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Decision support for using mobile Rapid DNA analysis at the crime scene

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ABSTRACT

Mobile Rapid DNA technology is close to being incorporated into crime scene investigations, with the potential to identify a perpetrator within hours. However, the use of these techniques entails the risk of losing the sample and potential evidence, because the device not only consumes the inserted sample, it is also is less sensitive than traditional technologies used in forensic laboratories. Scene of Crime Officers (SoCOs) therefore will face a 'time/success rate trade-off' issue when making a decision to apply this technology.

In this study we designed and experimentally tested a Decision Support System (DSS) for the use of Rapid DNA technologies based on Rational Decision Theory (RDT). In a vignette study, where SoCOs had to decide on the use of a Rapid DNA analysis device, participating SoCOs were assigned to either the control group (making decisions under standard conditions), the Success Rate (SR) group (making decisions with additional information on DNA success rates of traces), or the DSS group (making decisions supported by introduction to RDT, including information on DNA success rates of traces).

This study provides positive evidence that a systematic approach for decision-making on using Rapid DNA analysis assists SoCOs in the decision to use the rapid device. The results demonstrated that participants using a DSS made different and more transparent decisions on the use of Rapid DNA analysis when different case characteristics were explicitly considered. In the DSS group the decision to apply Rapid DNA analysis was influenced by the factors "time pressure" and "trace characteristics" like DNA success rates. In the SR group, the decisions depended solely on the trace characteristics and in the control group the decisions did not show any systematic differences on crime type or trace characteristic.

Guiding complex decisions on the use of Rapid DNA analyses with a DSS could be an important step towards the use of these devices at the crime scene.

"*The goal of decision theory is to help choose among actions whose consequences cannot be completely anticipated, typically because they depend on some future or unknown state of the world. Expected utility theory handles this choice by assigning a quantitative utility to each consequence, a probability to each state of the world, and then selecting an action that maximizes the expected value of the resulting utility. This simple and powerful idea has proven to be a widely applicable description of rational behaviour*."

(Parmigiani and Inoue [1], 2009, p. 56)

1. Introduction

Mobile and Rapid DNA analysis techniques are currently finding their way to the forensic crime scene [2,3]. Many companies and research groups have been working on creating fully integrated Rapid DNA technologies to analyse 1 to 6 high-template DNA samples parallel in a timely manner [4–9]. These promising systems are ready to be used in practice on crime scene samples, but these systems are less sensitive than laboratory analysis and thus have the potential risk of loosing evidence. However, these technologies are vastly advancing; the latest literature shows that samples with low quantities of DNA are able to be processed when directly pipetted in the cartridge indicating the future prospects of analysing a wide range of DNA trace samples, including touch DNA samples [10,11].

The first positive tests with a Rapid DNA technology in actual criminal investigations have been performed [12,13]. These, and other police agencies around the world, including the Dutch police force, are currently looking into ways to integrate this technology in practice.

Analysing DNA evidence with such a mobile technology may result

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in valuable intelligence information for the Criminal Justice System (CJS), with the power to identify a suspect within 2 h. However, the use of these techniques entails the risk of losing the sample and potential evidence, because the Rapid DNA analysis technology not only consumes the inserted sample, but is also less sensitive than traditional technologies used at the forensic laboratory [14]. To start using the technology in its current state it is essential to understand the decision dilemma of speed versus sensitivity and built a model that can be used to assist decisions concerning this dilemma throughout the progress of the technology.

The decision to use Rapid DNA analysis at the crime scene will be made with uncertainty as the results of the analysis are unknown. Rapid DNA analysis and laboratory analysis differ from each other on the variables ‘time’ and ‘sensitivity’. The decision maker can choose between receiving fast DNA analysis results with a less sensitive Rapid DNA device, which involves the risk of losing evidence that might have been preserved in the laboratory, or receiving feedback much later through more sensitive laboratory analysis, which involves the risk of losing time to identify and apprehend the offender. Thus, there is a trade-off between ‘*time*’ and ‘*success rate*’, and decision makers have to choose between fast but less certain results and slow but more certain results. Note that this depends on the advancement of the technology and is expected to change over time, but rapid analyses will not reach laboratory sensitivity in the near future.

Scene of Crime Officers (SoCOs) are accustomed to making decisions on analysing traces with uncertainty; because SoCOs infer both the relevance of the trace, and the possible utility of the trace analysis from the information they receive at the crime scene. What really happened during the commission of the crime is unknown, and ideally will be discovered during the investigation. Most of the SoCOs' decisions are likely based on best practices and intuition [15–18]. Because intuition involves unconscious processes, it remains unclear which factors underlie these intuitive decisions. Intuition can therefore lead to biased decision-making [17,19]. A previous study on the use of Rapid DNA devices showed that SoCOs perform more analysis when a Rapid DNA device is available, including analysis of traces with a low success rate [10]. This reliance on technology may initially be due to a form of availability bias - because the device is available it is used. The technological reliance may additionally be due to a technological ‘escalation of commitment’; once the technology provides a positive result, a rational decision maker may be more likely to gain confidence in this technology, and tends to commit to using the technology [20], even though this might not always be the best decision. Another important factor could be the influence of emotion on the decision-making process, potentially causing a form of mood bias. For instance, when a case has a high social impact, a personal desire to rapidly identify a perpetrator could negatively affect a rational decision. It therefore seems useful to guide decisions on DNA analyses of traces with explicit consideration of relevant factors. A proposed ‘hierarchical decision model’ can potentially guide SoCOs in their decision-making in selecting traces for DNA analysis, by considering the type of crime, the probative value of the evidence, and the DNA success rate of the trace [10,14]. However, this model is considered incomplete for Rapid DNA analysis, as it does not take into account the time/success rate trade-off. It is important to understand whether the factors ‘time’ and ‘sensitivity’ influence decision-making on using Rapid DNA analysis and how we could further assist the SoCO in this decision-making process.

Deciding on the use of Rapid DNA analysis in a particular case is a binary decision problem: either to use or not to use Rapid DNA analysis resulting in either a DNA profile or no DNA profile. Therefore, four possible outcomes need to be considered before deciding to use Rapid DNA analysis. Each of these outcomes has specific consequences. Especially critical in this complex choice are the consequences of a ‘wrong’ decision, leading to the negative situation of not obtaining a DNA profile (e.g. no perpetrator identification). This can either be a *true negative slow result* through laboratory analysis that comes after weeks or months, or a *true or false negative rapid result* through using Rapid DNA, in this case it is unknown whether the negative result would have led to a profile in the laboratory or not.

In order to reduce the complexity of decision-making and to minimise potential human errors in processing information associated with best-practices and intuition, such as concentrating on the most salient outcome or on ones' own past experiences, without considering all the different alternatives and probabilities - a coherent and rational way of making decisions about using Rapid DNA analysis that can endure courtroom scrutiny is a necessity. For this purpose, we design and test a Decision Support System (DSS) to support decisions on the use of a Rapid DNA device to analyse traces based on Rational Decision Theory. Rational Decision Theory (RDT) could serve as a method to systematically evaluate all opportunities and risks before making a decision [1]. For that reason, our study focuses first on designing this DSS and second on testing the effect of the DSS in an experimental setting, through the use of a vignette study. This way we can test whether the quality of the decision-making on the use of a mobile Rapid DNA device can be enhanced by the developed DSS.

The central research question in this paper is: *Does a Decision Support System that guides SoCOs to explicitly think about the impact of their decisions positively influence decisions on the use of mobile Rapid DNA technologies?*

In the experimental set-up, participating SoCOs were assigned to the *control group* (making decisions under standard conditions), the *Success Rate group (SR)* (making decisions with additional information on (Rapid-) DNA success rates of traces), or the *Decision Support System group* (DSS) (making decisions supported by a Decision Support System, including information on (Rapid-) DNA success rates of traces).

The use of RDT to guide decisions has been studied in different forensic and legal contexts for years [1,21–24]. For forensic identification purposes, this theory is often used and tested in a model as a way for scientists to structure arguments to reduce uncertainties and avoid fallacious interpretations [21,25–27]. A model might also support decision-making processes at the crime scene by giving coherent means of combining elements to reach a decision when the consequences of a choice are uncertain [27,28]. Within legal matters, RDT is also slowly finding its way into practice where quantifying decisions to convict or acquit a defendant beyond reasonable doubt could support judicial decision makers [17,22,29,30]. These studies show that the decision problem that goes with conducting Rapid DNA analyses in criminal investigations could benefit from this approach. The basic idea behind rational decision-making with RDT is that a complex decision problem can be solved more effectively by deconstructing it into separate segments. Instead of dealing with the problem as a whole, the decision-maker analyses the components and creates models of the problem's components. These segments are then merged to generate an overall model of the decision situation [31].

Through the use of this RDT concept, a simplified DSS was designed to support SoCOs in their decision to perform or not to perform Rapid DNA analysis at a crime scene. In this complex decision two elements are of importance: 1) the nature of the trace (the associated DNA success rate) and 2) the nature of the case (the associated significance and time sensitivity of the crime). It is expected that this DSS can support the SoCOs in their decision process, as they would be compelled to explicitly evaluate opportunities and risks, taking them into account before deciding to use Rapid DNA analysis. For this purpose, the next paragraph focuses on explaining the specifically designed DSS where first, the RDT is explained in terms of DNA success rates; and second, RDT is used to demonstrate how the factors of the case in terms of associated significance and time sensitivity of the crime will result in a numerical threshold value to rationalise the Rapid DNA analysis decision. The subsequent paragraphs show the experimental set up we designed to test the effect of the DSS, and the results of this test. Finally, both the designed DSS as well as the effect of the DSS are discussed in terms of improving decision-making at the crime scene when Rapid

There are four possible situations that can occur when deciding on the use of Rapid DNA analysis as described in situations γ, β, δ and α. You can:

	Profile is obtained*		No profile is obtained		
	γ) Analyse the DNA-sample with Rapid-DNA and a profile is obtained. You get this most positive result within 2 hours.	β) Analyse the DNA-sample at the laboratory and a profile is obtained. You get this positive result within 45 days	δ) Analyse the DNA-sample at the laboratory and no profile is obtained. You get this negative result in 45 days.	α) Analyse the DNA-sample with Rapid-DNA and no profile is obtained. You get this most negative result within 2 hours. *This could be because there is actually no profile or because Rapid-DNA is less sensitive and therefore did not measure the profile. Whereas a profile might have been obtained in the lab. Therefore possibly losing evidence.*	**Results in threshold
Option 1	100	10	5	50	39%
Option 2	50	10	5	100	72%
Option 3	100	10	5	100	54%
Option 4	50	10	5	500	93%

**Obtaining a profile could lead to identification of a perpetrator*

*** During the experimental study the thresholds were provided after choosing one of the four options*

Explanation

The numbers listed in each option are all related to one another. This means for instance, that obtaining a profile at the laboratory (β) in each option (1-4) has an absolute number of 10. However the actual strength of the number is relative, as it needs to be compared to the other numbers in the row of the option. For instance in option 1 it means that getting situation β is 10 times less important than getting situation γ.

Fig. 1. Decision support system to select a threshold for the use of Rapid DNA analysis.

DNA analysis becomes available.

2. A DSS for Rapid DNA

Rational Decision Theory suggests that at least two elements are needed to make a decision. For the Rapid DNA analysis dilemma this would be: 1) the success rate for Rapid DNA analysis and 2) a threshold level for this success rate for when to decide for Rapid DNA analysis. Therefore, when the Rapid DNA success rate of a certain trace is higher than the set threshold level for Rapid DNA analysis, the rational decision would be to rapidly analyse the sample; when the Rapid DNA success rate is lower, the rational decision would be *not* to analyse the sample with Rapid DNA. This concept is explained in more detail in the following subsections.

2.1. Element 1) probability of a Rapid DNA profile

The first element in the Rapid DNA analysis decision process relates to the type of trace, and the Rapid DNA success rate of the trace. Rapid DNA analysis is less sensitive than laboratory analysis; therefore the decision to use a Rapid DNA device depends on the laboratory success rate and the sensitivity of the Rapid DNA device [14,32]. From previous studies we know for example that a sample from a ski mask (also typed as a balaclava) has a laboratory success rate of 90% and an expected Rapid DNA success rate of 85% [14]. This means that 10% of the time a DNA profile will not be obtained using Rapid DNA analysis which is the 'correct' negative result (meaning that laboratory analysis would not have produced a DNA profile) and 5% of the time a false negative result is obtained (meaning that a DNA profile would have been generated in the laboratory, but not with Rapid DNA analysis) due to the lower sensitivity of the Rapid DNA analysis device.

Previous research offered the opportunity to determine these success rates for many traces [14,32]. Therefore, Element 1 in this designed DSS can be considered a given, and can be used for making rational decisions on Rapid DNA analysis for several types of traces.

2.2. Element 2) Rapid DNA analysis threshold level

In order to compare the probability of obtaining a Rapid DNA profile with the threshold for Rapid DNA analysis we need to quantify this threshold. The threshold can differ between individuals and across crime types. Although it is desirable to find universal thresholds for specific case variables, the values given to the thresholds are, by definition, personal and therefore always the choice of the decision-maker [27]. Therefore, we use several general rules in our model. Variables that are relevant in this respect would be: the perpetrator-relatedness of a trace, the laboratory DNA success rate of the trace, the quantity of other relevant traces found at the crime scene, and the type of crime being investigated. All variables that are considered can be incorporated in the model in principle.

We developed a simple model with only three variables: the type of crime investigated, the time pressure, and the type of trace to be analysed. Other variables that might influence this choice, such as the quantity of available traces, the perpetrator-relatedness of the traces, and laboratory DNA success rates of the traces, remain constant in our model.

The most important feature of the mobile Rapid DNA analysis device is the speed at which it can generate profiles; therefore, we included time pressure as a factor in our model, which is related to the factor crime type. Due to time pressure, we generally expect (not considering the crime type) an urgency to generate a Rapid DNA profile, and therefore we expect SoCOs to give more weight to the rapidity than to the sensitivity of the method, resulting in lower thresholds in a serial case than in a singular case. In singular cases, we expect SoCOs to give more weight to the sensitivity of the method used than to the speed. In relation to the crime type, we expect this effect to be related to the seriousness of the case. For example, rapidly obtaining a DNA profile in a serial homicide case is of higher social value than rapidly obtaining a DNA profile in a serial burglary case.

2.2.1. From values to numbers

When the decision to analyse a DNA trace has been made, a rational decision maker acknowledges and considers the variables and their values, and proceeds by assigning numerical 'weights' which are all related to one another, and to the four possible outcomes that can occur [1].

The two positive outcomes that can occur are:

γ) *Using* Rapid DNA analysis and obtaining a DNA profile.

β) *Not using* Rapid DNA analysis (but laboratory analysis instead) and obtaining a DNA profile.

Whereas the two negative outcomes are:

δ) *Not using* Rapid DNA analysis (but laboratory analysis instead) and *not* obtaining a DNA profile.

α) *Using* Rapid DNA analysis and *not* obtaining a DNA profile' (Fig. 1).

Decision makers want to avoid not obtaining a DNA profile and losing precious time. The decision maker has two options: analyse the trace by Rapid DNA or by regular DNA. Unfortunately, there is always a probability that a decision maker ends up in a situation of not obtaining a DNA profile α (a fast true or possibly a false negative) or δ (a slow true negative). When choosing the option: 'Rapid DNA', the decision-maker could end up in situation α. When choosing the option: 'laboratory DNA', the decision maker could end up in situation δ. Assigning weights to each of the four situations (α, β, γ, and δ) would result in a decision threshold for when to opt for Rapid DNA analysis. Based on previous in-house research with Dutch SoCOs conducted to define potential suitable values for the designed cases in the experiment, four appropriate threshold options were chosen (Fig. 1). These cases will be further explained in Section 3, section *The crime scenes*.

As an example, Option 1 in Fig. 1 shows the two situations with positive consequences: '*obtaining a DNA profile rapidly (γ)*' is rated '100', and '*obtaining the profile at the laboratory (β)*' is rated '10'. This means that obtaining DNA profiles rapidly is considered 10 times more desirable than obtaining DNA profiles from the laboratory at a later date (γ is 10 times higher than β). The two situations with the negative consequence resulting in *no* DNA profile are rated as '50' for *rapid analysis (α)* and as '5' for *laboratory analysis (δ)*. This shows that, in this example, more emphasis is placed on obtaining positive results rapidly than on avoiding negative consequences. In this case, the most positive consequence (obtaining a DNA profile rapidly, γ) is rated 2 times higher than avoiding the most negative consequence (potential false negative when not obtaining a profile rapidly, α) (α is 2 times higher than γ).

In another option, such as Option 4 in Fig. 1, the weights of these four outcomes are different. In this option, more emphasis is placed on avoiding the most negative consequence *(α)*, which is rated as '500'. In addition, the most positive consequence (γ) is valued less in this option, this situation is now rated '50'. In this option, avoiding the most negative consequence is considered 10 times more important to avoid than obtaining a DNA profile rapidly in the most positive situation (α is 10 times higher than γ).

By assigning weights to the four possible situations that can occur, the importance of the outcomes can differ and be quantified. The outcome of the Rapid DNA analysis threshold further depends on the laboratory DNA success rate of the traces, because this defines the maximum success rate of the Rapid DNA analysis. Considering these aspects, the numerical threshold value to opt for Rapid DNA analysis can be computed. Based on RDT, taking into account the weight of the four consequences and the probability of a negative laboratory result, it can be mathematically calculated that deciding to use Rapid DNA analysis is preferable when the probability of obtaining a Rapid DNA profile of a certain trace is higher than the calculated threshold (see the Box *Derivation the formula used for setting thresholds*, for the formula used to calculate the thresholds).

In Option 1, this would mean that when the Rapid DNA success rate of a certain trace is higher than the calculated threshold of 39% it is rational to decide to use Rapid DNA analysis. For Option 4, this would mean that the Rapid DNA success rate of this trace needs to be higher than the calculated threshold of 93% to decide for Rapid DNA analysis.

2.2.2. Making the decisions

The final step in the development of this Decision Support System is to combine the calculated threshold value (Element 2) with the probability of obtaining a Rapid DNA profile from a certain trace (Element 1). When this Rapid DNA success rate crosses the threshold, the decision maker should decide to use the Rapid DNA device, if not, the rational decision would be to not use the Rapid DNA device.

For instance, when a ski mask is collected as evidence, the *Rapid DNA* success rate of 85% exceeds the set threshold value of 39% from Option 1 in Fig. 1, and the decision should therefore be made to use Rapid DNA analysis.

Box 1: Derivation of the Formula used for Setting Thresholds

The formula designed for this study based on RDT is derived in the following steps:

1) Decision d_1 = rapid analysis; decision d_2 = no rapid analysis (but laboratory analysis).
2) True states θ_1 = DNA profile, θ_2 = no DNA profile.
3) Denote a probability for a decision I and state j by $P_i(\theta_j)$. Probabilities to true states for d_1: $p_1(\theta_1)$ and $p_1(\theta_2) = 1 - p(\theta_1)$ and for d_2: $p_2(\theta_1)$ and $p_2(\theta_2) = 1 - p_2(\theta_1)$.
   i) Because d_2 = *no rapid analysis* means laboratory analysis, the probabilities of obtaining a laboratory DNA profile (or not) are needed. It is assumed in this study that $p_2(\theta_2) = 0.15$.
4) Assign values $u(d_i, \theta_j)$ to the consequence of decisions in relation to the true states (d_i, θ_j). The social values of the possible outcomes of the analysis decision are shown in Fig. 1.
   i) With the assumption: if Rapid DNA resulted in a DNA profile, laboratory analysis would also have resulted in a DNA profile.
5) Calculate the decision with the maximum expected $u(d_i, \theta_j)$. From a rational point of view, the decision with the highest expected value is

$$\bar{u}(d_i) = \Sigma_j\, u(d_i, \theta_j)\, p_i(\theta_j) \tag{1}$$

   i) With the assumptions: *1*. If a decision-maker opts for laboratory analyses and a DNA profile was obtained, the outcome of the Rapid DNA analysis is unknown (since Rapid DNA has a lower success rate). Therefore, in this situation it is assumed that the value for obtaining a DNA profile in the laboratory is independent of the hypothetical outcome of Rapid DNA; and *2*. If a decision-maker opts for Rapid DNA and no DNA profile is obtained, the outcome of laboratory analyses is unknown (due to a larger success rate for the laboratory analyses, a profile may have been obtained). Therefore, in this situation it is assumed that the value for not obtaining a DNA profile with Rapid DNA is independent of the hypothetical outcome of a laboratory analysis.

6) If positive values are chosen for all of the parameters in the calculations of expected values according to Eq. (1), we must assign a negative sign to α and δ in the formulae to indicate their adverse, negative outcomes: no DNA profile.

The following table summarises the above calculations:

	True state θ_1: profile	True state θ_2: no profile	Expected values (weight)
d_1 rapid	γ	$-\alpha$	$u_{d1} = \gamma\, p_1(\theta_1) - \alpha(1 - p_1(\theta_1))$
d_1 probability	$p_1(\theta_1)$	$p_1(\theta_2) = 1 - p_1(\theta_1)$	
d_2 no rapid	β	$-\delta$	$u_{d2} = \beta\, p_2(\theta_1) - \delta(1 - p_2(\theta_1))$
d_2 probability	$p_2(\theta_1) = 1 - p_2(\theta_2)$	$1 - p_2(\theta_1) = p_2(\theta_2)$	

7) Then, when we apply RDT $\bar{u}(d_1) > \bar{u}(d_2)$ the formula can be deduced to:

$$\gamma\, p_1(\theta_1) - \alpha\,(1 - p_1(\theta_1)) > \beta\,(1 - p_2(\theta_2)) - \delta\, p_2(\theta_2))$$

solving for $p_1(\theta_1)$ gives

8) $(\gamma + \alpha)\, p_1(\theta_1) > \beta + \alpha - (\beta + \delta)\, p_2(\theta_2)$

$$\mathbf{P_1}(\theta_1) > \frac{\beta + \alpha - (\beta + \delta)\mathbf{p_2}(\theta_2)}{(\gamma + \alpha)} \quad (when\ \ \gamma + \alpha\ is\ positive; being\ so\ by\ \ definition)$$

3. Material & method

3.1. Experimental set-up

3.1.1. Testing variables

In order to analyse the influence of a DSS on deciding to analyse DNA traces rapidly at the crime scene or to forward the samples to the laboratory, a vignette experiment was designed.

Participating SoCOs were taken through a crime scene on paper. In the set-up of this experiment, the following three independent variables were examined to determine if they influenced the decision to use Rapid DNA analysis:

1. Crime type: homicide or burglary
2. Trace type: ski mask or fabric glove
3. Time pressure: serial or singular

Other variables such as the quantity of traces, perpetrator-relatedness of the traces, and laboratory DNA success rates of the traces remained constant.

For the purpose of analysing the testing variables when Rapid DNA analysis is an option, comparable homicide and burglary cases were designed that were presumed to be either a serial or a singular case, where a Rapid DNA analysis decision on both a mask and glove trace had to be made.

In this experiment we focused on the effects of a DSS on the decision making for Rapid DNA analysis. This article does not focus on handling this technology at the crime scene, but solely on the decision for rapid or laboratory analysis. If traces are considered suitable for rapid analysis, additional decisions need to be made, for instance on the preferred sampling method. Compatibility between the sampling method and the analysis device might be an issue, which ultimate influences the final decision to either or not deploy a rapid device. These additional decisions were not included in this study. The study focuses on the general, more future proof decision between more speed and more sensitivity.

For this reason, the handling procedures for rapid devices were considered equal to laboratory procedures in this vignette study. Participants were told that the potential collection and analysis of DNA samples would be performed in a specially designed vehicle with a contamination free compartment matching the laboratory environment.

3.1.2. DSS – calculating the threshold value

The threshold value for Rapid DNA analysis, calculated by using the DSS, is influenced by the laboratory DNA success rate. For this reason, to determine the effect of the variable ‘trace type’ in the experiment, two traces were chosen with comparable laboratory DNA success rates but different Rapid DNA success rates. This resulted in using a ‘ski mask’ with a laboratory DNA success rate of 90% and a ‘fabric glove’ with a laboratory DNA success rate of 80% [32]. This difference in laboratory DNA success rates did not influence computing the numerical threshold values through the DSS and was therefore considered a constant. When using these different probabilities for obtaining a negative laboratory result (0.1 for the ski mask or 0.2 for the fabric glove), there appeared to be a negligible influence of the laboratory DNA success rate on quantifying the Rapid DNA analysis threshold; therefore, this probability was set to: p(neg_lab) = 0.15.

3.1.3. The crime scenes

The burglary and homicide cases presented in this experiment were created based on actual crime scenes. To compare the cases, they were designed in such a way that they can be considered similar. In both cases, the crime scene investigation showed that the lock on the door was forced and the apartment was turned upside down. Jewellery had appeared to have been stolen; and when searching for evidence, it was found that the perpetrator most likely wore gloves, as many smudged prints were noticed on items. This lead to the collection of the following traces:

1. **Print**, from dresser, potentially from a glove
2. **Tool marks**, at the door from breaking open the lock
3. **Ski mask**, sampled from the inside, around the mouth area

The homicide case was presented as a burglary gone awry when the owner came home during the burglary, and was killed by the burglar, leading to the collection of the following additional traces:

4. **Blood**, (most likely the victim's), sampled from the pool of blood where the victim
was found. There were no additional blood spatters that indicated that the perpetrator
might be injured.
5. **Wallet**, with smudge of blood (most likely the victim's)
6. **Clothes from the victim**, the Medical Examiner's office secured the

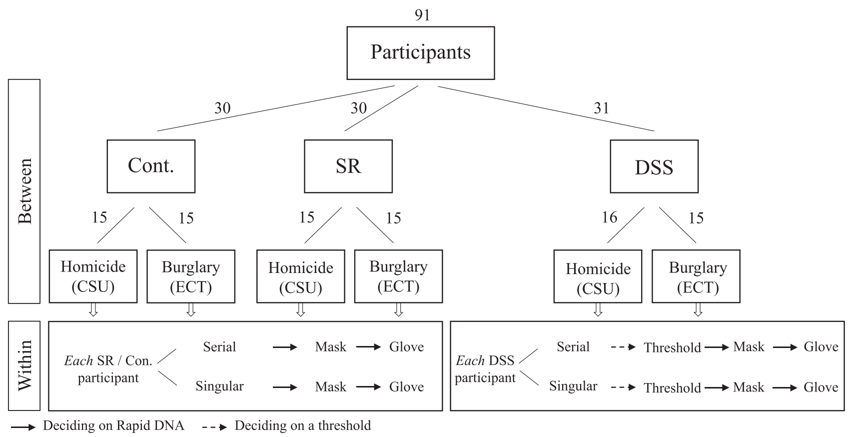

Fig. 2. Experimental design.

victim's clothes.
Most of them contain bloodstains (most likely the victim's).

Additionally, all the participants received the information that it was reasonable to assume that the perpetrator fled the scene, left the ski mask, and that this trace was the only perpetrator related DNA trace. It was also made clear that there was no reason to believe that the case was either a pattern burglary, or a serial homicide. Subsequently, the participants had to decide to use the Rapid DNA device or to forward the DNA sample to the laboratory, and had to explain their decision in detail.

Whether the participants chose rapid analysis or forwarded the sample to the laboratory, everyone received the information that unfortunately the sample did not result in a DNA profile and therefore could not be compared to the DNA database. They were informed that this result was a *correct* negative result, meaning that with standard DNA analysis procedures at the laboratory, the same result would have been obtained as with a rapid device.

Additional new investigative information was provided that a partner SoCO discovered a fabric glove near the apartment building. Because it was 21st July, mid-summer, finding a glove outside could be considered odd. The partner therefore collected and secured the glove and handed it over. The participants were further informed that the glove had a similar pattern to the print marks found on several items at the crime scene. It therefore fit the hypothesis that the perpetrator wore this particular glove while committing the crime. Again the participants were asked if they would analyse the sample, this time from the inside of the glove, with the mobile Rapid DNA device and to explain their decision in detail.

Similar burglary and homicide scenarios were written with the addition of time pressure. The burglary case was designed as a pattern burglary and the homicide case was designed as a serial killing.

3.1.4. Experimental conditions

To examine whether a DSS would influence the decision to use Rapid DNA, and how this decision is affected by the testing variables three experimental conditions were conducted:

1. Control group: participants worked under standard protocol without any additional information
2. Success rate (SR) group: participants were provided with additional information on DNA success rates
3. Decision support system (DSS) group: participants were guided through the decision-making process of analysing a DNA trace, including using information on DNA success rates.

For the DSS, information on DNA success rates is required. To account for the potential influence of the DNA success rate information on the decisions in the DSS group, the SR group was added. This made it possible to analyse any effects of the provided DNA success rate information on the Rapid DNA analysis decision, and any additional effects of the DSS on this decision.

3.1.5. DNA success rates

Because the testing variable ‘trace type’ is incorporated in the study, laboratory DNA success rate knowledge is an important factor. Therefore, a DNA success rate questionnaire was designed to test the prior knowledge of the participants on this aspect. For this reason, the participants in the SR and DSS group had to fill out this questionnaire at the beginning of the case study. In this way, questionnaire findings were not influenced by the DNA success rate information of the ski mask and fabric glove trace they obtained during the experiment. Participants in the control group are considered the baseline. They received this questionnaire on DNA success rates at the end of the experiment, to prevent influences of this questionnaire on their decision-making process.

3.1.6. Participants

A total of 91 experienced SoCOs from the New York City Police Department participated in the study, of which there were 46 Detectives from the Crime Scene Unit (CSU), and 45 Officers from the Evidence Collection Team (ECT). CSU Detectives typically investigate crime scenes where a victim is likely to die, whereas ECT Officers typically investigate high volume crimes. For this reason, the ECT participants performed the burglary experiment and the CSU participants performed the homicide experiment.

In total the participants consisted of 63 males and 28 females. The participants had an average age of 40 years old, 6 years of experience as a SoCO and 15 years of experience at the NYPD. There were no differences on these background variables between the ECT and CSU participants. However, the degree of education appeared to be significantly different, the ECT participants were significantly higher educated than the CSU participants. For this study all participants were equally divided and randomly assigned into the three experimental groups (DSS, SR and Control). In this case, there were no differences in background variables between the three experimental conditions.

3.1.7. Experimental design

The experimental design is shown in Fig. 2. All participants were equally divided over the three experimental conditions (Control, SR and DSS). The participants in each condition either processed a homicide or a burglary case. In addition, *within* each case there were variations; each participant completed a case with time pressure (a serial burglary or homicide), and a similar case without time pressure (a singular burglary

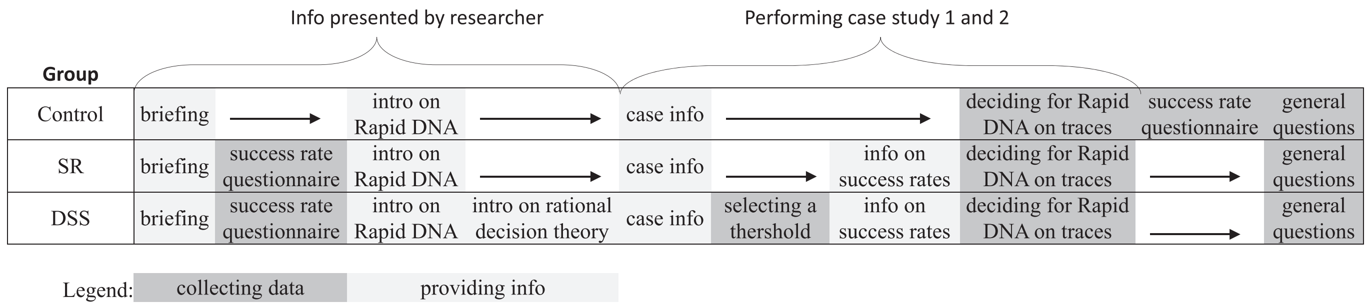

Fig. 3. Experimental procedure.

or homicide). In both of these cases, each participant had to decide on using Rapid DNA analysis for the ski mask trace and the glove trace. In this way all participants had to decide four times either for or against the use of a Rapid-DNA device (2 trace types, and 2 case variations). The participants in the DSS group first had to decide on a threshold before making the Rapid DNA decision on the traces. In this way all DSS participants had to decide two times on a threshold.

To account for the potential sequence effects, half of the participants started with a serial case and the other half with a singular case.

3.2. Experimental procedure

The experimental groups followed a strict experimental procedure as outlined in Fig. 3. All participants received general information about the experiment, information on the Rapid DNA device and information on the case. The control group is considered the baseline and had to decide for or against Rapid DNA analysis within the cases, solely through the general information provided. Participants in the SR group received information on DNA success rates in addition to the general information, prior to making decisions on Rapid DNA analysis. The DSS participants were guided through the Rapid DNA decision-making process, on top of receiving additional DNA success rate information prior to opting for Rapid DNA analysis.

All participants had to fill out a DNA success rate questionnaire; participants in the SR and DSS group filled out this questionnaire at the start of the experiment and participants in the control group at the end of the experiment.

3.2.1. Briefing

The participants were informed that they were part of a study regarding the use of mobile Rapid DNA devices at the crime scene. It was emphasised that this was not a test and there were no right or wrong answers, that they are the experts we wanted to learn from and that the results of the study would be handled anonymously.

3.2.2. Introduction on Rapid DNA analysis

The participants were told that the Rapid DNA device contains all the DNA analysis steps integrated into one system and that to use this device the DNA evidence needs to be sampled at the scene (additional training in the future) before the DNA sample can be inserted in the Rapid DNA instrument. It was further explained that when a DNA profile is obtained, an automatic search of the Combined DNA Index System (CODIS) is performed. The use of the Rapid DNA device could therefore result in feedback on the sampled evidence within 2 h. The device can be used for all types of DNA samples, as the evidence would be swabbed and the swab would be inserted into the instrument. Finally, participants were informed that Rapid DNA is less sensitive than laboratory analysis and the sample would be consumed, that results from Rapid DNA analysis could identify a suspect within 2 h, compared to on average 45 days at the laboratory, and that a DNA profile obtained with Rapid DNA would be acceptable in court.

3.2.3. Case information

All participants received the case and were instructed to assume they were the assigned Detectives investigating the case, and therefore, they had to decide on using the Rapid DNA device for certain DNA samples. Participants were informed that the case was fictional but was created based on an actual criminal investigation; therefore, it also included the standard ambiguity and uncertainties associated with an actual case and performing a crime scene investigation. All information that was known about the case was provided.

3.2.4. Deciding on Rapid DNA analysis

The participants had to decide on the use of a Rapid DNA analysis on both the mask and glove trace. The participants were further instructed to describe their motivations behind their decisions in detail.

3.2.5. Questionnaire on DNA success rates

Participants were asked to assess the expected success of obtaining DNA profiles that could be used for comparison on a 7-point Likert scale; with 1 denoting an extremely low success rate, and 7 denoting an extremely high success rate.

3.2.6. Post-experimental general questions

The experiment concluded with additional questions regarding DNA evidence, taking chances, taking risks, making decisions on the use of and operating the Rapid DNA device, cost analysis, benefit of a Rapid DNA device, and for the DSS group, the benefit of a Decision Support System.

3.2.7. Information on DNA success rates in the DSS and SR groups

Before making a decision to use Rapid DNA or laboratory analysis, participants in the DSS and SR groups were provided with additional information on the DNA success rates of a ski mask and fabric glove trace (Fig. 4). The success rate for obtaining a DNA profile when using the Rapid DNA device is 85% for the mask and 60% for the glove and when laboratory analysis is conducted the success rate is 90% for the mask and 80% for the glove.[1]

*False negative means that the Rapid DNA device did not measure the actual profile because the quantity of DNA in the sample is below the threshold value of the device.

3.2.8. Introduction on rational decision theory for DSS group

The DSS group was further informed that the use of Rapid DNA analysis has a ‘time/success rate trade off’, which meant that two dependent variables have to be considered when deciding to use the device. On the one hand is the time factor, as Rapid DNA analysis could accelerate the investigative process. On the other hand is the sensitivity factor (success rate), due to the Rapid DNA device being less sensitive than laboratory analysis, which means a potential risk of losing evidence when using Rapid DNA analysis. In order to use the DSS (which

[1] For this experiment we used simplified DNA success rates that were close to the actual DNA success rates [32] to make it more comprehensible for SoCOs.

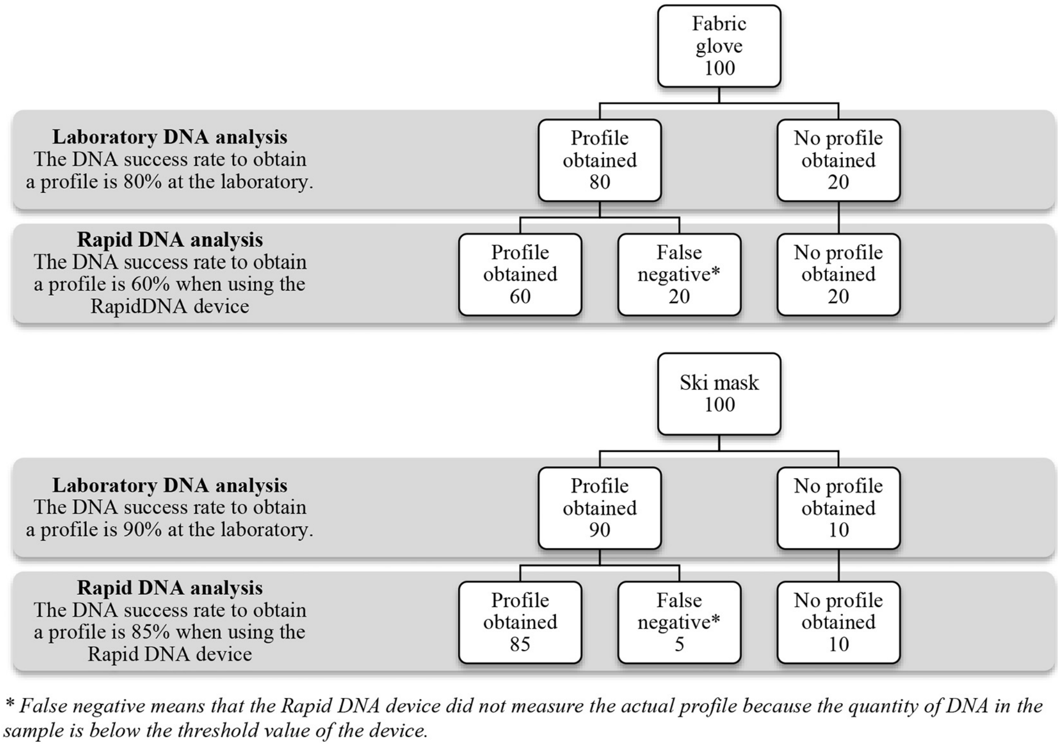

Fig. 4. DNA success rates of ski masks and fabric gloves, at the laboratory and with Rapid DNA analysis.

You are going to the theatre tonight.
Will you take an umbrella with you?

Decision \ Result	Rain	No rain
Umbrella	1	10
No umbrella	20/100	2

Results in threshold 36% / 11%

The numbers are all related to each other

Fig. 5. Simple example explaining the decision support system. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

was developed to guide SoCOs in their decision-making), the basic elements of RDT were explained to the participants. Firstly, they had to choose a personal threshold fitting their case. Secondly, the participants had to decide on whether or not to apply Rapid DNA analysis, through the use of this threshold, along with information on DNA success rates.

The explanation of the RDT and the application of the DSS were explained with reference to a simple example of going to the theatre that night, and having to decide whether or not to bring an umbrella. In this example the result is 'rain' or 'no rain' in the given night, and the decision to bring an 'umbrella' or 'no umbrella' (Fig. 5). These combinations result in four possible situations that can occur that night. There are two 'positive' situations (i.e. 'rain and umbrella' and 'no rain and no umbrella') and two 'negative' situations ('no rain and umbrella' and 'rain and no umbrella'). These situations each have specific consequences, and in order to proceed, these consequences need to be given a weight. A straightforward approach to defining these weights is by assigning numbers that are related to one another. For instance, the situation 'it rains and an umbrella is brought' has a positive consequence that we tentatively give the weight '1' to start. The other positive situation that 'it will not rain at night and no umbrella was brought' potentially has even more positive consequences (i.e, one does not get wet, but one is also not carrying an umbrella, etc.) and it could be decided that this is a two times better situation to occur than 'it rains and an umbrella is brought'. This implies assigning a weight of '2' to the situation 'no rain and no umbrella' (Fig. 5).

Alternatively, a situation that is to be avoided would be 'no rain but an umbrella has been brought'. It has negative consequences because an umbrella that is not needed is carried all night. For instance assigning this situation with a weight of '10' would mean that its consequences are 10 times more extreme compared to the consequences of 'it rains and an umbrella is brought', or 5 times more extreme compared to the situation of 'no rain and no umbrella'. The other negative situation, with intuitively the worst consequences, is 'rain and no umbrella is brought'. For instance, assigning this option with '20' implies that this situation has the most extreme consequences relative to the others.

By combining these assigned numbers for all situations (Fig. 5) along with using RDT, a threshold of 36% was calculated. This would imply that, when the weather forecast gives a chance of rain > 36%, the most rational decision is to decide to bring an umbrella. Therefore, when the weather forecast gives a 30% chance of rain, the rational decision would be to *not* bring an umbrella (30% chance of rain < threshold 36%).

New situations produce new consequences and, in all likelihood, a different decision threshold.[2] For instance, when additional information is provided about wearing a $2000 suit or dress that night, which one prefers not to get wet, this would potentially make the consequences of 'rain and not having brought an umbrella' even more extreme. Changing the weight given to 'rain and no umbrella' to 100 would therefore result in a threshold of 11%. Hence with a weather forecast of 30%, the rational decision would be to *bring* an umbrella (30% chance of rain > threshold 11%).[3]

The example described above was used to explain how assigning numerical weights work to reach a personal threshold value, which

[2] Please note the same situation may have different consequences for different individuals because the consequences are personal and consequently the decision threshold may differ.

[3] If one would wear a suit that absolutely cannot get wet this implies one should always bring an umbrella. One could also choose to wear a different suit or travel in a different way but this would lead to a whole new decision process which we will not address here.

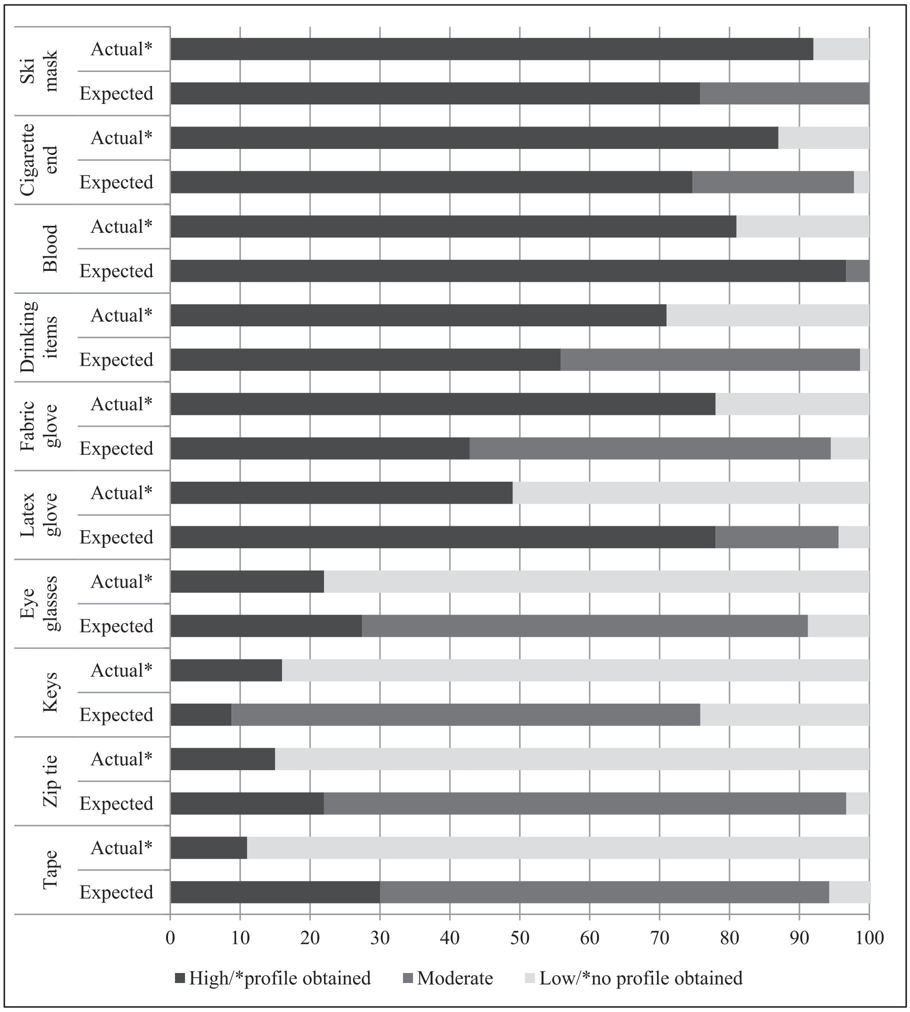

Fig. 6. Expected success rates for obtaining a DNA profile versus the actual success rates [32].
Traces are ranked from highest to lowest *actual* success rates.
The *actual* success rate scale shows the probability of obtaining (any kind of) DNA profile or no profile. The *expected* success rate scale shows the percentage of participants rating the trace on a 7-point Likert scale, we consider 1–2 as low, 3–5 as moderate and 6–7 as high.

allows decisions to be made on the use of Rapid DNA analysis in a criminal case. In the case under consideration, information was provided regarding a homicide or burglary crime scene, in which one DNA sample was collected that could lead to the perpetrator. The Decision Support System, as described in Section 2.2.1, was further explained to the participants. The participants in this study were taken through all four options before using the threshold, in combination with the DNA success rate information, to make the Rapid DNA decision in their case study.

3.2.9. *Selecting a threshold in the DSS group*

In the first case, information on determining a threshold was provided. Subsequently the participants received the calculated threshold that accompanied their chosen option, 39%, 54%, 72% or 93% (Fig. 1). It was made explicit that RDT suggests that for a certain DNA sample, the decision to analyse the DNA sample with the Rapid DNA device should be made when the probability of obtaining a DNA profile with Rapid DNA is larger than 39/54/72/93%.[4] The participants then performed a 'test' on how to use this threshold to decide whether or not to analyse a DNA sample with Rapid DNA analysis, when the DNA sample (in this case) has a 70% success rate of obtaining a DNA profile with Rapid DNA analysis. With thresholds 39% and 54% it would be rational to decide to *use* the Rapid DNA device; whereas, with thresholds 72% and 93% it would be rational to decide *not to use* Rapid DNA, and to forward the sample to the laboratory. Before proceeding to the next step, the participants were asked if they were satisfied with the given threshold. If the participants were unsatisfied, they had to manually change their threshold based on a scale of 1% to 100%; in addition, they had to rate the four situations based on their manually chosen threshold. From that point forward the manually chosen threshold was applied.

In the second case, the time pressure of the case changed and the participants were asked if they were still satisfied with their previously set threshold. When unsatisfied, the procedure to select a threshold was repeated.

In all decision steps, the participants were asked to describe their motivations behind their given answer in detail.

4. Hypothes and assumptions

To test if SoCOs' decision-making can be enhanced with the developed DSS, we tested the effect of the variables 'crime type', 'trace type'

[4] Note that the calculated success rate threshold for Rapid DNA is larger than the actual success rate for laboratory DNA which was set at 85%. It may be assumed that actual success rates for Rapid DNA will always be smaller than actual success rates for laboratory DNA. Therefore, when the calculated threshold is 93% the decision-maker will always opt for laboratory DNA, irrespective of the performance of Rapid DNA.

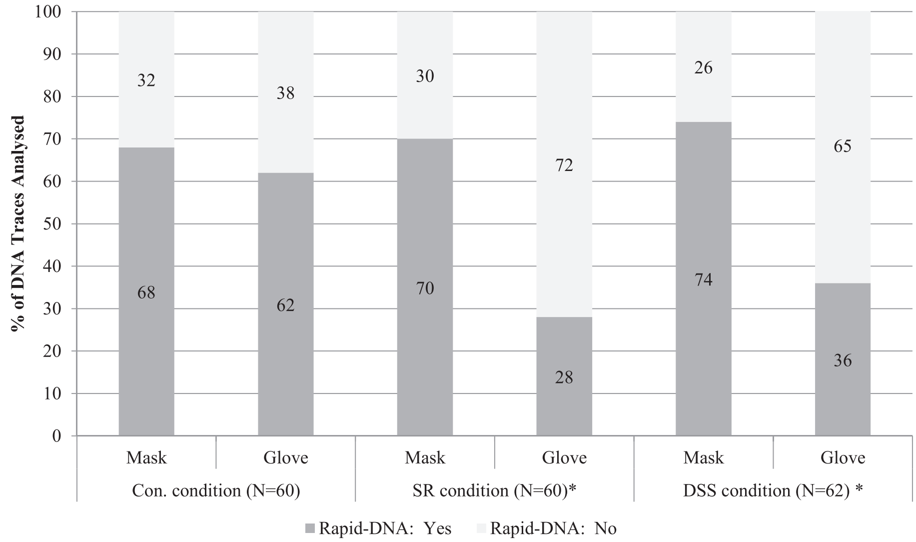

Fig. 7. The influence of 'trace type' (Mask vs. Glove) on the decision to use Rapid DNA analysis within the three conditions: control, success rate, and decision support system.

and 'time pressure' on deciding to use the Rapid DNA device on traces within the three experimental conditions. It was expected that SoCOs, who will be guided to think explicitly about the impact of their decision, will:

1) value the significance of the crime as higher within a serious case, putting more emphasis on avoiding false negatives in these cases. Therefore, opting to use the Rapid DNA device more often in a burglary case compared with a homicide case.
   a. Thus, higher thresholds are expected in a homicide case compared with a burglary case.
2) value the sensitivity of the Rapid DNA device higher for more successful DNA traces, leading to the decision to use the Rapid DNA device on the mask trace more often than the glove trace.
3) value the time sensitivity within the case as more important when the case experiences a time pressure, leading to more Rapid DNA analysis decisions in a serial type case compared to a singular type case.
   a. Thus, lower thresholds are expected in a serial case compared with a singular case.

In addition, we expect the SoCOs in the control and SR group to value the significance of the crime as higher within a serious case (see Hypothesis 1a).

SoCOs in the SR group also receive additional information on DNA success rates. It is therefore expected that the SoCOs in the SR group will also value the sensitivity of the Rapid DNA device higher for more successful DNA traces (see Hypothesis 2).

5. Results

5.1. DNA success rate study

The participants had to assess the expected success rates of obtaining a DNA profile for several trace items on a 7-point Likert scale. We further categorised this scale as: 1–2 = low, 3–5 = moderate, and 6–7 = high chance of obtaining a DNA profile. The expected success rates for obtaining a DNA profile, as rated by the participants, were then compared to the actual success rates; these actual success rates were unknown to the SoCOs during this study [32].

Participants in the three experimental conditions showed no difference in rating DNA success rates of several samples. The results of the most frequently analysed samples are shown in Fig. 6. This figure indicates that actual DNA success rates do not always correspond with the participant's expectations, especially when the actual DNA success rates are low. In these instances, the participants less accurately assessed the success rate of obtaining a DNA profile. A zip tie, for instance, has an actual success rate of 15%, meaning that in 15% of the zip tie samples analysed at the laboratory a DNA profile is generated. However, almost all participants (95%) rated the zip tie trace incorrectly as a relatively successful trace (high and moderate combined) in obtaining a DNA profile. All participants correctly rated the ski mask trace as a successful trace, 75% considered the trace as a highly successful trace and the remaining 25% considered the trace as a moderately successful trace in expecting to obtain a profile. For the fabric glove the majority of the participants (95%) expected the trace to have relatively high success rate (high and moderate combined), this roughly coincides with the actual success rate of almost 80%.

Therefore, we generally considered the participants to have relatively sound baseline knowledge on *laboratory* DNA success rates for the traces used in this experiment, namely the ski mask and the fabric glove.

5.2. Deciding on Rapid DNA analysis

5.2.1. Quantitative results

Each participant had to decide four times on the use of a Rapid DNA device. To account for the fact that we have this repeated measure on the binary dependent variable 'use of Rapid DNA', a Generalised Estimating Equation (GEE) was performed using the software SPSS [33]. Because the goal of this experiment was to study the possible effects of 'crime type', 'trace type' and 'time pressure' on the use of Rapid DNA within the three group conditions (control, SR and DSS) the GEE was performed within each of these conditions.

5.2.1.1. Sequence effect. The GEE-model showed no sequence effects: the decisions to use a Rapid DNA device did not differ depending on the order of the cases within the three groups. This factor was therefore not taken into account for subsequent data analysis.

5.2.1.2. Crime type. Contrary to our expectations, using the same GEE-model, no difference for the variable 'crime type' within each of the group conditions was observed. This suggests that dealing with either a homicide or a burglary does not influence the decision to use Rapid

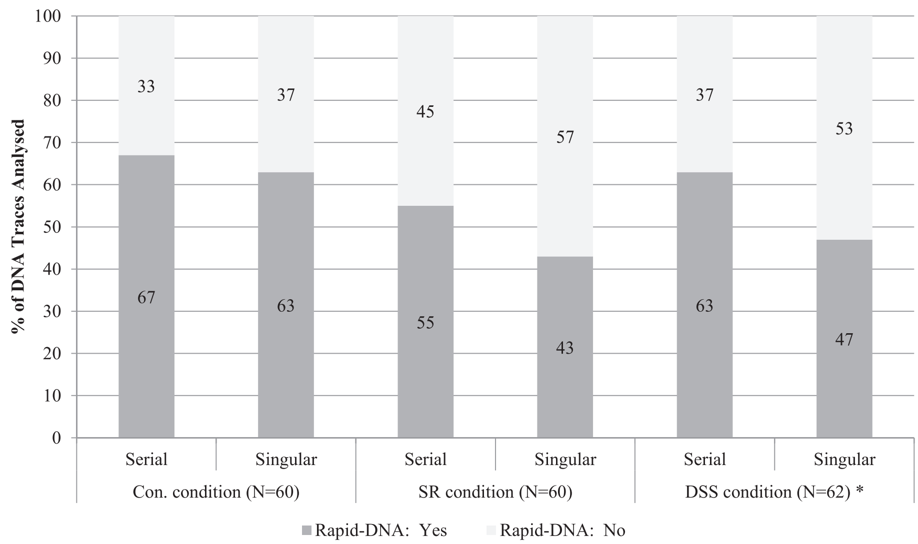

Fig. 8. The influence of 'time pressure' (serial vs. singular) on deciding to use Rapid DNA analysis within the three conditions: control, success rate and decision support system.

DNA analysis on a trace. For this reason, the results of the use of Rapid DNA analysis from the comparable burglary and homicide case were evaluated together in subsequent analysis.[5]

5.2.1.3. Trace type. Fig. 7 shows the differences in deciding to analyse either a mask or a glove trace with Rapid DNA analysis. This figure illustrates that the number of mask samples analysed with Rapid DNA was considerably higher compared with the number of glove samples rapidly analysed in the SR and DSS groups. Within the control group this difference is not observed, where deciding for Rapid DNA analysis on the mask or glove was roughly the same. This figure also indicates that participants in the control group decided to rapidly analyse a glove sample twice as often compared with participants in the SR or DSS group. This suggests that the participants in the SR and DSS groups are more hesitant to use Rapid DNA analysis on a trace with a lower DNA success rate.

Using the GEE-model within each of the conditions showed the same effect. Participants decided to use Rapid DNA analysis significantly more on the mask trace than on the glove trace in both the SR group (B = 1.78, Chi-square = 18.52 (df = 1), $p < 0.000$) and the DSS group (B = 1.66, Chi-square = 13.90 (df = 1), $p < 0.000$). The associated odds ratios showed that within both the DSS group and the SR group, participants were almost 6 times more likely to decide to use Rapid DNA analysis for the mask trace than for the glove trace.

The above results, therefore, indicate that not only guiding SoCOs with a DSS, but also merely providing information on DNA success rates, influences the decision to analyse a specific DNA trace with Rapid DNA analysis.

5.2.1.4. Time pressure. Fig. 8 shows the results of deciding to use Rapid DNA analysis in a case with, and without, time pressure. The figure indicates that within the control condition the decision to analyse a trace rapidly is independent of the time pressure (serial or singular) associated with the case. Within the SR condition there is a tendency to use the Rapid DNA device slightly more often within a serial case than in a singular case, but the variable 'time pressure' did not reach a significant effect within this.

condition. In the DSS condition the participants decided significantly more often to use the Rapid DNA device within a case that is time-sensitive compared to a similar case that is not time-sensitive (performing a GEE-analysis B = 0.66; Chi-square = 5.73 (df = 1), p = 0.017). The odds ratio tells us that, within the DSS group, participants were almost two times more likely to decide for using Rapid DNA analysis in a serial case, where time pressure plays a larger role, compared with a singular case. This indicates that the time pressure associated with a criminal case influences the decision to analyse traces with a Rapid DNA device when SoCOs are guided through rational decision making with the use of a DSS.

5.2.2. Qualitative results

All participants described the motivations behind their decisions to either use Rapid DNA, or to forward the sample to the laboratory for analysis on the traces. In addition, participants in the DSS group had to describe their decisions on the chosen threshold prior to deciding to use Rapid DNA analysis. These specified decisions also determine the decision on using Rapid DNA analysis and were, therefore, combined in the analysis for the DSS group.

All specified decisions were analysed taking the following factors into consideration: 'DNA type', 'wait for laboratory analysis (safer/better/more reliable/controlled environment)', 'loss of evidence (consuming the sample)', 'DNA success rates', 'limited evidence (only one piece)', 'ID the suspect/provide a lead', 'time pressure', 'rapid results at the crime scene', 'weighing options - Rapid DNA vs. laboratory', and 'glove not found at the scene'. In addition, the factor 'mentioning the threshold' was taken into account for understanding decisions on threshold selection.

Taking all participants together (Control, SR and DSS), the main reasons to decide for Rapid DNA analysis were the DNA success rate of the trace (43%), the time sensitivity of the case (38%), the importance of identifying the suspect (30%), the risk of losing evidence (28%), and getting results rapidly at the crime scene (25%). For instance, a participant in the control group stated: "*Ski mask left by suspect has a high probability of skin cell DNA being present on the item and sufficient quantity to make a profile with which to identify the suspect. Suspect is likely to strike again based on the info available. Use of Rapid DNA device may lead to quicker apprehension of suspect and less loss of life.*"

However, clear differences were observed between the three experimental conditions on their reasoning to decide for Rapid DNA analysis as shown in Fig. 9. On average, the control and SR group participants rationalised their decisions with two reasons, whereas the DSS group participants rationalised their decisions with four reasons on average.

[5] A comparable study on DNA success rates was performed with Dutch SoCOs [10].

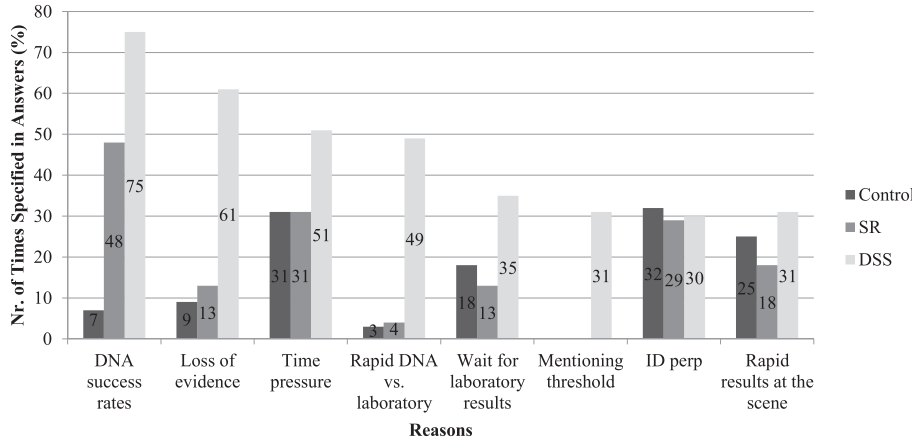

Fig. 9. Qualitative data on deciding to use Rapid DNA analysis on the DNA traces.

The control group showed no strong pattern in justifying their Rapid DNA decisions, mainly mentioning the time pressure of the case (31%), the importance of identifying the perpetrator (32%) and desiring rapid results at the scene (25%). The participants in the SR group showed a similar pattern. In addition, they used DNA success rates overall as a reason in 48% of the cases. This factor was considered as a reason to use Rapid DNA analysis (39%): "*The Rapid DNA analysis has an 85% success rate and it will cut down the time in which a result would come back significantly. I would rather that than wait for results from the lab*". But, DNA success rates were considered more often when deciding *not* to use rapid analysis (56%): "*In this case I would send the sample to the lab even with the long turnaround time the probability of the mobile DNA analysis getting a profile is only 60% with 20% false negative, the lab has 80% success rate. A 20% reduction in the probability of a match is just too high*".

The control group only mentioned DNA success rates in 7% of the times. However, this factor was never mentioned as a reason *not* to use Rapid DNA analysis and only rarely when using rapid analysis (10%): "*The rationale is that it was probably worn by the suspect, and for a decent amount of time. Definitely long enough to leave substantial DNA on the inside of the mask*".

The participants in the DSS group, on the other hand, showed a much stronger pattern justifying Rapid DNA decisions (Fig. 9). They relied on DNA success rates as a reason to a higher extent (75%), either to use Rapid DNA analysis: "*The DNA success rate obtained when a ski mask was processed with Rapid DNA analysis was only slightly lower than if the item was sent to the lab*" or not to use Rapid DNA analysis "*If there is a greater likelihood of success with traditional analysis when compared to Rapid DNA analysis in this case I would choose to send the glove for traditional DNA lab analysis*."

In addition, the DSS participants often discussed the risk of losing evidence (61%), especially when deciding not to use Rapid DNA analysis: "*Submitting the sample to the lab. The success rate is 5% higher and the lab does not necessarily consume the sample submitted. In this case with only one DNA sample sending it to the lab is a safer option.*"

Although the majority of the participants in the DSS group relied on DNA success rates to decide on rapid analysis, the use of the threshold was explicitly mentioned in 31% of the cases: "*Because my threshold was 39% and the success rate was 85% the rapid method of DNA testing should be used to obtain a profile for this single burglary*" or: "*I would send the glove to the police lab, as it probably belongs to the perpetrator and there is only a 60% success rate with the Rapid DNA device (my threshold is at 70%)*.

Overall, an important reason stated was the time sensitivity of the case (38%). However, the time sensitivity of the case was noted considerably more often by the DSS participants (51%) compared with the participants in the control group (31%) or the SR group (31%). When dealing with a *serial* case the DSS participants mentioned this factor (time sensitivity) to a larger degree as a reason to decide for Rapid DNA analysis (64%): "*Perpetrator is believed to be a serial killer. A rapid analysis of DNA should be conducted to avoid additional victims being killed*", whereas in a singular case the time pressure factor was less often discussed and mostly used to reason that there was no 'rush' in analysing a trace rapidly because there was no indication of a pattern and thus no time pressure (42%): "*Because this appears to be a lone case burglary I would elect to send the item to the lab, time is not of the essence in this case*".

Also, the participants in the DSS group often explicitly compared the Rapid DNA option with the laboratory option (49%) before making a decision: "*The success rate of Rapid DNA vs. laboratory is very close. I would think that the swift closure and capture of the serial killer would outweigh the extra 5% of success considered it comes at a cost of waiting 45 days*." This was rarely performed by participants in the control or SR group.

A final interesting observation was the mentioning of the glove found outside, not at the crime scene: "*Any identification from a piece of evidence found outside the initial crime scene would have a difficult time holding up in court.*" This factor was only mentioned when deciding *not* to use Rapid analysis and was mostly mentioned by the control group (19%), somewhat less by the SR group (11%) and rarely by the DSS group (2%).

5.3. Selecting a threshold

An important part of this study was designing and testing the use of the DSS based on Rational Decision Theory. For this reason, we discuss in more detail the effect of working with a DSS in a criminal investigation.

5.3.1. Quantitative results

The participants in the DSS group (N = 31) were guided to explicitly acknowledge all possible decisions and the consequences of analysing a sample with Rapid DNA, or forwarding the DNA sample to the laboratory. For this reason, they had to set their personal threshold prior to deciding to use Rapid DNA analysis, within both a serial and a singular case (performing either a burglary or homicide type case), resulting in a total of 62[6] selections across 4 possible thresholds: 39%, 54%, 72% or 93%.

To account for the fact that, again, we have a repeated measure, but now on the categorical dependent variable 'threshold', a GEE was

[6] An administrative error on the first threshold of one ECT participant occurred. The chosen option for a threshold was option C but threshold 72% was given back, therefore for the quantitative analysis this threshold was not taken into account. However, the participant was satisfied with this threshold and did not change it, therefore the subsequent results were taken into account for this participant.

performed using the software SPSS [33]. The goal of this analysis was to determine the effects of 'crime type' and 'time pressure' for the thresholds.

5.3.1.1. Sequence effect. The GEE model showed no sequence effect in choosing a threshold. This means that deciding on a threshold is independent of evaluating a serial or a singular case first.

5.3.1.2. 'Crime type' and 'time pressure' effects. Overall, threshold 39% was chosen 17 times, threshold 54% 10 times, threshold 72% 22 times and threshold 93% 12 times. There was no effect of 'crime type' or 'time pressure' on the selected thresholds for the use of Rapid DNA analysis. These results demonstrate that there are a wide variety of ideas about which threshold best fits cases.

5.3.1.3. Threshold switching from case to case. Overall 80% (24/30[6]) of the participants in the DSS group did not change their threshold in the second case they had to evaluate; they continued using their first chosen threshold even though the time pressure in the second case changed. The six participants that did change their threshold either switched from a higher threshold in a serial case to a lower threshold in a singular case (2/6) or from a lower threshold in a serial case to a higher threshold in a singular case (4/6).

5.4. Qualitative results

Utilising the first chosen threshold, the participants started with a test on using the threshold for making Rapid DNA analysis decisions. 29 out of the 31 DSS participants responded accordingly, and showed they understood how to use the theory for deciding on rapid analysis.

Only in the first case (either serial or singular) the participants had to deal with they had to explain in detail why they chose one of the four options leading to the threshold. Due to this set-up we analysed the qualitative data on selecting one of the four options 15 times in a singular case and 16 times in a serial case. This qualitative data was analysed in the same way as the qualitative data analysed for deciding to use the Rapid DNA device Section 5.2.2.

Overall the participants mainly considered the following factors when choosing a threshold option to use for the Rapid DNA analysis decision: 'loss of evidence' (19/31), 'wait for laboratory analysis' (15/31), 'weighing Rapid DNA vs. laboratory' (13/31), 'time pressure' (12/31) and 'rapid results at the scene' (10/31).

However, even though the quantitative analysis showed no significant difference, there were clear contrasts in reasoning within a serial case compared with a singular case, as shown in Fig. 10. For a singular case, the majority of the participants (11 out of 15) decided to wait for results and have the laboratory analyse the DNA sample. In addition, they also often mentioned sensitivity and/or the risk of losing evidence (12/15), for instance one participant wrote: "*Results obtained (possibly) after 45 days from the lab is vastly superior than obtaining results (positive or negative) quickly and consuming what DNA evidence you have collected.*"

Within a serial case more than half of the participants (9/16) reasoned they preferred DNA results as fast as possible and/or considered the time pressure of the case (10/16), explained by one participant as: "*Being that this is a serial killer and we believe that he will keep killing until he is caught, it is important to ID him/her as soon as possible.*" However, four participants evaluating a serial case considered waiting for laboratory results to be the best option: "*No evidence from other crime scenes in this pattern. I would rather take the time to analyse through the lab than rush with Rapid DNA.*" Whereas, just one participant mentioned wanting to obtain rapid results and use Rapid DNA in a singular case.

Although the factor 'losing evidence' was considered by the majority when dealing with a singular case, only 7 out of 16 participants in a serial case mentioned it. This led to emphasising laboratory analysis 3 times: "*You might lose evidence. So in some way it is better to get results after 45 days*" and in 3 instances the time pressure still prevailed: "*It is more important to make an early identification than the possibility of losing some potential DNA.*"

Less than half of the participants in both the serial case (7/16) and the singular case (6/15) actually discussed and considered the laboratory option versus the rapid option when making a decision on a threshold option. For instance, within a serial case: "*Being that this is a serial killer and we believe that he will keep killing until he is caught, it is important to ID him/her as soon as possible. The problem would be that the only probative evidence in the case would be completely consumed by the Rapid DNA analysis. This is why I chose option 2. It recognises the importance of a fast turn-around but also puts weight to the possible destruction of key evidence.*" and with a singular case: "*There is only one piece of DNA evidence that is related to the perpetrator. It is more important to have that sample analysed in the lab, even though it will take 45 days to have that sample available for additional testing, than it is to have the results within 2 h and possibly losing the sample for additional testing.*"

5.5. Using the thresholds

In the DSS group, even though an effect of deciding to use the Rapid DNA device was observed on the variables 'time pressure' and 'type of trace', half of the participants (16/31) made at least one decision for rapid analysis that did not correspond to their chosen threshold (this applied to 29 decisions in total). This occurred both in the first case (either serial or singular) and in the second case (either serial or singular) they dealt with. Based on RDT these decisions could be considered 'irrational'. Of these 16 participants, 15 correctly answered the

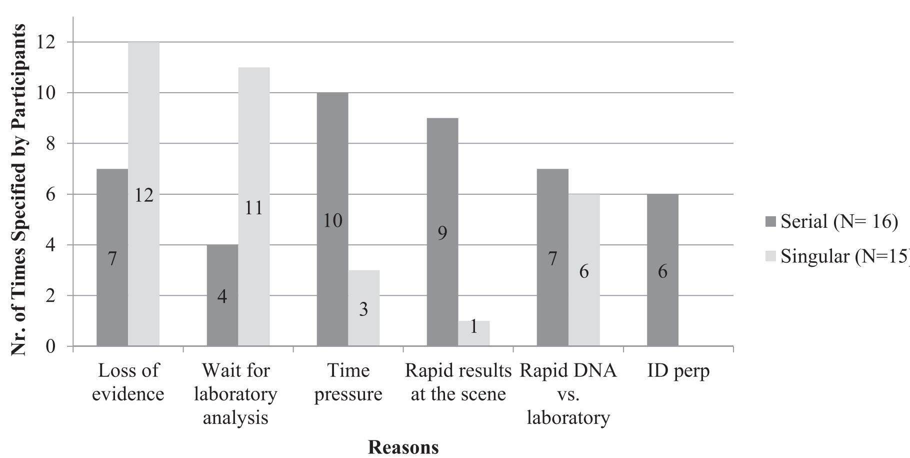

Fig. 10. Qualitative data on deciding for a threshold option.

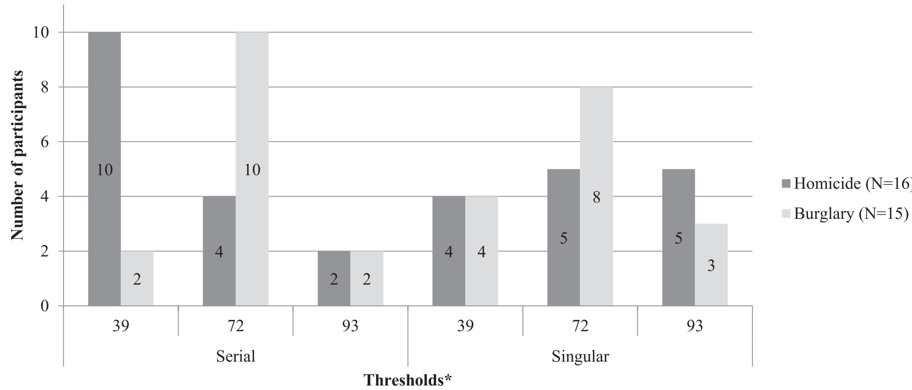

Fig. 11. 'Fitting' thresholds.

test question on using RDT for deciding on DNA analysis. In addition, the previously analysed qualitative data showed that these decisions were well-reasoned and thoroughly through-out decisions. The threshold and/or the DNA success rates were explicitly discussed when opting against the chosen threshold on using the Rapid DNA device. For instance, a participant with threshold 54% on the glove chose not to analyse the sample whereas when considering this threshold the DSS suggests to analyse the sample rapidly: "*In this situation I would avoid the 20% false negative and take my chances with the 80% profile obtained at the lab*".

The participants who decided, against their chosen threshold, to forward the sample for laboratory analysis mentioned it was safer and more reliable to opt against rapid analysis "*Even though the percentage is above 50% I think with the severity and importance of this case I would have the lab test the evidence because the labs success rate is 20% more effective*." In contrast the majority of the participants deciding against their chosen threshold to use Rapid DNA analysis reasoned that rapidly identifying the perpetrator is most important "*Analysing the glove with the rapid DNA would possibly lead to identifying a perpetrator in regards to these homicides. It is more important to identify the perpetrator in this case quickly then to possibly get results from the lab at a later date*."

This raised the question whether we could find more 'appropriate' thresholds for the cases when considering 'fitting' thresholds for the 16 participants that decided against their chosen threshold for using Rapid DNA analysis. We analysed which thresholds they should have chosen, based on their given answers, and combined these with the thresholds of the 15 participants who correctly used the DSS. In this experiment, the two lowest thresholds should lead to the same results of using Rapid DNA analysis. However, the results show that when threshold 54% is chosen, all participants actually desired a higher threshold. Participants desiring a low threshold mostly chose the lowest threshold of 39%. There were three participants that chose threshold 93% or 72% but should have chosen a lower threshold, therefore we assigned threshold 39% to them. Fig. 11 shows that threshold 54% disappears and a somewhat stronger pattern of thresholds is observed, especially when dealing with a *serial* homicide or burglary case. Participants handling a homicide appear to actually desire lower thresholds in a serial case, and higher thresholds in a singular case. For participants handling a burglary, it appears best to actually utilise threshold 72%.

The GEE analysis showed that the interaction of 'crime type' (homicide or burglary) and 'time pressure' (serial or singular), significantly influenced the fitting thresholds ($B = -1.10$, Chi-square $= 7.52$ ($df = 1$), $p = 0.006$). Within a *serial* case the threshold that best fits a homicide is 39%, whereas threshold 72% best fits a burglary. For a singular burglary case threshold 72% again seems to fit best, whereas no clear pattern of threshold selection is observed for the singular homicide case.

5.6. Added value of Rapid DNA and DSS

Rapid DNA analysis added value for CSI.

$>$ 90% of the participants (85 out of 91) saw added value for using a Rapid DNA device in their investigative process. As stated by a few participants: "*It can possibly link DNA to a suspect in hours as opposed to days or months*", "*Quickly identifying a suspect can be critical to apprehension and possibly saving lives*", "*It's a great tool to expedite results. However, I would only use it when there are several pieces of evidence. Better results are more important than speedy results*", "*Could be useful tool when performing routine ECT jobs*".

DSS added value for SoCOs.

The majority of participants in both the burglary (13/15) and the homicide (14/16) groups were very positive about the DSS, and saw added value in using RDT during decision-making when Rapid DNA analysis becomes available at the crime scene. Some statements of the participants on this matter: "*Decisions on where and when to use the Rapid DNA device should be made with 'risks' vs 'rewards' kept in mind.*" "*With this DSS you can make decisions on a case by case situation. You can decide how serious or minor the crime is or how quickly you need to find the perp. Many factors can be combined whether to decide to use the Rapid DNA device or not.*" "*Anytime you think about the possibilities/consequences on a crime scene and use common sense about what could have taken place, your investigation will proceed in a thought out and orderly fashion.*"

6. Discussion

When the identification of perpetrators through rapid systems becomes a standard law enforcement practice, standardisation and error minimisation becomes crucial. When Rapid DNA analysis is operable at the crime scene, the desire to search DNA traces for rapid analysis to confirm hypotheses could potentially lead to overestimating the actual value of the information, or loss of potential informative DNA results. Therefore, it is fundamental that the process to decide to use a Rapid DNA device be accepted within the criminal justice system.

For this reason, it is essential that decisions are, preferably, not solely based on the thoughts, ideas and expertise of just one individual. A practical solution to (potentially) correct for human errors and biases may be a DSS for Rapid DNA analysis. In the current explorative study, a principal DSS was designed for this purpose, to be used by the SoCO at the crime scene. This study provides evidence for the fact that a systematic approach, which consists of weighing all possible outcomes before deciding to use a Rapid DNA analysis device, may assist SoCOs in their decision-making process. The results demonstrated that participants made different, and more thoughtful, choices on analysing traces rapidly when explicitly acknowledging the effect of all possible outcomes, compared to participants who were not encouraged to weigh the different decision outcomes.

The DSS we developed and tested for this study should be seen as a prototype, which could be customised with additional (case) specific information that could be considered in the decision to use a Rapid DNA device. For instance, this initial designed DSS for Rapid DNA analysis focused on standard STR DNA analysis and did not include potential other types of DNA analysis, such as Y chromosome analysis or RNA analysis. For this reason, the experiment was designed in such a way that the case hypotheses (evidence was left by perpetrator who fled the scene) only require standard DNA analysis. However, additional case characteristics, requiring other sorts of analyses could indeed influence the decision to choose for rapid or laboratory analysis. With the current technology, it should always be decided to send the evidence to the laboratory if such analyses are needed. To expand and optimize the designed DSS, such variables could be added.

In this study, the effect of the variables 'crime type', 'trace type' and 'time pressure' were analysed on the decision to use the Rapid DNA device within three experimental conditions, namely the control group, the SR group and the DSS group.

Contrary to our hypothesis, there was no effect of 'crime type' (burglary or homicide) when deciding to use the Rapid DNA device. However, the group of participants deciding on burglary cases differed from the group of participants deciding on the homicide cases. The Crime Scene Unit participants from the NYPD processed homicide type cases, and the participants of the Evidence Collection Team only processed comparable burglary type cases. The results could indicate that CSU participants handle a homicide case in the same way as ECT participants handle a burglary case. On the other hand, it could be debated whether we actually examined crime type or the difference between CSU and ECT participants. To explicitly investigate 'crime type', future analysis should be performed with a more general population that is used to analysing both crime types. However, NYPD SoCOs either strictly deal with serious crimes, or more high volume crime type cases. For this reason, we cannot conclude whether or not a difference exists in handling a burglary or homicide case, when Rapid DNA analysis is an option, based on the current study.

To decide whether traces can be analysed with a rapid device, it is crucial to have knowledge on the likelihood that a trace contains sufficient DNA to generate a DNA profile. In this study the likelihood of obtaining DNA profiles from specific traces in the lab – the so-called '*laboratory* DNA success rate' – was considered basic knowledge. However, this study demonstrated that participants lacked awareness about the laboratory DNA success rates of many traces, especially of the low quantity DNA traces. Similar results were found in a study with Dutch SoCOs [10]. In addition, the results of the current study showed that the control group did not use Rapid DNA analysis differently on the mask trace than on the glove trace. This is probably due to the fact that the participants in the control group were unaware of the different Rapid DNA success rates of those two traces, and therefore did not take into account the sensitivity of the rapid device, and its consequence for traces with a low success rate. In reality, NYPD SoCOs currently working in CSU and ECT do not receive feedback on their analysed traces. Therefore, they are not familiar with the results of the samples they submit for analysis and lack knowledge on DNA success rates. It is highly recommended that SoCOs obtain feedback on the results of the submitted samples and develop insight on DNA success rates, especially when Rapid DNA is introduced.

The qualitative data support this conclusion, and revealed that DNA success rates were mainly considered by participants in the SR and DSS group before deciding to use Rapid DNA analysis. This resulted in deciding to use Rapid DNA analysis significantly more often on the mask trace compared to the glove trace. This was expected and indicates that knowledge on DNA success rates is necessary in making evidence-based decisions for Rapid DNA analysis.

Only participants in the DSS group showed an effect of the variable time pressure, and decided to analyse significantly more DNA traces rapidly within a serial case compared to a singular case. The qualitative data again support this finding, with participants in the DSS group accounting for time pressure considerably more often than participants in the SR or control group, and especially when dealing with a serial case. This suggests that there is an increase in taking risks for gains with the pressure of time, supporting more risk acceptance in time-sensitive cases [34,35].

A final interesting finding is that the qualitative data on the motives underlying the decision to use the Rapid DNA device showed that SoCOs in the control group considered crime relatedness of the trace, even though this was presumed to be a given. Participants in the control group regarded 'finding the glove outside' as less crime related, potentially not holding up in court, and thus not material for Rapid DNA analysis. This was mentioned less in the SR group and rarely in the DSS group and could indicate that making decisions through a DSS should be handled with caution, especially when factors are not explicitly incorporated in the system. In this study only the three testing variables 'crime type', 'trace type' and 'time pressure' were incorporated into the model. This shows the importance of designing a flexible DSS that could be customised with additional factors in the future.

The fact that participants in the DSS group showed a stronger difference in deciding to use the Rapid DNA device, but also made more elaborate and thorough decisions, could be interpreted as an effect of using the DSS. In this condition, participants were explicitly guided to consider all possible outcomes and consequences, and in combination with information on DNA success rates, they had to decide on the use of the Rapid DNA device. These DNA success rates were essential for the use of the DSS as designed for this study. When the threshold to use the Rapid DNA device was below the Rapid DNA success rate of the specific trace, the DSS suggests it is 'rational' to choose immediate DNA analysis at the crime scene. It is important to determine whether universal baseline thresholds can be set for specific cases to assist in the decision-making process for Rapid DNA analysis. In this study, a greater variety was observed between individuals on what they consider an appropriate threshold.

The expectation of this study was that baseline thresholds could be extrapolated for specific cases. The goal of using a DSS is to make case-based decisions rather than individual-based decisions. An explanation for the variety of threshold choices could be the somewhat low sample size of 31 (16 homicide participants and 15 burglary participants). However, the 'new' concept of.

assigning values to possible outcomes might also be considered a difficult task, which is of course a practical problem when trying to identify uniform thresholds. The method used to set values for these outcomes may not have been ideal, and it is a challenge to search for other methods that are more suitable for this purpose. More than half of the participants made Rapid DNA decisions that did not correspond to their chosen threshold. The elicitation of reliable values that can be used to set a threshold might be a difficult matter. One option is to determine a threshold on which several individuals may find inter-subjective agreement [1,21]. Implicitly every decision-maker must utilise a certain threshold to deal with the 'time/success rate trade off' to finalise on the use Rapid DNA analysis [17]. The future challenge is to agree upon the best-fitting uniform thresholds for several cases and create easy-to-use expert systems.

The qualitative data suggests that when evaluating a serial case, time pressure appears to be an important factor when choosing a threshold, and deciding for Rapid DNA analysis; whereas, within a singular case, the loss of evidence is an important reason to choose laboratory analysis more often, indicating that different factors are important to consider when deciding on a threshold in a serial and singular case. This, however, was not observed when looking at the chosen thresholds, possibly due to the fact that participants found it difficult to value the various outcomes, and to set their threshold. This might result in participants rationally deciding against their chosen threshold, because they became more aware of the effect of the chosen threshold when applying it in a concrete case. This could be seen as a form of 'latent rationality'.

When considering 'fitting' thresholds which correspond to the decisions the participants finally made, participants tended to desire the lowest thresholds in a serial case; whereas, as became clear from the qualitative data, they considered the time pressure more often as an important factor. When deciding on a threshold in a *serial* homicide case, more emphasis is placed on obtaining a rapid outcome, thus lower thresholds seem to fit better with these cases. In a singular burglary or homicide case, and a *serial* burglary case, participants tended to be more error-focused, placing more weight on avoiding (false) negative results, which leads to higher thresholds. This indicates that when a crime is more significant and serial, people tend to accept potential errors faster. The qualitative data support these results.

It is also important to realise that generally the process of deciding for Rapid DNA analysis could be guided by internal factors such as experience, confidence, state of mind and personality of the decision maker [36] This is also known as 'image theory', where decisions are made based on whether they fit personal values, goals and strategies of the decision maker [37,38]. In criminal investigations, the internal factor 'emotion' may influence the decision to use Rapid DNA analysis, especially when the case is more serious and the "desire to see justice done" may be stronger [37,39]. Therefore, SoCOs may have different preferences on choosing thresholds and using the Rapid DNA device for different types of crime, and they rationally follow their preferences [40]. Collectively, this could explain the wide variety of thresholds chosen, and is worthy of future experimental study. Deliberate practice, where exercises are focused on improving particular tasks, involving immediate feedback, time for problem-solving and evaluation, with the opportunity for repeated performance, could refine behaviour and therefore rational decisions on choosing a threshold and using the Rapid DNA device may be attained [41]. The path forward necessitates not only identifying fitting thresholds for several cases, but also educating SoCOs in operating crime scene investigations using a Rapid DNA device.

Integrating Rapid DNA technologies at the crime scene will result in adjusting current forensic procedures. In order for SoCOs to make accepted decisions, training will play a vital role in making the SoCOs aware of the cognitive processes involved in the perception of risk and decision-making, and therefore needs to be part of future CSI best practices [36]. For the optimal use of Rapid DNA analysis, SoCOs have to be made aware of the existence of certain biases such as contextual and personal factors that could influence their decision [37]. This study proposed the use of a DSS as a guide to systematically approach the decision problem of performing Rapid DNA analysis within a criminal investigation. The SoCOs appeared to be excited about integrating such a DSS into their CSI routine and see added value for making more reliable decisions when Rapid DNA analysis finds its way to the forensic crime scene.

In conclusion, while certain challenges still exist, this study provides positive evidence that integrating a DSS for the use of Rapid DNA analysis influences the decision-making process of analysing DNA traces at the crime scene. We believe this, therefore, to be an important step towards guiding the integration process of Rapid DNA analysis at the crime scene, to make effective and efficient decisions in the criminal justice system.

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