Forensic Science International: Mind and Law 4 (2023) 100125

Contents lists available at ScienceDirect

Forensic Science International: Mind and Law

journal homepage: www.sciencedirect.com/journal/forensic-science-international-mind-and-law

The possible impact of stress on forensic decision-making: An exploratory study

Mohammed A. Almazrouei [a,b,c], Itiel E. Dror [a,b,d], Ruth M. Morgan [a,b,*]

[a] UCL Department of Security and Crime Science, University College London, 35 Tavistock Square, London, WC1H 9EZ, UK
[b] UCL Centre for the Forensic Sciences, University College London, 35 Tavistock Square, London, WC1H 9EZ, UK
[c] Decision Neuroscience Lab, Wu Tsai Institute, Yale University, 100 College St, New Haven, CT, 06510, USA
[d] Cognitive Consultants International (CCI-HQ), London, UK

ARTICLE INFO

Keywords:
Forensic decision-making
Human factors
Stress
Human performance
Risk-taking
Fingerprinting

ABSTRACT

Stress has been shown to have an impact on the quality of decisions made by professionals in a variety of domains. However, there is lack of research examining the impact of stress on forensic decision-making contexts, where experts can face various levels of stress. This exploratory study examines fingerprint decisions made under stress, by novices ($N = 115$) and fingerprint experts ($N = 34$). Findings suggested a potentially complex relationship between stress and expert performance. On the one hand, in this study stress seemed to *improve* the performance of both novices and experts on fingerprint assessments, but mainly for same-source evidence. In contrast, the induced stress appeared to have an impact on risk-taking. When the same-source prints were difficult, a trend emerged with stressed experts taking less risk and reported more inconclusive conclusions with higher confidence than the control group. Furthermore, stress had a significant impact on the overall confidence levels and response times of novices, but not experts. These findings suggest that stress and decision-making tasks are important factors that should be considered when considering optimal working environments for increasing decision quality.

1. Introduction

Workplace stress has an impact on the quality of decisions made by professionals in a variety of expert domains, from healthcare (Arora et al., 2010) to policing (Akinola & Mendes, 2012). However, research discussion on the potential impact of stress on *decision-making* in forensic science has only recently been considered (e.g., Almazrouei et al., 2021; Jeanguenat & Dror, 2018). Stress has "clear implications for professions that are characterised by high levels of work pressure and intense cognitive demands" (Deligkaris et al., 2014, p. 118), so a consideration of the implications of stress upon forensic examiners is timely (Almazrouei et al., 2020; Helsloot & Groenendaal, 2011).

Several studies have investigated the influence of biasing task-irrelevant information (e.g., Dror & Charlton, 2006; Earwaker et al., 2015; Smalarz et al., 2016) or motivational and emotional factors (e.g., Charlton et al., 2010; Dror et al., 2005; Hall & Player, 2008; Osborne et al., 2014) on decisions in a forensic science context (for a review, see, Kukucka & Dror, 2022). However, there is a lack of research that investigates the impact of stress on forensic decision-making. Since fingerprint evidence is widely used and can carry significant weight in court proceedings (Mustonen et al., 2015), the research reported here considered the possible impact of stress on a fingerprint decision-making task. The trends that have been identified may well apply and reflect the impact of stress across other forensic domains where pattern recognition tasks are important (e.g., handwriting, toolmarks, etc).

Stress may have both negative and positive effects, with many documented contexts where it can have a positive impact on human performance and decision-making (Kowalski-Trakofler et al., 2003; Paton & Flin, 1999; Yerkes & Dodson, 1908). For example, moderate stress may cause individuals to meet deadlines (Benson & Casey, 2013; Jeanguenat & Dror, 2018). However, as stress increases to high levels, performance starts to drop (Benson & Casey, 2013; Sehsah et al., 2021; Yerkes & Dodson, 1908). For instance, LeBlanc et al. (2005) asked 30 paramedics to calculate drug dosage after working in a highly stressful scenario and found that acute stress increased errors. Hence, it is important to ascertain when/if stress can improve or impair forensic decision-making. This is an important question to address as the findings will contribute to an understanding of how decisions can be optimised

* Corresponding author. UCL Centre for the Forensic Sciences, University College London, 35 Tavistock Square, London, WC1H 9EZ, UK.
E-mail address: ruth.morgan@ucl.ac.uk (R.M. Morgan).

https://doi.org/10.1016/j.fsiml.2023.100125
Received 5 June 2023; Received in revised form 31 October 2023; Accepted 17 November 2023
Available online 22 November 2023

and contribute to efficient, accurate and robust crime reconstructions (Morgan, 2017).

The few studies on fingerprint decision-making that included a stress factor were limited in a number of ways. Some assessed the impact of a stressor (predominantly time pressure) on fingerprint decision-making in approaches that may make the findings not be ecologically valid (Kellman et al., 2014; Stevenage & Bennett, 2017; Thompson & Tangen, 2014; Zou et al., 2021). For example in some studies, the time provided to make a decision was unrealistically short (e.g., 2 s to reach a conclusion (Stevenage & Bennett, 2017)). In forensic settings, there is not often such time pressures (Kellman et al., 2014). Additionally, some of these studies used a two-alternative forced choice experimental paradigm (TAFC; see Bogacz et al., 2006) whereby the participants had to either decide an identification or an exclusion, but were not allowed to reach an inconclusive decision (e.g., Stevenage & Bennett, 2017; Thompson & Tangen, 2014; Zou et al., 2021). In casework, inconclusive decisions are allowed (Dror & Langenburg, 2019). Inconclusives are often considered to be less risky decisions compared to conclusive judgments (Dror & Langenburg, 2019), but they can have practical implications (e.g., potentially not identifying suspects) and should be considered when assessing expert performance (Dror & Scurich, 2020).

There are a number of different methodologies used to induce stress on human subjects in research. One approach includes elements of social–evaluative threats, when one is judged negatively by others, such as receiving negative feedback. Another approach is uncontrollability, when nothing can be done to avoid negative consequences or change a situation, such as having a time limit for completing a task (Allen et al., 2017; Dickerson & Kemeny, 2004).

A meta-analysis of 208 laboratory-based stress studies found that stressors that combine the social–evaluative threats and uncontrollability approaches produced the greatest stress response in human subjects (Dickerson & Kemeny, 2004). In addition, it has been suggested that stressors that contain uncontrollable threats to the social self, such as public speaking, can have ecological validity (Allen et al., 2017) as they can occur in daily life (Lehman et al., 2015). Furthermore, they are common across cultures (Dickerson & Kemeny, 2004) and can be unpredictable or uncontrollable, even in professional domains (Akinola & Mendes, 2012; Arora et al., 2010; Schuetz et al., 2008). An example from the medical domain would be to have unexpected external visitors observing the progress of a surgical procedure (Schuetz et al., 2008).

The aim of this exploratory study was to collect data about the potential impact of uncontrollable social evaluative stressors on fingerprint decision-making tasks. The study was comprised of two experiments: the first with novice participants, and the second with fingerprint expert participants. The first experiment acted as a pilot study to test the experimental design with novices prior to launching the second experiment with fingerprint experts, and it also served as a comparison to consider the possible impact of stress on experts relative to novices.

2. Method

2.1. Fingerprint stimuli

Prior to the study, 23 fingerprint pairs were chosen from a database of fingerprint pairs where the ground truth was known (i.e., same-source or different-source). The fingerprint pairs were assessed for difficulty by nine fingerprint experts (mean experience, 13.8 years; range, 3–34), in order to choose pairs of varying difficulty for inclusion in the experiments. For the difficulty assessment, the fingerprint pairs were presented side by side with a 5-point difficulty scale. A mean rating among the experts of 3.5–5.0 was considered "difficult"; 2.5–3.5 "medium"; and 1.0–2.5 "easy."

Of the 23 piloted pairs, 12 pairs were chosen for the study; six difficult pairs of which three were same-source and three were different-source pairs, and six easy pairs of which three were same-source and three were different-source pairs. The fingerprint pairs were randomly distributed and counterbalanced within Qualtrics by condition and by difficulty, so each participant made assessments of six pairs: three were difficult and three were easy. The aim was to account for the range of difficulty that fingerprint experts encounter in real casework (Kukucka et al., 2020).

Overall, the novice participants in the first experiment made 690 decisions (115 participants × 6 pairs each), half were different-source and half same-source. The control group made 366 decisions and the stress group 324 decisions. In the second experiment, expert participants made 204 decisions (34 participants × 6 pair of prints; 104 different-source and 100 same-source). The control group made 96 decisions and the stress group made 108 decisions (see Appendix A).

2.2. Stress manipulation

The stress manipulation involved asking participants to answer 24 general knowledge and mathematical questions under a time limit, and feedback was given (e.g., "**WRONG!**" or "**TIME OUT!**"). Participants in the control group answered a comparable number of general knowledge and mathematical questions, but without time limits and with no feedback. Furthermore, the questions in the stress condition were selected to be more difficult and prone to error than those in the control group in order to increase the level of stress (by increasing the probability of participants making mistakes and receiving negative feedback). Hence, this experimental design included both social evaluative threat (such as feedback messages after answering each question) and uncontrollability stress elements (such as time pressure for answering the questions), as outlined in (Almazrouei et al., 2022).

2.3. Stress manipulation check

The effectiveness of the stress manipulation was assessed using the state anxiety scale (Spielberger et al., 1983). This established scale captures the situational anxiety levels of participants (i.e., the anxiety feelings at the present moment). This scale consists of 20 statements (e.g., I feel nervous) for which users indicate their degree of agreement on a 4-point scale, in regard to how they feel "right now". The scores range from a minimum of 20 to a maximum of 80 (Spielberger et al., 1983). While this is a self-reporting assessment, the scale has been validated and is commonly used to measure the effectiveness of stress manipulations (Arora et al., 2010; LeBlanc et al., 2005; Spielberger et al., 1983; Tanida et al., 2007).

2.4. Attention check screeners

Four attention check screeners were used to check that participants paid attention to the study tasks (Oppenheimer et al., 2009). Two of the four attention checks were related to a video on how to make a fingerprint assessment (in the first experiment with novices). Here, participants were asked to summarize the content of the video in two to three sentences. Additionally, the time they spent watching this 5-min, 43-s video was also assessed. The other two attention check screeners were related to completing the state anxiety scale. An additional item was embedded within the questionnaire as an attention check, requesting participants to "please tick somewhat." Furthermore, the pattern of answering the state anxiety questionnaire was checked (e.g., whether a participant consistently stating the same response of "Not at All" in an arbitrary fashion).

The responses of participants who failed one or more attention check questions was escalated for manual review. During the review, the researchers assessed the response pattern of the participant, such as whether they reported the same response throughout the survey (Clemmow et al., 2020). We were conservative in excluding a participant's response, due to the potential risk of bias (Berinsky et al., 2014), unless there were clear signs of a lack of attention based on the exclusion criteria (e.g., viewing the 5-min video on fingerprint assessment in less than a minute).

2.5. Measures

Participants were asked to report a conclusion (identification, exclusion or inconclusive) and the confidence level in their conclusion for each fingerprint pair. To understand the potential impact of stress on these decisions, the proportions (%) of each category of conclusion was calculated (see Appendix A). In addition, response times were recorded in Qualtrics without the knowledge of participants.

2.6. Procedure

Both experiments followed a between-subjects design, with participants randomly allocated via Qualtrics software into either a stress or a control condition. In each condition, there were three blocks. In each block, the participants made decisions on two pairs of fingerprints after which they answered eight general knowledge and mathematical questions. In the stress condition, these eight questions were difficult, presented with time limits, and feedback was given to participants. In the control condition, the questions were relatively easy, presented with no time limit and no feedback was provided to participants. In total, each participant answered 24 general knowledge/mathematical questions and made decisions on six pairs of fingerprints. The six pairs of fingerprints varied in difficulty and the ground truth.

After the three blocks of general knowledge and mathematical questions and the pairs of prints, the effectiveness of the stress manipulation was measured with the state scale of State–Trait Anxiety Inventory (see Spielberger et al., 1983). Participants were then asked to provide their demographic information. At the end of the experiment, participants were debriefed and told that this study specifically aimed to induce momentary stress. In the debriefing, participants were given the opportunity to withdraw their data without giving a reason and without it affecting their rights and benefits.

Novices in the first experiment received a short training on how to make fingerprint assessments before starting the actual study. This consisted of a 5-min online video tutorial and three exercises on fingerprint assessments in which feedback was given (one identification, one exclusion and one for inconclusive).

Ethical approval was granted by UCL Research Ethics Committee (#15395/003). This study was not pre-registered; hence, criteria, such as those pertaining to excluding participants or cutoffs for interpreting the observable findings, were not pre-specified. However, data and Qualtrics program survey flow for the study are publicly available in OSF (https://osf.io/3mxu9/). In addition, the programmed study link—with full access to the study in Qualtrics—can be shared upon reasonable request from the corresponding author.

2.7. Participants

In the first experiment with novice participants, the participant selection criteria were 25–60 years of age with a minimum level of high school (or equivalent) education. These parameters were chosen to ensure that the cohort were comparable with that of expert fingerprint examiners and comparable to other studies with forensic experts. For example, Holt et al. (2017) reported the mean age for the 670 forensic examiners they surveyed was 39 years (median = 37, range = 23–66), and a few (6% of sample, $n = 40$) had an education level equivalent to that of a two-year degree or less.

Data were collected from 120 novice participants using the Prolific Academic platform. Five participants were excluded from the analysis (withdrew their data, did not meet the inclusion criteria as they were under the age of 25; or failed most of the attention checks). This left a final sample of 115 novice participants of whom 54.8% were males ($n = 63$; prefer not to disclose the sex: $n = 1$, 0.9%). The mean age of participants was 35 ($SD = 8$; range = 25–60). There were 61 (53%) participants in the control condition and 54 (47%) in the stress condition.

In the second experiment, data were collected from 34 fingerprint experts of whom 38.2% were males ($n = 13$) and 58.8% were females ($n = 20$; prefer not to disclose the sex: $n = 1$, 2.9%). The experts were based in five different countries: Bahrain, Saudi Arabia, the United Arab Emirates, the United Kingdom, and the United States. The mean experience of participants in fingerprint assessments was 17.4 years ($SD = 11.0$; range = 1–35). The mean age of participants was 43 ($SD = 10$; range = 25–57).

It is of note that initially there were 43 expert participants, but nine dropped out, all from the stress condition. This was perhaps a sign that the stress condition was indeed stressful. As a result of the drop-out, more expert participants were assigned to the stress condition. In the end, 18 experts (52.9%) were in the stress condition while 16 experts (47.1%) were in the control condition.

3. Results

3.1. Stress manipulation

In the first experiment, the mean stress levels, as measured by state anxiety scale, were higher for the stress group compared with the control group, Welch's $t\,(96.34) = -6.84$, $p < .000$, with a mean of 51.15 ($SD = 13.10$) compared with a mean of 36.33 ($SD = 9.63$), respectively. The Welch *t*-test was used when the assumption of homogeneity of variances was not met, as assessed by Levene's test for equality of variances.

Neither age nor sex moderated state anxiety levels. Specifically, there was no correlation between momentary stress levels and age in either the control group ($r\,(61) = -0.08$, $p = .547$) or the stress group ($r\,(54) = 0.004$, $p = .976$). Moreover, there was no main effect of sex, $t\,(112) = -0.18$, $p = .857$, with a mean of 43.53 ($SD = 13.63$) for females and a mean of 43.06 ($SD = 13.71$) for males.

In the second experiment, the mean state anxiety score was higher for the stress group ($M = 40.22$, $SD = 10.77$) compared with the control group ($M = 36.94$, $SD = 12.07$). However, this was not statistically significant, $t\,(32) = -0.84$, $p = .408$. State anxiety levels were not moderated by age ($r\,(34) = -0.26$, $p = .145$), years of experience ($r\,(34) = -0.30$, $p = .090$) or sex ($t\,(31) = -1.48$, $p = .148$).

3.2. Decisions for same-source evidence

The findings suggest that stress contributed to a possible improvement in fingerprint expert assessments for same-source evidence (see Fig. 1). Specifically, stress resulted in an observable increase in identification decisions (47% *vs.* 55%) and a decrease in exclusion decisions (20% *vs.* 12%)—both changes could be categorised as improvement in performance. It appears that the difficulty of the fingerprint evidence moderated these findings, since increased identifications and decreased exclusions were most noticeable in the easy pairs.

Overall, stress did not seem to influence expert risk-taking for same-source evidence (i.e., inconclusive decisions). However, stressed experts were evidently more risk averse when the fingerprint pairs were difficult (71% *vs.* 54%). Interestingly, stress resulted in similar changes to decisions for novices and experts, but only for the overall changes (see top chart of Fig. 1).

3.3. Decisions for different-source evidence

Overall, stress did not appear to contribute to noticeable decision-making changes in either the expert and novice cohorts (see Fig. 2). However, the difficulty of the fingerprint assessments played a role in this potential negligible effect of stress (consistent with same-source findings). For instance, for easy pairs, stress did not seem to influence expert decisions or risk-taking at all—a possible sign of ceiling effect. However, for difficult pairs, stress appeared to contribute in observable

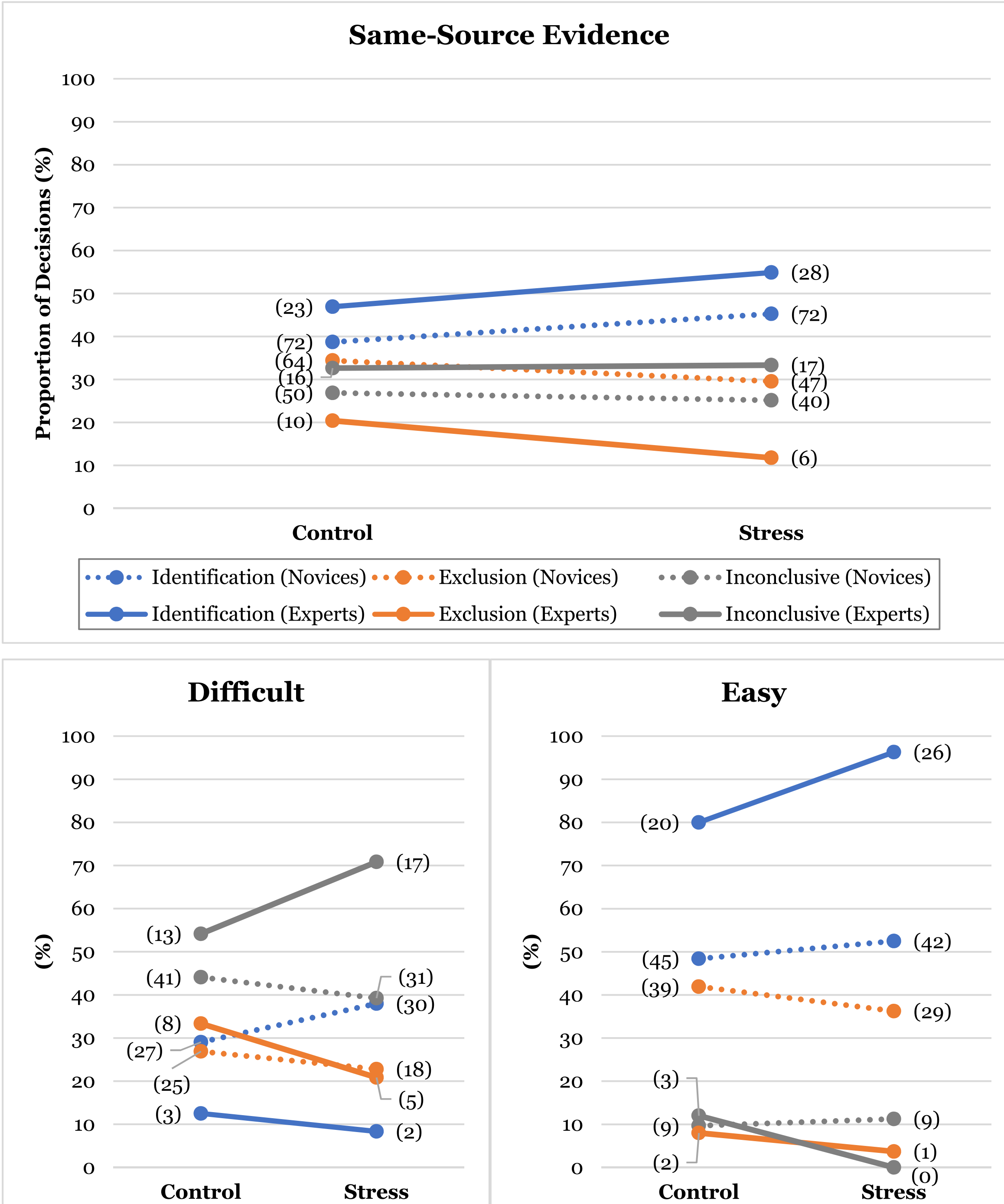

Fig. 1. Proportions of decisions on same-source evidence for all fingerprint pairs (top), difficult pairs (bottom left) and easy pairs (bottom right). Number of decisions is shown in brackets; lines represent directionality of change between control and stress conditions.

changes that can be categorised as improved performance (i.e., an increase of exclusions: 50% *vs.* 57% and decrease in identifications: 4% vs. 0%). No clear pattern was discernible for the decisions of novice participants.

3.4. *Confidence levels and response times*

On average, nonexperts in the first experiment had moderate confidence in making their decisions ($M = 59.60$; $SD = 23.56$). In comparison, fingerprint experts had high confidence in making their decisions in the second experiment ($M = 89.35$; $SD = 15.94$). Table 1 summarises the findings on the potential impact of stress on confidence levels as well as response times. An additional targeted significance test was made on inconclusive decisions made by experts on difficult same-source evidence, since we wanted to understand the observable change in these decisions further (see bottom left chart of Fig. 1).

The response time for each decision was recorded in seconds. In the first experiment, an outlier was identified and excluded, whose score was more than 30 IQRs above Q3 (i.e., the 75th percentile) (see, Kukucka et al. (2020)). Similarly, one outlier was also identified and excluded in the second experiment. With a single score excluded, novices spent an average of 26.67 s ($SD = 26.27$; $Med = 18.30$) on each

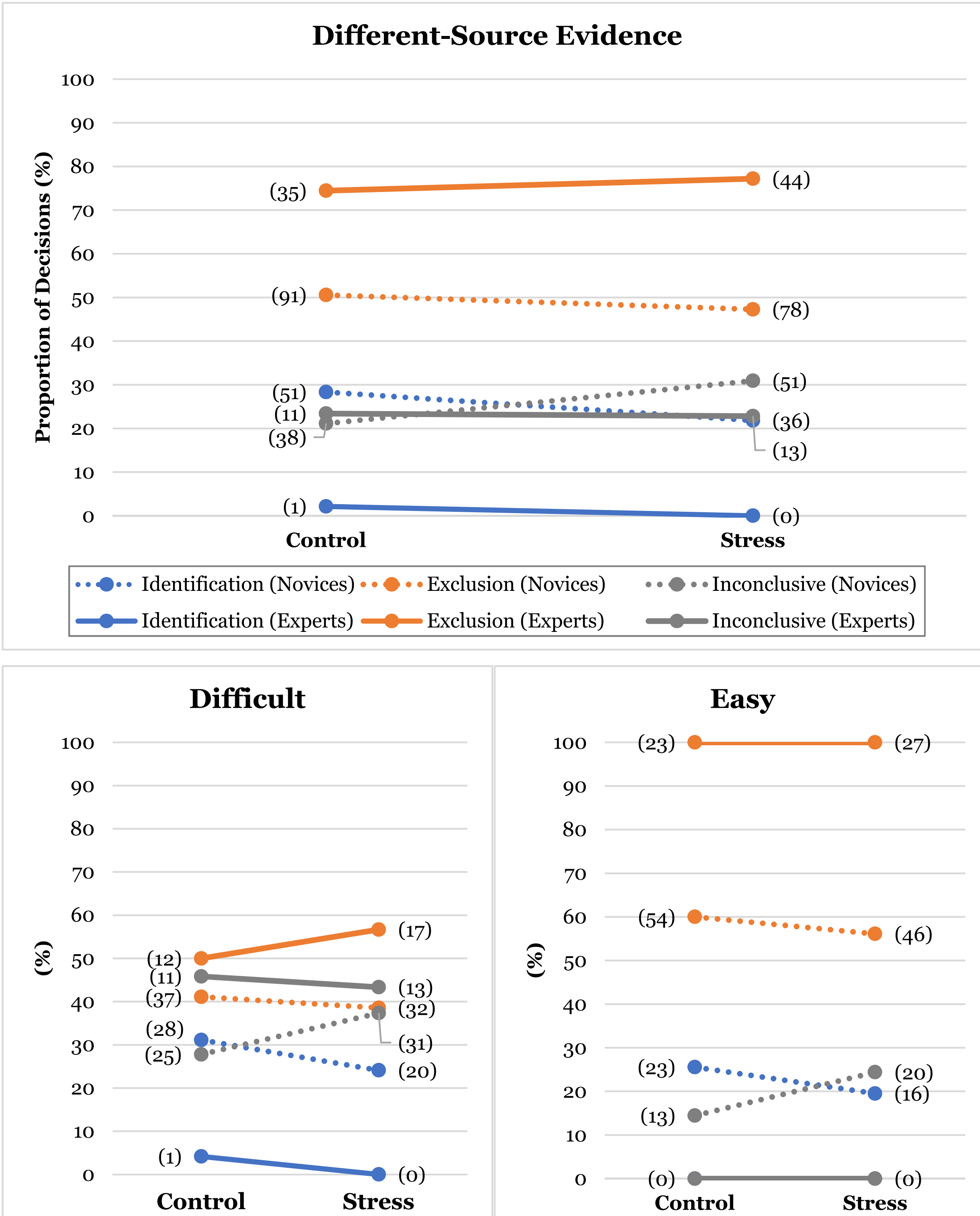

Fig. 2. Proportions of decisions on different-source evidence for all fingerprint pairs (top), difficult pairs (bottom left) and easy pairs (bottom right). Number of decisions is shown in brackets; lines represent directionality of change between control and stress conditions.

judgment and experts spent considerably longer with an average of 128.59 s ($SD = 177.40$; $Med = 68.66$) on each decision. Nevertheless, the response times remained skewed as assessed by the histograms and Q-Q plots. Hence, Mann-Whitney U was used to compare response times across the stress and no-stress conditions (see Table 1).

4. General discussion

The findings indicate that stress, as induced in this experiment, may contribute to an improvement in fingerprint decision-making for both novices and experts, but mainly for same-source evidence. These findings of this exploratory study are consistent with the published literature on the impact of moderate stressors on performance. Specifically, when stress is moderate, it can improve human performance (Epel et al., 2018; Yerkes & Dodson, 1908), including for experts in professional domains (e.g., in policing (Akinola & Mendes, 2012)). This could be due to alertness and improved attention (Kowalski-Trakofler et al., 2003; Paton & Flin, 1999)—a cognitive function that is mediated by working memory (Deligkaris et al., 2014). The induced stress level in the current study is considered 'moderate' because the mean state anxiety scores in the

Table 1
The impact of stress on confidence Levels (CL) and response times (RT).

	Control	Stress	Significance Testing	
Novices				
CL (%, mean (*SD*))	61.34 (22.26)	57.70 (24.84)	t (653.35) = 2.02	p = .044
RT (sec, mean rank)	362.26	325.44	U = 52,790.50, z = −2.42	p = .015
Experts				
CL (%, mean (*SD*))				
Overall	87.06 (18.37)	91.38 (13.19)	t (170.31) = −1.91	p = .058
Inconclusives for difficult same-source evidence	72.77 (23.76)	89.71 (13.84)	t (18.12) = −2.29	p = .034
RT (sec, mean rank)	110.02	94.94	U = 4368.00, z = −1.83	p = .068

stress group (i.e., 51.15 for the experiment with novices, and 40.22 for the experiment with experts) were mid-way between the minimum score of 20 and maximum score of 80.

It is acknowledged that forensic experts already operate in stressful situations, including potentially uncontrollable social evaluative threats. A key implication of this preliminary study is that it may be useful to monitor the levels of stress of forensic experts and establish what may be considered to be moderate stress levels. It may also be beneficial to monitor the level of challenge specific tasks represent, as a means of considering the sense of stress during the performance of the task. Previously published research suggests that underload, boredom and repetitive tasks can impair performance of individuals (Driskell et al., 2014).

However, it must be emphasized that the stressor used in this study did not appear to induce a clear improvement in decision making, especially in different source-evidence contexts where changes were negligible. Several explanations could account for this observation. It could be that stress does not impact decisions in the different-source evidence in the same way as same-source evidence. Another explanation could be that the nine experts who dropped out resulted in a different pattern of results than might otherwise have been if they had completed the study. This latter point could also explain the nonsignificant differences in stress manipulation for experts, as those who were possibly most impacted by stress dropped out of the study and did not complete it. Yet, since all the experts who did not complete the study were from the stress group, this by itself may reflect the effectiveness of the stress manipulation and warrant further study.

Stress did not appear to have a noticeable effect on fingerprint expert risk-taking, since the proportions of inconclusive decisions was comparable in the stress and control condition for both the same-source and different-source evidence. However, when the same-source prints were challenging, there appeared to be a trend that stressed experts were more conservative than non-stressed experts. Specifically, stressed experts reported more inconclusive decisions than non-stressed expert participants (a 17% difference), and with higher confidence levels. It is also worth noting that most of these difficult decisions were reported as inconclusives for both the stress and control conditions (more than 50%). This makes interpreting the impact of stress on expert performance challenging, especially given that inconclusives are already complex to interpret (Dror & Langenburg, 2019). On the one hand, reaching an inconclusive decision can be justifiable, given the difficulty level of the fingerprint pairs and that experts may be motivated to avoid erroneous identifications (Mannering et al., 2021). On the other hand, it has been contended that reporting a large rate of inconclusives can result in a practical trade-off in potentially having fewer crimes resolved (Mannering et al., 2021; Ulery et al., 2011).

As expected, fingerprint experts seemed to perform better than novices under stress and under no-stress (see Figs. 1 and 2). Experts took more time in making their judgments—on average, they spent about five times longer in making their judgments compared with novices. Moreover, the stressor in this study appeared to have a noticeable contribution to the fingerprint decision-making process of novices, but not as much on experts. Specifically, stressed novices made their fingerprint decisions faster and with lower confidence levels than the control group of novices (see Table 1).

Nevertheless, it is interesting that novices performed reasonably well despite the minimal training on fingerprint assessments they received in this experiment (e.g., identification decisions were reported in about 40% of decisions for same-source evidence, and the possible trend of improved performance for novices was similar to experts for same-source evidence; see Fig. 1). Even so, whilst previous research found that even minimal training in fingerprinting to novice participants was effective—reporting that trained novice participants performed significantly better on fingerprint assessments than untrained students—their performance remained substantially lower than fingerprint experts (Stevenage & Pitfield, 2016).

Whilst it appears that novices potentially outperformed experts in making more identifications for difficult same-source evidence, this could be due to experts being less risk taking in reaching conclusive judgments. Experts seemed to consistently report more inconclusive decisions than novices for both the difficult same-source and different-source fingerprint pairs, regardless of the stress condition. Indeed, previous empirical research has found that fingerprint experts were more risk averse than members of the general public (Mannering et al., 2021).

In the expert cohort, only one erroneous identification was made. However, the experts made a total of 16 erroneous exclusions. When examined closely, most ($N = 13$) of these errors arose from same-source fingerprint pairs that were determined to be difficult matching pairs in the pilot of fingerprint stimuli (see Section 2.2). Hence, on these occasions, it appears that the difficulty of the matching process played a more important role than the induced stress. Koehler and Liu (2021) suggested that experts can be prone to high error rates (up to 28.1%) when the fingerprints are difficult to assess. In such difficult assessments, opting for inconclusive decisions is what examiners tend to do depending how these are scored (Dror & Scurich, 2020). The scoring of the inconclusives decisions is tricky (Dror & Langenburg, 2019). See Dror and Scurich (2020) for possible ways to score them even when there is no scientific criteria to assess when these decisions are correct and when they are erroneous.

These initial exploratory findings offer insight that may contribute to a greater understanding of the relationship between stress and decision-making in forensic science. However, further experimental studies are needed to establish if there is a direct causational effect, and how such studies may contribute evidence to the new science of ‘well-being’ (Layard & De Neve, 2023a; 2023b). In addition, the study design has limitations that may limit its generalizability. First, this study is conducted online and therefore naturally induced less stress than real-life stress at work (Almazroueiv et al., 2022). In addition, being online, the fingerprinting task itself was different to casework conditions where fingerprint analysis is usually carried out in a workplace setting. Arguably, the working culture may also affect stress levels (Almazrouei et al., 2020), and can be related to practitioners’ decision-making (Lidén & Almazrouei, 2023). Hence, the findings from the experts who participated in this study are not necessarily generalizable to all contexts and other pattern recognition tasks.

Second, the stress task did not reflect the precise stressors that forensic practitioners face at work. The stressor in this study included general knowledge and mathematical questions, which may have caused participants to be anxious or embarrassed about their performance on trivia questions. This may have engaged different psychological processes than stressors forensic practitioners encounter in the workplace (e.g., emotional responses from math anxiety that is linked with working memory (Caviola et al., 2017)). However, practitioners may face situations with uncontrollable social-evaluative elements that approximate to the intended stress feelings induced from the stress task employed in this study. For example, in the medical domain, stressors can arise from unexpected visitors during time-pressurized procedures (Schuetz et al., 2008). In the forensic science discipline, these situations might occur when there is unexpected managerial audit to the forensic work, or from external auditors to ISO 17025/17020 accreditations.

Third, the approach taken to assess changes in the fingerprint decisions (not the confidence levels or response times; see Sections 3.2 and 3.3) that followed some previously published studies (e.g., Langenburg et al., 2009) may have introduced subjectivity and potentially increased the risk of bias in the interpretation of the results.

Fourth, this study did not investigate the individual differences in stress responses. It is important to remember that there are individual differences in responses to work related stress, both because different people may have different stress factors in their life outside of their work, as well as different people responding differently to stress. Hence, future research may consider looking into individual-level differences and how they relate to decision-making. One way to achieve this could be using behavioral economics paradigms (Levy et al., 2010), which have been used in the medical domain to assess when physicians describe a treatment to patients (Saposnik et al., 2017; Wiechers et al., 2014), or assess individuals' choices that could lead to obesity (Dan et al., 2021).

However, the data and initial findings of this study offer insight into the potential contribution of stress to decision-making in forensic science. By using established stressors of uncontrollable social-evaluative threats (see meta-analysis in Dickerson & Kemeny, 2004), this exploratory study addresses limitations of previous studies, such as the use of unreasonably short time pressures as a type of stressor (e.g., Stevenage & Bennett, 2017), or not including inconclusive decisions (e.g., Zou et al., 2021). Further, this study contributes evidence to the issue of consistency in forensic expert decision making (Dror, 2023) when stress factors are involved, thus hopefully driving efforts to understand the complexity of human factors to enhance decisions under either low or high stressing conditions. With better understanding of stress, even in an online research environment, it will be possible to identify alternative or modified approaches to optimize the transparency of decision making (Almazrouei et al., 2019; Almazrouei, 2020; Giurge & Bohns, 2021).

5. Conclusion

This exploratory study offers insights that indicate a complex relationship between stress and forensic expert decision-making. Specifically:

- Stress appeared to contribute to an improved performance of both novices and experts on fingerprint assessments, but mainly for same-source evidence.
- Stress did not seem to have an overall observable effect on the risk-taking of experts, measured through inconclusive decisions. However, when the same-source prints were difficult, experts under stress tended to exhibit less risk-taking by reporting more inconclusives than the control group.
- Fingerprint experts appeared to perform better than novices under stress and under no-stress.
- The stressor utilized in this study appeared to contribute to an impact on the overall confidence levels and response times of novices, but less so for experts.

This study demonstrates that stress may contribute to an improved performance of individuals in making decisions in a fingerprint comparison task. This study draws attention to the potentially positive impact of stress, and opens up avenues for research to explore the drivers and mechanisms of the contribution of stress in order to inform practice. Further research may offer additional insight as to whether there is value in forensic experts experiencing momentary stress, and ensuring working environments create opportunities for challenge and variability of forensic tasks performed by experts. In addition, exploring the impact of in-person experimental stressors which may be more reflective of stressors within the workplace may offer additional insight to the contribution of stress to decision-making. This study also highlights the importance of considering the risk-taking of experts, measured through inconclusive decisions, when assessing performance in stressful situations.

Funding

For this specific project: N/A.

Declaration of competing interest

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

Acknowledgments

We are very thankful for all the participants in taking the time to complete the study.

Appendix A. Fingerprint decision-making of novices and experts

A-1
Novices

Pair	ID-C	ID-S	Ex-C	Ex-S	Inc-C	Inc-S	Total-C	Total-S
Same-Source Evidence								
A0	8	7	5	8	16	10	29	25
B0	19	22	7	3	5	2	31	27
C0	0	1	13	7	20	19	33	27
D0	10	12	17	11	4	4	31	27
E0	15	13	16	13	0	2	31	28
F0	20	17	6	5	5	3	31	25
	38.7%	45.3%	34.4%	29.6%	26.9%	25.2%	$N = 186$	$N = 159$
Different-Source Evidence								
A1	3	3	18	19	11	7	32	29
B1	21	16	3	5	6	6	30	27
C1	4	1	16	8	8	18	28	27
D1	6	5	18	15	6	7	30	27
E1	1	1	25	20	4	5	30	26
F1	16	10	11	11	3	8	30	29
	28.3%	21.8%	50.6%	47.3%	21.1%	30.9%	$N = 180$	$N = 165$

A-2
Experts

Pair	ID-C	ID-S	Ex-C	Ex-S	Inc-C	Inc-S	Total-C	Total-S
Same Source Evidence								
A0	1	0	2	0	6	8	9	8
B0	1	1	5	5	2	1	8	7
C0	1	1	1	0	5	8	7	9
D0	5	9	0	0	1	0	6	9
E0	9	10	2	1	0	0	11	11
F0	6	7	0	0	2	0	8	7
	46.9%	54.9%	20.4%	11.8%	32.7%	33.3%	*N* = 49	*N* = 51
Different Source Evidence								
A1	0	0	6	9	1	1	7	10
B1	1	0	6	8	1	3	8	11
C1	0	0	0	0	9	9	9	9
D1	0	0	10	9	0	0	10	9
E1	0	0	5	7	0	0	5	7
F1	0	0	8	11	0	0	8	11
	2.1%	0.0%	74.5%	77.2%	23.4%	22.8%	*N* = 47	*N* = 57

Key: ID = Identification decision; Ex = Exclusion decision; Inc = Inconclusive decision; C = Control condition; S = Stress condition; Total = all fingerprint pairs assessed in each condition; A0 = same-source pair of latent print A; A1 = different-source pair of latent print A.

References

Akinola, M., & Mendes, W. B. (2012). Stress-induced cortisol facilitates threat-related decision making among police officers. *Behavioral Neuroscience, 126*(1), 167–174. https://doi.org/10.1037/a0026657

Allen, A. P., Kennedy, P. J., Dockray, S., Cryan, J. F., Dinan, T. G., & Clarke, G. (2017). The trier social stress test: Principles and practice. *Neurobiology of Stress, 6*, 113–126. https://doi.org/10.1016/j.ynstr.2016.11.001

Almazrouei, M. A. (2020). Comment on "cognitive and human factors in expert decision making: Six fallacies and the eight sources of bias. *Analytical Chemistry, 92*(18), 12725–12726. https://doi.org/10.1021/acs.analchem.0c03002.

Almazrouei, M. A., Dror, I. E., & Morgan, R. M. (2019). The forensic disclosure model: What should be disclosed to, and by, forensic experts? *International Journal of Law, Crime and Justice, 59*, 100330. https://doi.org/10.1016/j.ijlcj.2019.05.003.

Almazrouei, M. A., Dror, I. E., & Morgan, R. M. (2020). Organizational and human factors affecting forensic decision-making: Workplace stress and feedback. *Journal of Forensic Sciences, 65*(6), 1968–1977. https://doi.org/10.1111/1556-4029.14542

Almazrouei, M. A., Morgan, R. M., & Dror, I. E. (2021). Stress and support in the workplace: The perspective of forensic examiners. *Forensic Science International: Mind and Law.* , Article 100059. https://doi.org/10.1016/j.fsiml.2021.100059

Almazrouei, M. A., Morgan, R. M., & Dror, I. E. (2022). A method to induce stress in human subjects in online research environments. *Behavior Research Methods*. https://doi.org/10.3758/s13428-022-01915-3.

Arora, S., Sevdalis, N., Nestel, D., Woloshynowych, M., Darzi, A., & Kneebone, R. (2010). The impact of stress on surgical performance: A systematic review of the literature. *Surgery, 147*(3), 318–330. https://doi.org/10.1016/j.surg.2009.10.007

Benson, H., & Casey, A. (Eds.). (2013). *Stress management: Approaches for preventing and reducing stress*. Harvard Medical School.

Berinsky, A. J., Margolis, M. F., & Sances, M. W. (2014). Separating the shirkers from the workers? Making sure respondents pay attention on self-administered surveys. *American Journal of Political Science, 58*(3), 739–753. https://doi.org/10.1111/ajps.12081

Bogacz, R., Brown, E., Moehlis, J., Holmes, P., & Cohen, J. D. (2006). The physics of optimal decision making: A formal analysis of models of performance in two-alternative forced-choice tasks. *Psychological Review, 113*(4), 700–765. https://doi.org/10.1037/0033-295X.113.4.700

Caviola, S., Carey, E., Mammarella, I. C., & Szucs, D. (2017). Stress, time pressure, strategy selection and math anxiety in mathematics: A review of the literature. *Frontiers in Psychology, 8*, 1488. https://doi.org/10.3389/fpsyg.2017.01488

Charlton, D., Fraser-Mackenzie, P. A. F., & Dror, I. E. (2010). Emotional experiences and motivating factors associated with fingerprint analysis. *Journal of Forensic Sciences, 55*(2), 385–393. https://doi.org/10.1111/j.1556-4029.2009.01295.x

Clemmow, C., Schumann, S., Salman, N. L., & Gill, P. (2020). The base rate study: Developing base rates for risk factors and indicators for engagement in violent extremism. *Journal of Forensic Sciences, 65*(3), 865–881. https://doi.org/10.1111/1556-4029.14282

Dan, O., Wertheimer, E. K., & Levy, I. (2021). A neuroeconomics approach to obesity. *Biological Psychiatry*. https://doi.org/10.1016/j.biopsych.2021.09.019. S0006322321016310.

Deligkaris, P., Panagopoulou, E., Montgomery, A., & Masoura, E. (2014). Job burnout and cognitive functioning: A systematic review. *Work & Stress: An International Journal of Work, Health & Organisations, 28*(2), 107–123. https://doi.org/10.1080/02678373.2014.909545

Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychological Bulletin, 130*(3), 355–391. https://doi.org/10.1037/0033-2909.130.3.355

Driskell, T., Driskell, J. E., & Salas, E. (2014). Stress, performance and decision making in organizations. In S. Highhouse, R. S. Dalal, & E. Salas (Eds.), *Judgment and decision making at work* (1st ed., pp. 251–276). Routledge.

Dror, I. E. (2023). The most consistent finding in forensic science is inconsistency. *Journal of Forensic Sciences, 68*(6), 1851–1855. https://doi.org/10.1111/1556-4029.15369.

Dror, I. E., & Charlton, D. (2006). Why experts make errors. *Journal of Forensic Identification, 56*(4), 600–616.

Dror, I. E., & Langenburg, G. (2019). "Cannot decide": The fine line between appropriate inconclusive determinations versus unjustifiably deciding not to decide. *Journal of Forensic Sciences, 63*, 1–6. https://doi.org/10.1111/1556-4029.13854

Dror, I. E., Péron, A. E., Hind, S.-L., & Charlton, D. (2005). When emotions get the better of us: The effect of contextual top-down processing on matching fingerprints. *Applied Cognitive Psychology, 19*(6), 799–809. https://doi.org/10.1002/acp.1130

Dror, I. E., & Scurich, N. (2020). Mis)use of scientific measurements in forensic science. *Forensic Science International: Synergy, 2*, 333–338. https://doi.org/10.1016/j.fsisyn.2020.08.006

Earwaker, H., Morgan, R. M., Harris, A. J. L., & Hall, L. J. (2015). Fingermark submission decision-making within a UK fingerprint laboratory: Do experts get the marks that they need? *Science & Justice, 55*(4), 239–247. https://doi.org/10.1016/j.scijus.2015.01.007

Epel, E. S., Crosswell, A. D., Mayer, S. E., Prather, A. A., Slavich, G. M., Puterman, E., & Mendes, W. B. (2018). More than a feeling: A unified view of stress measurement for population science. *Frontiers in Neuroendocrinology, 49*, 146–169. https://doi.org/10.1016/j.yfrne.2018.03.001

Giurge, L. M., & Bohns, V. K. (2021). You don't need to answer right away! Receivers overestimate how quickly senders expect responses to non-urgent work emails. *Organizational Behavior and Human Decision Processes, 167*, 114–128. https://doi.org/10.1016/j.obhdp.2021.08.002

Hall, L. J., & Player, E. (2008). Will the introduction of an emotional context affect fingerprint analysis and decision-making? *Forensic Science International, 181*(1–3), 36–39. https://doi.org/10.1016/j.forsciint.2008.08.008

Helsloot, I., & Groenendaal, J. (2011). Naturalistic decision making in forensic science: Toward a better understanding of decision making by forensic team leaders. *Journal of Forensic Sciences, 56*(4), 890–897. https://doi.org/10.1111/j.1556-4029.2011.01714.x

Holt, T. J., Blevins, K. R., & Smith, R. W. (2017). Examining the impact of organizational and individual characteristics on forensic scientists' job stress and satisfaction. *Journal of Crime and Justice, 40*(1), 34–49. https://doi.org/10.1080/0735648X.2016.1216731.

Jeanguenat, A. M., & Dror, I. E. (2018). Human factors effecting forensic decision making: Workplace stress and well-being. *Journal of Forensic Sciences, 63*(1), 258–261. https://doi.org/10.1111/1556-4029.13533

Kellman, P. J., Mnookin, J. L., Erlikhman, G., Garrigan, P., Ghose, T., Mettler, E., Charlton, D., & Dror, I. E. (2014). Forensic comparison and matching of fingerprints: Using quantitative image measures for estimating error rates through understanding and predicting difficulty. *PLoS One, 9*(5), Article e94617. https://doi.org/10.1371/journal.pone.0094617

Koehler, J. J., & Liu, S. (2021). Fingerprint error rate on close non-matches. *Journal of Forensic Sciences, 66*(1), 129–134. https://doi.org/10.1111/1556-4029.14580

Kowalski-Trakofler, K. M., Vaught, C., & Scharf, T. (2003). Judgment and decision making under stress: An overview for emergency managers. *International Journal of Emergency Management, 1*(3), 278. https://doi.org/10.1504/IJEM.2003.003297

Kukucka, J., & Dror, I. E. (2022). Human factors in forensic science: Psychological causes of bias and error. In D. DeMatteo, & K. Scherr (Eds.), *The oxford handbook of psychology and law*. Oxford University Press. https://psyarxiv.com/8pqyt/.

Kukucka, J., Dror, I. E., Yu, M., Hall, L., & Morgan, R. M. (2020). The impact of evidence lineups on fingerprint expert decisions. *Applied Cognitive Psychology, 34*, 1143–1153. https://doi.org/10.1002/acp.3703

Langenburg, G., Champod, C., & Wertheim, P. (2009). Testing for potential contextual bias effects during the verification stage of the ACE-V methodology when conducting fingerprint comparisons. *Journal of Forensic Sciences, 54*(3), 571–582. https://doi.org/10.1111/j.1556-4029.2009.01025.x

Layard, R., & De Neve, J.-E. (2023a). *Wellbeing: Science and policy*. Cambridge University Press. https://www.cambridge.org/us/universitypress/subjects/economics/microeconomics/wellbeing-science-and-policy?format=PB.

Layard, R., & De Neve, J.-E. (2023b). A new science of wellbeing will change policy and decision making [The London School of Economics and Political Science. *Impact of Social Sciences Blog*. https://eprints.lse.ac.uk/118602/.

LeBlanc, V. R., MacDonald, R. D., McArthur, B., King, K., & Lepine, T. (2005). Paramedic performance in calculating drug dosages following stressful scenarios in a human patient simulator. *Prehospital Emergency Care, 9*(4), 439–444. https://doi.org/10.1080/10903120500255255

Lehman, B. J., Cane, A. C., Tallon, S. J., & Smith, S. F. (2015). Physiological and emotional responses to subjective social evaluative threat in daily life. *Anxiety, Stress & Coping, 28*(3), 321–339. https://doi.org/10.1080/10615806.2014.968563

Levy, I., Snell, J., Nelson, A. J., Rustichini, A., & Glimcher, P. W. (2010). Neural representation of subjective value under risk and ambiguity. *Journal of Neurophysiology, 103*(2), 1036–1047. https://doi.org/10.1152/jn.00853.2009

Lidén, M., & Almazrouei, M. A. (2023). "Blood, Bucks and Bias": Reliability and biasability of crime scene investigators' selection and prioritization of blood traces. *Science & Justice, 63*(2), 276–293. https://doi.org/10.1016/j.scijus.2023.01.005

Mannering, W. M., Vogelsang, M. D., Busey, T. A., & Mannering, F. L. (2021). Are forensic scientists too risk averse? *Journal of Forensic Sciences, 66*(4), 1377–1400. https://doi.org/10.1111/1556-4029.14700

Morgan, R. M. (2017). Conceptualising forensic science and forensic reconstruction. Part II: The critical interaction between research, policy/law and practice. *Science & Justice, 57*(6), 460–467. https://doi.org/10.1016/j.scijus.2017.06.003

Mustonen, V., Hakkarainen, K., Tuunainen, J., & Pohjola, P. (2015). Discrepancies in expert decision-making in forensic fingerprint examination. *Forensic Science International, 254*, 215–226. https://doi.org/10.1016/j.forsciint.2015.07.031

Oppenheimer, D. M., Meyvis, T., & Davidenko, N. (2009). Instructional manipulation checks: Detecting satisficing to increase statistical power. *Journal of Experimental Social Psychology, 45*(4), 867–872. https://doi.org/10.1016/j.jesp.2009.03.009

Osborne, N. K. P., Woods, S., Kieser, J., & Zajac, R. (2014). Does contextual information bias bitemark comparisons? *Science & Justice, 54*(4), 267–273. https://doi.org/10.1016/j.scijus.2013.12.005

Paton, D., & Flin, R. (1999). Disaster stress: An emergency management perspective. *Disaster Prevention and Management: An International Journal, 8*(4), 261–267. https://doi.org/10.1108/09653569910283897

Saposnik, G., Sempere, A. P., Prefasi, D., Selchen, D., Ruff, C. C., Maurino, J., & Tobler, P. N. (2017). Decision-making in multiple sclerosis: The role of aversion to ambiguity for therapeutic inertia among neurologists (DIScUTIR MS). *Frontiers in Neurology, 8*. https://doi.org/10.3389/fneur.2017.00065

Schuetz, M., Gockel, I., Beardi, J., Hakman, P., Dunschede, F., Moenk, S., Heinrichs, W., & Junginger, T. (2008). Three different types of surgeon-specific stress reactions identified by laparoscopic simulation in a virtual scenario. *Surgical Endoscopy, 22*(5), 1263–1267. https://doi.org/10.1007/s00464-007-9605-1

Sehsah, R., Gaballah, M. H., El-Gilany, A.-H., & Albadry, A. A. (2021). Work burnout and coping strategies among Egyptian forensic physicians: A national study. *Egyptian Journal of Food Science, 11*(1), 16. https://doi.org/10.1186/s41935-021-00230-w

Smalarz, L., Madon, S., Yang, Y., Guyll, M., & Buck, S. (2016). The perfect match: Do criminal stereotypes bias forensic evidence analysis? *Law and Human Behavior, 40*(4), 420–429. https://doi.org/10.1037/lhb0000190

Spielberger, C. D., Gorsuch, R., Lushene, R., Vagg, P., & Jacobs, G. (1983). *Manual for the state–trait anxiety inventory*. Consulting Psychologists Press. https://doi.org/10.1037/t06496-000.

Stevenage, S. V., & Bennett, A. (2017). A biased opinion: Demonstration of cognitive bias on a fingerprint matching task through knowledge of DNA test results. *Forensic Science International, 276*, 93–106. https://doi.org/10.1016/j.forsciint.2017.04.009

Stevenage, S. V., & Pitfield, C. (2016). Fact or friction: Examination of the transparency, reliability and sufficiency of the ACE-V method of fingerprint analysis. *Forensic Science International, 267*, 145–156. https://doi.org/10.1016/j.forsciint.2016.08.026

Tanida, M., Katsuyama, M., & Sakatani, K. (2007). Relation between mental stress-induced prefrontal cortex activity and skin conditions: A near-infrared spectroscopy study. *Brain Research, 1184*, 210–216. https://doi.org/10.1016/j.brainres.2007.09.058

Thompson, M. B., & Tangen, J. M. (2014). The nature of expertise in fingerprint matching: Experts can do a lot with a little. *PLoS One, 9*(12), Article e114759. https://doi.org/10.1371/journal.pone.0114759

Ulery, B. T., Hicklin, R. A., Buscaglia, J., & Roberts, M. A. (2011). Accuracy and reliability of forensic latent fingerprint decisions. *Proceedings of the National Academy of Sciences, 108*(19), 7733–7738. https://doi.org/10.1073/pnas.1018707108

Wiechers, I., Ruderman, L., & Levy, I. (2014). Does patient age affect physician decision making under varying risk and ambiguity? *American Journal of Geriatric Psychiatry, 22*(3), S98. https://doi.org/10.1016/j.jagp.2013.12.113

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18*(5), 459–482. https://doi.org/10.1002/cne.920180503

Zou, J., Liu, S., Sun, Q., Wang, C., & Liu, Y. (2021). How time pressure and fingerprint complexity affect fingerprint examiner performance in an Eye Tracking Study. *Forensic Science International, 328*, Article 111007. https://doi.org/10.1016/j.forsciint.2021.111007