Participant 4036132). Additionally, some participants (36/132; 27 %) specifically mentioned the need for a "low error rate" (Participant 3940372) to consider a tool or technology reliable while others (40/132; 30 %) emphasized the importance for the tool or technology to be recognized in the courtroom. For example, Participant 3955491 believed that "the court is ultimately the real test". Finally, few participants (17/132; 13 %) mentioned that a reliable tool or technology is one "that leads to concrete results" (Participant 4237533).

Among the 145 police officers who commented on the reliability of DNA phenotyping, 110 (76 %) explicitly wrote that since they believe they only had limited knowledge of the tool, they preferred not to offer an opinion on its reliability. Nevertheless, 34/145 (23 %) thought phenotyping was reliable because it is based on DNA. For example, Participant 3940543 wrote: "it uses DNA, which is reliable", while Participant 4059696 stated that "the percentage of matches is very high [with current DNA analysis]. It must be the same logic [for DNA phenotyping] as for the DNA that we know". Interestingly however, analysis of another question from the questionnaire revealed that the majority of respondents (140/144; 97 %) felt that they were not sufficiently trained in emerging DNA-based tools and technologies, including DNA phenotyping.

3.2.2. *Practical use of DNA phenotyping*

Respondents seem to perceive DNA phenotyping as potentially useful for various, if not all types of crimes, especially crimes against the person (e.g. homicide, sexual assault, home invasion). Without giving any type of crimes were DNA phenotyping could be used except for the example provided in the question (homicide), seventy-nine out of 137 (58 %) respondents said that phenotyping would be relevant in cases of crimes against the person, 24/137 (18 %) in crimes against property (e.g. burglary, arson), and 7/137 (5 %) in financial crimes (e.g. fraud) because "[…] even fraudsters who have manipulated documents or computers [have left their DNA], DNA is everywhere." (Participant 4066872). Also, 39/137 (28 %) police officers emphasized that they would particularly like to use it for major and/or violent crimes. Finally, a good proportion of respondents (47/137; 34 %) thought that phenotyping should be used for all crimes where DNA traces could not be matched to someone using standard STR genetic profiles for forensic identification purposes, because, they said, every lead can potentially be useful ("[…] any additional information can make a difference."; Participant 4020770) and every crime is important ("I consider that all crimes are important so [DNA phenotyping could be] useful in any kind of investigation, especially when there are no suspects […]"; Participant 4051035). Interestingly, 13 officers declared that they would use it for serial crimes, which were not an answer that was explicitely written by the researchers in the questionnaire.

Beyond crime types, police officers were also asked to indicate in what ways DNA phenotyping could be useful to their investigations.[7] According to 133/138 participants (96 %), it could restrict or orientate the search for people of interest in given cases. For example, it can "provide evidence that will move the investigation forward […]" (Participant 3963855), "[help] eliminate suspects and focus on the right group of individuals" (Participant 3954560), or "allow to refine search criteria corresponding to suspects" (Participant 3939439, who wrote "suspects" to indeed refer to authors of crimes). A smaller number of respondants (26/138; 19 %) added that phenotyping could help complement or confirm circumstantial information in cases (e.g. "to corroborate the witnesses' versions"; Participant 3956311) or that it "could even make it possible to complete and clarify the facial composite drawn up by the victim" (Participant 3959632). Fourteen out of 138 (10

[6] All translations in this article were made by the main researcher (AGL).

[7] As we expected DNA phenotyping to be unfamiliar to the majority of police officers, a brief description of this tool was included before the first question (see Supplementary Data S1), enabling them to answer some questions without prior knowledge of DNA phenotyping.

%) participants mentioned that DNA phenotyping could, in the absence of testimony, help in the "development of a facial composite" (Participant 4255226). Finally, 10 respondents (7 %) thought it could allow the "reopening of unresolved cases" (Participant 4232393), i.e. cold cases. Overall, police officers thus anticipate several benefits from DNA phenotyping at the investigative level.

3.2.3. Physical characteristics of interest

Participants were asked what physical characteristics they thought would be useful to predict from DNA (they could indicate any number of them). Eye colour was the most common answer (78/142; 55 %), followed by age (72/142; 51 %) and hair colour (69/142; 49 %; Table 2). This might be because some of them (eye colour and age) are "not as easy to modify" (Participant 3974444) or they "cannot be modified" (Participants 3940543, 3968155 and 4046627), but also because they are "observable physical characteristics" [as opposed to e.g. some illnesses] (Participant 4065527). Furthermore, a substantial proportion of respondents (52/142; 37 %) answered that they would like to have DNA predictions for as many physical traits as possible (we might propose, based on answers received, pigmentation traits, ethnicity,[8] height, age, sex, and others), mainly "to obtain a portrait of the suspect" (Participant 4066872) and because "any information that is possible and available is welcome. [It] can enhance a composite profile. Any additional information can make a difference" (Participant 4020770). Some police officers (25/142; 18 %) wrote they would like to obtain predictions for health conditions, such as "malformation or disability" (Participant 3957223), or diabetes (Participant 3955452). Three out of 142 (2 %) respondents would even like lifestyle-related predictions, such as eating habits (Participant 3968155) or other types of consumption (e.g. "smoker, drug and alcohol"; Participant 4246136). As underlined by some, illnesses and lifestyle can be "easily observable or easily known from their [familial/social] surrounding" (Participant 3940600), and are "more specific" (Participant 3963708).

When police officers were asked to narrow down their preferences to the three physical characteristics they considered most important, without ranking them, a majority chose eye colour (60/111; 54 %), followed by age (49/111; 44 %) and ethnicity (40/111; 36 %; Table 3).

Table 2
Most interesting physical characteristics to predict by DNA phenotyping from the police officers' perspective (n = 142/163).

#	Physical characteristic	Number of respondents	Percentage (%)[a]
1	Eye colour	78	54.9
2	Age	72	50.7
3	Hair colour	69	48.6
4	Everything possible	52	36.7
5	Ethnicity	47	33.1
	Height	47	33.1
6	Face	36	25.4
7	Sex	34	23.9
8	Skin colour	28	19.7
9	Weight	25	17.6
	Medical information	25	17.6

[a] The sum of this column is greater than 100 % because respondents could propose more than one characteristic.

[8] Participants used the terms "race" and "ethnicity" interchangeably in their responses. Since race is a classification based on observable physical characteristics with no biological basis (e.g. White) and ethnicity refers to a person's ethnic or cultural origins (e.g. Canadian), the term "ethnicity" was chosen for this article. Also note that biogeographical origin, which has been studied in an attempt to predict it using DNA but is not strictly speaking a phenotype, refers to an individual's geographical origin based on its DNA and is not equivalent to ethnicity or race. When we refer to the scientific literature discussing this trait, we use the term "biogeographical origin".

Table 3
Physical characteristics mentioned by police officers when asked which three they considered the most interesting ones to obtain from DNA phenotyping (n = 111/163).

#	Physical characteristic	Number of respondents	Frequency (%)[a]
1	*Eye colour*	*60*	*54.1*
2	*Age*	*49*	*44.1*
3	*Ethnicity*	*40*	*36.0*
4	Height	39	35.1
5	Hair colour	29	26.1
6	Sex	25	22.5
7	Weight	19	17.1
8	Medical information	19	17.1
9	Face	17	15.3
10	Skin colour	17	15.3

[a] The sum of this column is greater than 100 % because respondents could propose different characteristics.

These traits were closely followed by height (39/111; 35 %; Table 3).

3.2.4. Issues related to DNA phenotyping

Police officers are to some extent aware of problems associated with DNA phenotyping, although their knowledge about the subject remains limited. Of the 118 who answered the question about phenotyping-related issues, 91 (77 %) mentioned practical issues, including reliability, limited usefulness in certain situations, and risks of prediction errors that can mislead or bias investigations.[9] A total of 44 respondents (37 %) acknowledged legal issues (eligibility in court, reliability can be challenged by the defense, etc.), 30 (25 %) raised social issues (ethical, human rights, racial profiling, social acceptance), 25 (21 %) raised technical issues (availability, time before obtaining the results, implementation problems in forensic laboratories), and 18 (15 %) mentioned that costs could be an impediment to use DNA phenotyping.

Finally, when asked their opinion regarding DNA phenotyping in criminal investigations on a scale of 1–10, with 10 being very favorable to its use, police officers were divided, with three predominant scores of 5, 8 and 10, and a mean score of 7.8 ± 2.2 (Fig. 3). However, more than

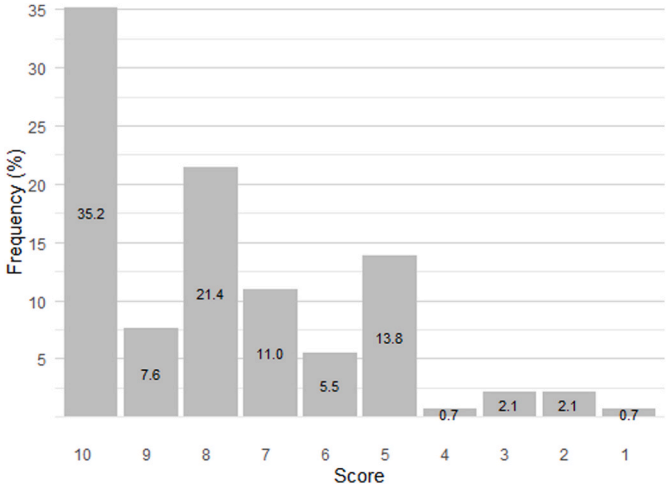

Fig. 3. Distribution of the responses to the question "Do you have a more unfavorable or favorable opinion regarding the use of DNA phenotyping in criminal investigations (1 being very unfavorable and 10 being very favorable)?" (n = 145/163).

[9] The examples in this paragraph are issues identified by the principal researcher from the responses of the interviewees, but not necessarily their exact words.

80 % of them had a favorable opinion (i.e. ≥6 scores) regarding the use of this tool in their work.

4. Discussion

Our study surveyed Québec police officers using an online questionnaire to assess their knowledge and opinion on DNA phenotyping, and consequently, to appraise the usefulness of this tool in a judicial context from their perspective. Our aim was to broaden the picture of the potential that DNA phenotyping can have in criminal investigations. So far, this potential had been evaluated with respect to scientific aspects, such as markers selection, statistical models, or predictive power, but very little from the perspective of main targeted users (i.e. police investigators). Previously, a single study had explored the police's perspective on DNA phenotyping, by interviewing six officers. While the small sample forbids generalizations, this pioneer study nonetheless provided some interesting, and even intriguing results. For example, at least some officers do not consider a formal scientific validation of technologies or tools to be mandatory before their operational implementation (thereby prioritizing the generation of new investigative leads while understanding that some of them may be wrong and will be sort out during the investigation). In the present study, the sample amounts to 48.9 % (163/333) of the surveyable population, i.e. all police officers and crime scene examiners from the SQ who are susceptible to request forensic analyses or to participate to them (e.g. through trace detection *in situ*). Our online questionnaire captured a diversity of perspectives and experiences [26] and facilitated questioning of the study's large, diverse and dispersed population [27]. It generally shows that police officers would like to use DNA phenotyping in their investigations and believe in its benefits, particularly for crimes against the person, conditional of the tool being proven reliable (see section 3.2.1 for a definition of reliability from the respondents' perspective). However, they believe that they lack essential training and knowledge on the subject.

4.1. Knowledge on DNA phenotyping in a forensic context

Respondents' knowledge of DNA phenotyping was assessed to understand the foundation on which they base their perception of the usefulness of this tool in forensic science. A majority did not know about it, which was expected given that the number of cases where DNA phenotyping was used is low in Québec (even though first use of FDP in a criminal investigation was reported in 1999 [41], and interest from the scientific community and judicial actors has been growing ever since). Nevertheless, more than a third (37 %) had some knowledge about it, which is a fair proportion given that DNA phenotyping had only been used four times in Québec at the time of the questionnaire, to our knowledge. This may be partly explained by the fact that most officers learned about phenotyping in mainstream medias (e.g. newspapers, television) or through professional channels (e.g. training, conference), rather than by using it within the context of a casework. When respondents were asked if they knew of any companies offering DNA phenotyping services, Parabon NanoLabs may have been mentioned by participants mainly because some of them have used the company in one or more of their cases and/or heard about it from colleagues who have. Another reason may be that this company is providing training and actively promote its products through exhibitor stands at numerous conferences, webinars and presentations [42–45].

4.2. Opinion on DNA phenotyping in a forensic context

4.2.1. General reliability and reliability of DNA phenotyping

The three types of criteria to consider a tool as reliable from the respondents' perspective (scientific, legal, and practical) are incompletely met by DNA phenotyping. Regarding the scientific aspect, research has focused on improving the reliability and precision of physical trait predictions (e.g. Refs. [13,46–48]). However, several studies have shown that the reliability of this tool is very variable across the human populations in which it has been tested (e.g. Refs. [49–57]). As for the legal aspect, some respondents mentioned the issue of the admissibility of evidence in the courtroom. However, DNA phenotyping is an investigate tool, used to generate intelligence, not evidence. Therefore, it is worth asking in which situations its admissibility in court could be challenged. In a lawsuit, admissible DNA evidence would rather be the accused's STR genetic profile matching that obtained from the crime scene trace, even if the same trace was previously used for a phenotyping analysis during the police investigation. However, some might argue that phenotyping results could be relevant to a criminal case, as they describe a part of the process followed by the police to locate and arrest an unknown suspect [58]. It would be interesting to conduct future research on the views of lawyers and judges in Québec and Canada on this subject. As an example, DNA phenotyping, as well as genetic genealogy, were used by police investigators to help identify a suspect in a homicide that took place in Ontario, Canada. The suspect was later convicted for murder. During the trial, the judge advised the jury not to consider DNA phenotyping and genetic genealogy results as evidence for determining guilt or innocence, thereby suggesting these should be treated as investigative tools, hence not as admissible evidence in court [59]. DNA phenotyping indeed does not offer the discriminating power of STRs to help with individual identification but it can contribute to narrow down the population of interest in the search for the source of the trace. Moreover, as mentioned by MacLean and Lamparello [60], at best, phenotyping results can only raise hypotheses about a person's guilt because they only provide information on class characteristics and cannot be used for identification. DNA phenotyping should then always be restricted to the investigative stages and supported by complementary information [16,29,61]. Overall, answers given by police officers in the current study tend to partially agree with that statement, since they consider phenotyping primarily as an aid to their investigations, and a few respondents (19) explicitly mentioned that DNA phenotyping results should be supported by conventional DNA profile analysis. Therefore, it could deprive the justice system of this tool if police investigators awaited some caselaw validation of the admissibility of DNA-predicted phenotypes as evidence in court. However, while police officers seem to view DNA phenotyping primarily as an investigative tool, many have also written about the importance of the admissibility in court. The reasons why this admissibility is important are not known, but it may be due to the fact that they are unfamiliar with the aims and limitations of the scientific tools and technologies used in an investigation, leaving it to the court, the fact-finder of an individual's guilt or innocence, to pronounce on their eligibility. This suggestion is partly supported by the fact that participants in this study did not feel sufficiently trained in DNA tools and technologies. This could also be explained by the finding that Québec police officers seem to use forensic science primarily to produce evidence for the court [62], and not in an intelligence perspective. As for the practical aspect, i.e. the need for concrete results, it is difficult to assess whether it has brought or will bring such results, given that DNA phenotyping has hardly been used in Québec and, of the cases where it has been used, none have been resolved. In other countries, the usefulness of DNA phenotyping results in investigations is not always clear. For example, in the USA, Parabon NanoLabs displays a few cases on its website where DNA phenotyping has had a major impact on the case [63], but the proportion of cases where DNA phenotyping has enabled progress compared to cases where it has been used is not known. Parabon stated in 2020 that since 2018, more than 120 cases had been solved using their genetic genealogy and phenotyping services, but did not disclose the total number of cases in which they had been used, citing ongoing investigations [64].

4.2.2. Training in emerging DNA tools and technologies

Our results showed that a majority of police officers thought there was a lack of training in emerging DNA tools and technologies, even

though they recognize the importance of knowing about DNA evidence to solve crimes [65]. This conclusion is in line with those of other studies that explored the knowledge of police officers about different forensic-related technologies, including established DNA typing tools such as STR profiles [65–68]. This is also consistent with the responses of some of our participants, who indicated that phenotyping was reliable because it is based on DNA, suggesting that they consider this criterion as sufficient to win their confidence in the tool and revealing some misconceptions about DNA technologies. This raises concern over the sufficiency of their training on forensic tools such as DNA phenotyping. We may need to reconsider how such tools should be introduced and explained to police officers to ensure that they use FDP at its full potential despite its current limitations, but also how forensic DNA results would be best communicated to them to avoid misunderstandings or incorrect interpretation within the operational context. Useful discussions on the communication of DNA phenotyping results can be found in Refs. [69–72]. Furthermore, since a knowledge gap has been identified and FDP has only been used four times in Québec to our knowledge, it would be important to now involve other judicial actors in the reflection on how FDP should (or should not) be developed to become an effective tool for police officers. This discussion has already been initiated in some researches [73,74].

4.2.3. *Perceived usefulness of DNA phenotyping compared to its actual one*

Although surveyed police officers mostly had no knowledge about DNA phenotyping and believed they were not sufficiently trained in emerging DNA tools and technologies, they were nonetheless interested in using it for a variety of purposes in their investigations. They envision a greater use of DNA phenotyping in crimes against the person than in crimes against property, such as burglaries. It then seems that police officers prioritize seriousness over volume regarding the type of crimes for which DNA phenotyping should be used. Similarly, Hopman [29] found that phenotyping was mostly used in major crimes, as there is often a greater urgency to solve them. However, a non-negligible proportion of our respondents (26 %) investigate mainly major crimes, which could somewhat bias their preference, i.e. lead them to underestimate the usefulness of DNA phenotyping for less severe crimes. Indeed, the tool could also be part of a more forensic-intelligence oriented approach to serial crimes of any types, committed by highly prolific perpetrators. This is well illustrated in Ref. [75], where DNA phenotyping predictions were combined with other information to prioritize a list of persons of interest to target in a serie of burglaries.

Police officers would like to obtain from DNA phenotyping predictions many traits and other characteristics, if not everything (genetically) possible: pigmentary traits (eye, hair and skin colour), height, facial reconstruction, sex, weight, age, ethnicity, and even medical information. Nevertheless, they would prioritize eye colour, age, ethnicity and height. Some of these characteristics may have been chosen because they cannot be modified or are harder to modify (e.g. height, ethnicity [even though the latter is not a phenotype]), or because they are more easily observable and typically found on facial composites or wanted posters obtained from witness testimonies (e.g. eye and skin colour, height). Eye colour was the trait most cited by police officers. While it can be altered by wearing coloured contact lenses, this trait is more complicated to modify than, for example, hair colour. In addition, in Canada, eye colour is recorded in some databases on which the police can rely on in their investigations (e.g. driver's license databases). Other physical characteristics mentioned by our respondents were also harder to alter in their appearance (e.g. age, face and height). However, even though height and face are of interest for police officers, scientists have yet to identify polymorphisms that predict reasonably well these phenotypes for operational purposes (if they ever do). On the other hand, the question arises as to whether it is easy to faithfully report on physical traits simply by observing someone. As shown in Ref. [76], even a seemingly simple trait like eye colour was assigned different values by different observers, despite the use of a three-category system (blue, intermediate and brown) and a two-category system (blue and brown), thus limiting the number of possible answers.

Few police officers would like DNA phenotyping to predict all possible characteristics (physical traits and others), including illnesses and even some lifestyle information (e.g. smoking). It makes sense that the more characteristics are predicted, the more complete is the reconstructed portrait of the unknown who left the DNA trace, and the more the population of interest (suspectable) can be narrowed down [19,77]. However, this also raises ethical questions about how much of a person's physical and other characteristics should be predicted to potentially help in a case [73,78]. Moreover, what would happen if the phenotypic prediction contradicted other information in the case, for example if predicted height did not match close to that estimated by a witness? What information would the police officer favor? Our results suggest that the answer will depend in part on the known or perceived reliability of the tool, which is currently deficient for traits like height [8,9]. Furthermore, when faced with contradictions of this kind, would it not be less interesting for police officers to use DNA phenotyping if the results consistently show that witness testimonies perform better (i.e. are closer to the actual phenotypes)? These questions deserve further investigation, but with that in mind, it could be more interesting to integrate this information with other investigative data, such as where the offence was committed and whether the DNA retrieved from the scene matches DNA found at other crime scenes, rather than relying solely on phenotypic results [75].

Questions about physical traits were intended to help focus research efforts on these characteristics if they can be predicted using genetics, but also to help reconcile police expectations with the reality of genetics if we observed a divergence between the two, which was the case (section 4.2.2). This confirms the need to better train police officers in the tools that use DNA. These questions were also designed to better understand the needs of police officers and, if the characteristics they chose could not be predicted by genetics, to question the usefulness of DNA phenotyping in a forensic context. However, it appears that the physical characteristics mentioned by police officers can be predicted using genetics (even if some may eventually fail to achieve sufficient accuracy), supporting the use of FDP in criminal cases.

Overall, the three scores given by police officers regarding the use of DNA phenotyping in criminal investigations (5, 8 and 10, 10 being very favorable) are consistent with three different types of respondents. Those who scored a 5 preferred not to emit an opinion, mainly due to their self-declared lack of knowledge on the subject; those who scored an 8 were cautious in their approach, understanding the potential of DNA phenotyping while being aware of its limits; and those who scored a 10 were much more optimistic in their perceived usefulness of DNA phenotyping.

4.3. *Limitations of the study*

The qualitative method used to conduct this research has its limitations. Given that this was the first substantial study of the subject, the online questionnaire was chosen to obtain broad coverage of the topic, i.e. in its main themes, by surveying a large proportion of the relevant population. However, even if the sample size was considerable, only one agency was questioned regarding FDP in the province of Québec. Furthermore, this approach also has the disadvantage of not being able to ask for more detail on a particular topic compared to semi-structured interviews, for example [27]. Nevertheless, the results obtained provide a basis for developing future research on the subject, with a larger sample that would include other agencies in Québec and/or Canada, and which might involve narrowing down or deepening the analysis of certain more specific themes or issues that emerged, using more refined methods such as semi-structured interviews. Given that the sample size for this type of method is smaller, the advantages of our method remain unaffected, since it enabled us to survey the population of interest in a broad and representative way. Also, since all participants in this study

are working under Québec's jurisdiction and Canadian laws, their knowledge and opinions are not necessarily generalizable to other police forces elsewhere. There is also always a risk that respondents answered what they thought they should say based on their job title within the police [79]. In addition, the coding of qualitative information from questionnaires is a partly subjective process, so it could vary between analysts and cause some variation in their conclusions [80]. Future research could thus try to reproduce the present study with a similar questionnaire in other police forces, or use semi-structured interviews [79] to better understand opinions about DNA phenotyping. Also, coding could be done by multiple analysts to gain greater confidence in the conclusions drawn [80].

5. Conclusion

DNA phenotyping is a tool that has gained increased interest in the forensic field to help solve cases where DNA found at a crime scene could not match a profile. However, its perceived usefulness has not been evaluated in depth by questioning the first users of it: police officers. The main objective of this study was therefore to evaluate the perceived usefulness of this tool at the operational level by questioning Québec police officers on their knowledge of DNA phenotyping and their opinion on its use. The results obtained showed that the majority of police officers did not know, or only know the basis, about DNA phenotyping. Results also support that police officers would like to use this tool, especially to solve crimes against the person, but not at any cost, as reliability is important to them. However, misconceptions about FDP, and scientific tools and technologies used in an investigation in general, uncovered by this research, highlighted the gap between, on the one hand, police officers' understanding and expectations of FDP and, on the other hand, the real possibilities of forensic DNA phenotyping. It then raises the question of whether specific training by professionals regarding scientific evidence would be necessary and encourages other judicial actors to participate in the operationalization of FDP now that a knowledge gap has been identified. Going further, this research reinforces the importance of understanding the needs of police officers from the experimental phase of a tool, not only to guide researches, but also to ensure that the tool developed corresponds to an operational need and capacity, and that it will be used at its full potential [62].

CRediT authorship contribution statement

Audrée Gareau-Léonard: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Vincent Mousseau:** Writing – review & editing, Methodology. **Frank Crispino:** Writing – review & editing, Supervision, Conceptualization. **Emmanuel Milot:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fsisyn.2025.100586.

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