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Can face identification ability be trained? Evidence for two routes to expertise

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Abstract

Is it possible to train face identification ability? To answer this question, we review the literature on professional training for facial image comparison practitioners, and the broader psychology literature on training for prosopagnosia patients and the general population. Our review of these literatures finds very little evidence that training can improve face recognition or face matching accuracy. However, one group of specialist practitioners – facial examiners – throw this conclusion into question. Facial examiners consistently outperform novices and show qualitative differences in how they perform matching tasks, suggesting that they have acquired their expertise via professional training. To account for these findings, we propose that there are two routes to expertise in face identification: the core face recognition system which cannot be trained, and an alternative feature-based route which can be trained. We encourage academics and practitioners to work together to identify effective and efficient training methods to teach facial image comparison practitioners to extract maximal identity information from facial features.

Keywords: Facial image comparison, face recognition, face matching, training, biometrics, forensic science.

Introduction

Establishing someone's identity is central to many of the security procedures we rely on to maintain law and order, and protect national security. One of the most common methods of verifying identity is to compare images of a person's face, for example when border control agents compare a traveller's face to their passport photo, or when forensic practitioners decide if the person captured committing a crime in CCTV footage matches a police mugshot. Because these identification decisions play an important role in society, it is important that people make them accurately.

It is therefore surprising, and somewhat concerning, that many facial image comparison practitioners make a high proportion of errors on these tasks (see White, Towler, & Kemp, this volume). For example, White, Kemp, Jenkins, Matheson, and Burton (2014) showed that passport issuance officers made 20% errors on the Glasgow Face Matching Test – a deceptively difficult test which requires participants to decide if two simultaneously presented photographs taken on the same day under studio conditions are of the same person or different people. Research has also revealed large individual differences in practitioners' ability to perform unfamiliar face matching tasks. Some practitioners perform close to chance whilst others achieve 100% accuracy on tests conducted in the laboratory (e.g., White, Kemp, Jenkins, Matheson, et al., 2014; Wirth & Carbon, 2017).

Mitigating the risks associated with practitioners' identification errors is a priority for government and forensic organisations, particularly in the wake of highly critical authoritative reports criticising the lack of scientific validation and reliability in the forensic sciences (see National Research Council, 2009; PCAST, 2016). A potential response to these reports is to rely more heavily on automated facial recognition technology, which has improved steadily in recent years (see Grother & Ngan, 2014; Grother, Ngan, & Hanaoka, 2018, 2019) and is now widely used at national borders and in police investigations (see Noyes & Hill, this volume).

However, it is important to appreciate that humans remain a critical component of face recognition systems, and will do so for the foreseeable future (see Towler, Kemp, & White, 2017). Indeed, many uses of face recognition software have actually *increased* the need for human processing. For example, when using a query image to search a large database of faces, as is the case when using this technology in police investigations, it is the responsibility of investigators to examine the array of possible matches that the software returns to decide if the suspect appears in the array. Professional staff who use this technology in their daily work are extremely prone to error, identifying the wrong face from the array on 40% of trials (White, Dunn, Schmid, & Kemp, 2015).

To mitigate against these risks, professional organisations typically provide practitioners with training to equip them with the skills necessary to make accurate identification decisions. But, how effective is this training? And, is it even possible to train face identification ability? To answer these questions, we first review the literature on professional training for facial image comparison practitioners. This uncovers a long history of training practitioners to adopt a systematic feature-by-feature comparison strategy, and evidence that modern professional training courses do not improve accuracy, despite adhering to international best-practice guidelines (see Towler et al., 2019).

Evidence from these three strands of investigation suggests that face identification ability may be *untrainable*. However, in a final section we review evidence from a specialist group of forensic practitioners known as ‘facial examiners’, who show consistently higher accuracy than novices. Their superior accuracy appears to be driven by qualitative differences in the way they approach the task, which they derive from training. To reconcile these findings, we argue that examiners’ expertise reveals an alternate route to training face identification ability, which bypasses the ‘core’ face recognition system. We discuss the implications of this for the future of facial image comparison training.

Professional face matching training dates back to the late 19th century. French criminologist Alphonse Bertillon is thought to have become frustrated by the police's inability to discriminate first-time offenders from reoffenders, so he invented the Bertillon system of identification or "Bertillonage" (Bertillon, 1896). Bertillon's system involved recording anthropometric measurements of a person's height, arm span, torso length, head length, head width, right ear, left foot, left middle finger and cubit (the distance between the elbow and tip of the middle finger; see Figure 1A). These measurements were recorded on identity cards alongside front-facing and profile photographs and other information such as eye, skin, and hair colour, and scars (see Figure 1B).

The information recorded on these identity cards was thought to be individuating, such that comparison to other cards would permit officers to identify people already in the system. Bertillon also invented a complicated filing system that allowed officers to easily locate relevant identity cards amongst hundreds of thousands of cards (U.S. National Library of Medicine, 2014). Bertillon taught his identification system to law enforcement officers throughout France and it quickly spread to other European countries, the Americas, and Asia (Piazza, 2016). Bertillon's teaching style was eccentric, making use of large posters that illustrated the possible variants of each facial feature, photographs of corpses, skeletons, and wax figures (see Figure 2).

Figure 2. Training to use the Bertillon system of identification in France.

There are also documented examples of face identification training from the 1960's. Stasi passport inspectors responsible for passport control at Checkpoint Charlie, a key crossing point from West to East Berlin, were trained using booklets containing the various types of noses, mouths, ears, eyes, hairlines and even moustaches (see Figure 3A; Drost, 2016). Inspectors were required to learn each of the feature variants – for example, pointed, straight, triangular, quadrangular, elliptical noses – so that they could recognise and classify the facial features of people attempting to cross the border. The reasoning behind this strategy was that the officers could detect imposters if the facial feature classifications in the passport photograph did not match those of the traveller standing before them¹. There is also evidence that inspectors were taught to break facial features down into their sub-components for more detailed comparison (see Figure 3B).

¹ See Towler, White, and Kemp (2014) for an evaluation of this type of facial feature classification strategy.

Figure 3. Face identification training materials provided to Stasi passport inspectors at Checkpoint Charlie. Inspectors were taught to (A) classify facial features, and (B) break them down into their sub-components for more detailed comparison.

In 1964, the newly appointed head of the passport division at Checkpoint Charlie concluded that laborious comparison of each facial feature was poorly suited to passport control, where inspectors only had a few moments to determine if the traveller held a valid passport. He was also coming under increasing pressure to eliminate errors – the Stasi would regularly send informants to the border holding fraudulent passports to test passport inspectors.

The head of the passport division believed that face identification was an intuitive skill, and that the officers needed to be trained to develop an expert gaze or “wichtig schauen” (Drost, 2016). He began secretly taking photographs of travellers and their passports, and used these to create flashcards so that his officers could practice making face matching decisions and receive feedback on their accuracy (see Figure 4A). He also interviewed his staff to find out which facial features they were using to make identifications. They reported that they tended to focus on the eyes, nose, and mouth, but that they would first attempt to get an overall impression of the face. He incorporated this information into training for new recruits, creating training materials to encourage them to divide the face into three horizontal sections and compare the similarity of each section in turn (see Figure 4B).

Figure 4. Flashcards developed by the head of the passport division at Checkpoint Charlie. (A) Passport inspectors would decide if the faces showed the same person or different people and receive feedback on the

accuracy of their decisions. (B) Passport officers used these flashcards to practice dividing faces into sections, and comparing the similarity of each section in turn. The correct answers for these image pairs are unknown.

We recently reviewed eleven current training courses provided to practitioners working in national security, police, intelligence, passport issuance, immigration and border control around the world (see Towler et al., 2019). We found that professional face matching training has changed surprisingly little since these earlier attempts (see content summary in Figure 5). Modern training remains focussed on the detailed analysis of facial features, rather than the face as a whole (see Towler et al., 2019). Training courses teach trainees about the anatomy of facial features, and the sub-parts of each feature (e.g., the tragus, helix, antihelix, and lobe of the ear), sharing striking similarities with the Stasi training material in Figure 3B. Modern professional training actively discourages trainees from examining the face holistically, and instead encourages them to break each face down into its sub-features and systematically compare the similarities and differences between them. Some training courses are run online, but most are still run face-to-face and include practical exercises and feedback (see Towler et al., 2019). Once again, these modern training practices share striking similarities to the Stasi training (see Figure 4).

	Country	Format	Days	Facial anatomy	Facial feature comparison	Photography	Practical exercises	Feedback	Error-rates	Cites empirical support for material
A	Australia	Online	1 hr	✓	✓	✗	✓	✓	✗	✗
B	Finland	Online	1 hr	✓	✓	✓	✓	✓	✗	✗
C	Australia	Face-to-Face	0.5	✓	✓	✓	✓	✓	✗	✗
D	UK	Face-to-Face	3	✓	✓	✓	✓	✓	✗	✓
E	Australia	Face-to-Face	0.5	✓	✓	✗	✓	✓	✗	✗
F	Australia	Face-to-Face	0.5	✓	✓	✗	✓	✓	✗	✗
G	Australia	Online	0.5	✓	✓	✓	✓	✓	✗	✗
H	USA	Face-to-Face	1	✓	✓	✓	✓	✓	✗	✗
I	USA	Face-to-Face	5	✓	✓	✓	✓	✓	✗	✗
J	Global	Face-to-Face	3	✓	✓	✓	✓	✓	✓	✗
K	Global	Face-to-Face	5	✓	✓	✓	✓	✓	✓	✗

Figure 5. Summary of current professional facial image comparison training course content from around the world. Modern training courses typically teach practitioners facial anatomy and encourage feature-by-feature comparison. Figure reprinted from Towler et al. (2019) under CC BY licence.

Modern training courses adhere to international best-practice guidelines set out by the Facial Identification Scientific Working Group (FISWG; see Facial Identification Scientific Working Group, 2011; Towler et al., 2019). But do these professional training courses actually improve the face matching accuracy of trainees? To address this question we evaluated the effectiveness of four representative professional training courses (Courses A-D in Figure 5) by testing novices and genuine trainees immediately before and after completing a training course (see Towler et al., 2019). We found strong evidence that short online courses and a half-day face-to-face course do not improve face matching accuracy (see also Woodhead, Baddeley, & Simmonds, 1979).

We also tested an intensive 3-day face-to-face course run by the Metropolitan Police in London. In this case, we found some evidence of improvement. Trainees improved by 6% on the standard lab-based Glasgow Face Matching Test, but not on a test designed to be representative of the police casework for which the training was designed. Further, we found no evidence that training produced qualitative markers of expertise in facial image comparison (see Towler et al., 2019). Therefore, evidence from evaluation tests indicates that professional training courses do not provide a satisfactory solution to improving face matching accuracy in practitioners.

Psychological approaches to training

Practitioners' attempts to develop effective training courses in face matching appear to have been largely unsuccessful. But have psychologists fared better? Psychologists have been investigating how to train face identification ability for many years, and in contrast to professional training – which is based on precedent, practical experience, and practitioners' intuition – have typically taken a theory-driven approach to training, based on scientific understanding of face processing and familiar face recognition (e.g., DeGutis, Bentin, Robertson, & D'Esposito, 2007; Powell, Letson, Davidoff, Valentine, & Greenwood, 2008; White, Kemp, Jenkins, & Burton, 2014). The short answer is no.

Improving familiar face recognition in prosopagnosia patients

Psychologists first became interested in face identification training as a means of treating patients with prosopagnosia (see Beyn & Knyazeva, 1962). Prosopagnosia is a condition characterised by a profound deficit in face recognition, which can leave patients unable to recognise their family, friends, colleagues, and sometimes even themselves (see Behrmann, Avidan, Thomas, & Humphreys, 2010). Some patients acquire prosopagnosia after suffering a brain injury (known as acquired prosopagnosia), whereas others simply fail to develop normal face processing skills despite otherwise normal perceptual, cognitive and neurological functioning (known as developmental or congenital prosopagnosia). Because of prosopagnosia's profound effects on patients' day-to-day social functioning and mental health (see Yardley, McDermott, Pisarski, Duchaine, & Nakayama, 2008), psychologists have sought to improve their ability to learn and recognise familiar faces, i.e. their 'normal' face recognition ability (see Bate & Bennetts, 2014; DeGutis, Chiu, Grosso, & Cohan, 2014 for reviews).

Remedial holistic processing training

One theory-driven approach to improving face recognition abilities of people with prosopagnosia is to remediate their normal holistic face processing mechanisms. Normal face processing is thought to rely on holistic processes, whereby faces are encoded as unified wholes

rather than as a collection of parts (see Tanaka & Farah, 1993; Young, Hellawell, & Hay, 1987). Similarly, familiar face recognition is thought to rely on stored identity representations that encode holistic properties of faces (see Bruce & Young, 1986). Because prosopagnosia patients have significant impairment in holistic face processing and difficulties building robust holistic face representations (see Avidan, Tanzer, & Behrmann, 2011; Bukach, Bub, Gauthier, & Tarr, 2006; Busigny, Joubert, Felican, Ceccaldi, & Rossion, 2010; Farah, Wilson, Drain, & Tanaka, 1998; Levine & Calvanio, 1989; Palermo, Rivolta, Wilson, & Jeffery, 2011; Ramon, Busigny, & Rossion, 2010), this approach is neatly aligned with theoretical understanding of normal cognitive functioning in face recognition.

Attempts to train holistic face processing in patients with acquired prosopagnosia have, however, been unsuccessful. In an early attempt, Ellis and Young (1988) aimed to improve face processing in 8-year old acquired prosopagnosia patient KD using four different training tasks, including simultaneous matching of familiar and unfamiliar faces with feedback, and learning face-name associations. After 18-months of daily training, KD showed no evidence of improvement on any of the four tasks.

More recently, DeGutis, Cohan, Kahn, Aguirre, and Nakayama (2013) used a procedure designed by DeGutis et al. (2007) to train 46-year old acquired prosopagnosia patient CC to integrate configural face information. CC categorised computer-generated faces as belonging to either category 1: faces with higher eyebrows and lower mouths, or category 2: faces with relatively lower eyebrows and higher mouths compared to category 1. DeGutis and colleagues reasoned that these categorisations would be slow and effortful at first, but that with practice, CC might learn to integrate the feature spacings simultaneously, increasing her sensitivity to the configuration of internal facial features – a skill thought to be critical to holistic processing (see Piepers & Robbins, 2012). CC showed some evidence of improvement on the categorisation task, but this did not generalise to novel faces – which is of course a critical requirement if the training is to be beneficial in helping patients learn to recognise new people.

Researchers have noted that it may not be possible to recover normal face recognition functioning in patients with acquired prosopagnosia because the neural mechanisms supporting face recognition have been irreversibly damaged (see DeGutis, Chiu, et al., 2014). Patients with developmental prosopagnosia however, have under-developed but intact neural mechanisms which may be more amenable to training.

With this in mind, DeGutis et al. (2007) attempted to improve holistic face processing in 48-year old developmental prosopagnosia patient MZ using the feature spacing categorisation procedure described above. At the start of training, MZ took nearly 13 seconds to categorise each face as belonging to category 1 or 2. After 4,000 trials of daily training over 1 week, and another 12,000 trials of daily training over 3 months, several months later, MZ's accuracy and reaction time on the feature spacing categorisation task were similar to 10 control participants. She also performed within the normal range on standardised tests of face recognition, including the Cambridge Face Memory Test (see Duchaine & Nakayama, 2006), and showed a greater N170 (a robust neural marker of brain responses) to faces than objects, which had not been the case prior to training. However, the longevity of these training effects is unclear. MZ reported that the improvements she experienced in day-to-day life disappeared one month after the first week of training, and while they re-emerged during the second training period it is not clear whether these improvements were longer lasting.

Other attempts to train holistic processing in developmental prosopagnosia patients have been less successful. DeGutis, Cohan, and Nakayama (2014) administered the feature spacing categorisation training to a group of 24 developmental prosopagnosia patients. They observed improvements to holistic face processing on front-view face perception tasks, but not on tasks that required face discrimination from different viewpoints. Dalrymple, Corrow, Yonas, and Duchaine (2012) also report an unsuccessful attempt by DeGutis and colleagues to train 12-year-old TM to discriminate between photographs of his mother and other women using feedback.

The evidence to date indicates that it may be possible to improve holistic processing in developmental prosopagnosia patients to some extent. However, these effects are inconsistent and do not necessarily produce reliable, lasting improvements that support face recognition. Further, given that positive results are more likely to be published compared to null results, it is possible that other unsuccessful training has been carried out but not published.

Feature-based compensatory strategy training

While prosopagnosia patients' normal face recognition system is impaired, there is evidence that featural face processing is spared in these patients. For example, patient KD was severely impaired at recognising faces, but was able to accurately discriminate between pairs of isolated facial features; when those features were embedded in the context of the whole face, she was no longer able to discriminate between them (Ellis & Young, 1988). This suggests that some people with prosopagnosia can access identity information contained in individual facial features, but that a disruption in the ability to view features in the context of a whole face interferes with this ability. Other research also suggests that this disruption can be overcome when performing unfamiliar face matching tasks, because people with both acquired (e.g., Benton & Van Allen, 1972) and developmental prosopagnosia (Duchaine & Nakayama, 2004; White, Rivolta, Burton, Al-Janabi, & Palermo, 2017) can achieve normal scores on standardised tests of unfamiliar face matching; consistent with the idea that unfamiliar face matching tasks can be performed using a piecemeal process of feature comparison (Megreya & Burton, 2006).

Because of this, some researchers have proposed an alternative approach to training prosopagnosia patients: teaching them to take advantage of the feature-based processing that appears to be left at their disposal. Indeed, many prosopagnosia patients report using compensatory strategies to recognise familiar people, such as relying on distinguishing facial features, blemishes, idiosyncratic face movements, voice, hairstyle, glasses, clothing, and jewellery (Adams, Hills, Bennetts, & Bate, 2019). Deliberate attempts to train these compensatory strategies may therefore provide an alternate means of improving face recognition accuracy. Unlike holistic processing training, compensatory strategy training can improve face recognition accuracy for patients with both acquired and developmental prosopagnosia.

In acquired prosopagnosia, training patients to pay attention to facial features (Beyn & Knyazeva, 1962), or to discriminate and describe the facial features of familiar people (Mayer & Rossion, 2007) led to reports of improved face recognition in day-to-day life. Powell et al. (2008) attempted to train acquired prosopagnosia patient WJ to learn faces using three different procedures: caricaturing (where faces were digitally caricatured to be more distinctive), semantic associations (e.g., "This is Anita the policewoman whose camera was stolen from a

fashion show yesterday.”), and feature-based descriptions (e.g., “This is Victoria. She has large eyes and freckles.”). Only feature-based descriptions produced an improvement on a subsequent recognition test, increasing accuracy from 70% to 95% after training. However, we note that WJ’s performance prior to training was quite high, indicating that perhaps he wasn’t overly impaired on this particular task to begin with.

In developmental prosopagnosia, Brunsdon, Coltheart, Nickels, and Joy (2006) taught 8-year old AL to recognise 17 familiar faces by memorising their age and gender, and 3 distinctive facial features for each person, such as eyebrow shape, wrinkles and face shape. They found improved recognition of new images of the familiar faces, and anecdotal reports of a reduction in AL’s tendency to misidentify unfamiliar people as family members, and confuse family members in daily life. Schmalzl, Palermo, Green, Brunsdon, and Coltheart (2008) used the same distinctive feature training for 4-year old K, and they also found improved recognition of new instances of the trained identities, and eye-movement patterns that were more similar to people with no face recognition deficits (i.e. focussed on internal rather than external features).

Feature-based compensatory strategies essentially bypass the core face recognition system, but nevertheless appear to be the most promising approach to training prosopagnosia patients. This is an intriguing finding in the context of the broader familiar face recognition literature, where performance is typically impaired when observers are forced to adopt a piecemeal feature-processing strategy (see Coin & Tiberghien, 1997; McKone & Yovel, 2009). It is therefore remarkable that this type of training allows prosopagnosia patients to reliably recognise familiar faces at all. Importantly, it points to the possibility that through training, we can learn to reliably recognise faces using processes *outside* the core face recognition system (see also Bruce & Young, 1986; Brunsdon et al., 2006).

This is an important insight that can potentially provide a route to professional training, and so we return to this in greater detail later. Importantly, however, training interventions for people with prosopagnosia have understandably focussed on improving their ability to recognise *familiar* faces, to facilitate their day-to-day functioning. In forensic settings, face identifications almost exclusively involve *unfamiliar* people, which is a qualitatively different cognitive task to familiar face recognition (Megreya & Burton, 2006). Familiar face recognition is based on *memory* and relies on activation of stored identity representations, whereas unfamiliar face identification relies on *pictorial matching* processes, where face images are simultaneously compared to determine if they show the same person or different people.

Improving unfamiliar face matching accuracy in the general population

A number of studies have aimed to improve unfamiliar face matching accuracy in the general population. This interest has not necessarily been fuelled by the applied importance of the task, as is the case for professional training, but rather because unfamiliar face matching poses an intriguing theoretical problem. We can recognise familiar faces almost perfectly, we easily learn and become familiar with new people, and any unfamiliar face has the potential to become familiar. Perfect unfamiliar face matching accuracy is therefore tantalisingly just out of reach; if we can make an unfamiliar face familiar, we can solve the problem of unfamiliar face matching. As a result, training to improve unfamiliar face matching has mostly focussed on recreating or emulating some of the processes involved in learning and recognising familiar faces.

Fast-tracking the creation of stable face representations

Familiar face recognition is thought to rely on stable face representations that are abstracted from multiple encounters with a face, and which allow us to recognise faces even in unusual views (e.g., a friend wearing a Halloween costume). If it is possible to fast-track the formation of these representations, at least partially, they should support face matching and improve accuracy. Consistent with this, learning an identity from multiple images leads to improved accuracy on both memory (Murphy, Ipser, Gaigg, & Cook, 2015) and matching tasks (Andrews, Jenkins, Cursiter, & Burton, 2015; Ritchie & Burton, 2016). Even just providing multiple images to compare to another image during a matching task improves accuracy (Dowsett, Sandford, & Burton, 2015; Matthews & Mondloch, 2018; Menon, White, & Kemp, 2015; White, Burton, Jenkins, & Kemp, 2014; but see Kramer & Reynolds, 2018; Ritchie, Mireku, & Kramer, 2019). The accuracy benefits associated with using multiple images of an identity tend to be around 10%.

However, as we might expect, the benefit of providing multiple images is identity-specific. Multiple images do not confer improvements that generalise to new, unfamiliar identities (Dowsett et al., 2015; Matthews & Mondloch, 2018). And so while it is possible to train people to identify a particular unfamiliar person more accurately via multiple images, this type of training has utility only for a limited set of applied cases, such as those where multiple images of the offender are available for comparison to the suspect. Providing multiple images does not lead to generalised improvements in a person's ability to identify new unfamiliar faces.

Collaborative decision-making

Because we tend to learn people's faces by interacting with them in a social context, some studies have attempted to recreate this aspect of familiarisation. Bruce, Henderson, Newman, and Burton (2001) asked pairs of participants to watch short videos of people, and discuss their faces as they watched the video. In a subsequent recognition test participants decided if the studied identities appeared in 8-person arrays. Participants who had discussed the faces with their partner were 10% more accurate than those who had watched the video alone.

Dowsett and Burton (2014) asked pairs of participants to complete a 1:1 face matching task by working together and discussing the images. They found that face matching decisions made in pairs were more accurate than those made individually (see also Jeckeln, Hahn, Noyes, Cavazos, & O'Toole, 2018). They also investigated whether this benefit would generalise to new unfamiliar identities which had not been discussed, and found that after working with a partner, the lower-ability person in the pair subsequently showed significant improvements when working alone on a face matching task that contained new unfamiliar identities.

Dowsett and Burton (2014) argued that the discussion must have revealed information that was useful during the paired face matching task, and which could also be usefully applied to future comparisons. They suggested that the discussion may have alerted the low-performer to the value of facial features they would have otherwise neglected, or taught them a more effective comparison strategy. It is unclear exactly what was learned during the discussions, but this study demonstrates that collaborative decision-making can improve the face matching accuracy of low-performers.

Feedback

In our day-to-day encounters with faces, we receive feedback about the accuracy of our identification decisions. When we greet a friend we recognise at a café we get immediate

feedback that we have correctly recognised them. We may also receive immediate feedback if we fail to recognise an acquaintance or mistake a stranger for someone we know. Errors of this kind are particularly unpleasant and damaging to interpersonal relationships, so we are likely to be sensitive to feedback to help us avoid such situations in the future. In professional settings, practitioners rarely receive feedback about the accuracy of their decisions. If they do, it tends to be the subjective opinion of a more senior practitioner or the verdict of a court case, often months or years after the initial identification decision was made. Feedback training may therefore improve unfamiliar face identification accuracy.

White, Kemp, Jenkins, and Burton (2014) gave participants trial-by-trial feedback on the Glasgow Face Matching Test, such as "You answered correctly: These images are of the same person". They found that accuracy increased by 10% over the course of the training, and that the benefits transferred to a subsequent test containing new identities, even though feedback was no longer provided. However, as was the case in Dowsett and Burton's (2014) paired decision-making study, the benefit of feedback training was specific to low-performing participants.

Further, feedback training does not always improve accuracy. Alenezi and Bindemann (2013) found that instead of improving accuracy, feedback served to merely maintain baseline performance, counteracting a decline in performance observed in participants who did not receive feedback. However, feedback in this study was provided after the images were removed, whereas feedback in White, Kemp, Jenkins, and Burton (2014) was delivered while the faces remained onscreen, which may have helped maximise its benefit.

Alenezi and Bindemann's (2013) finding that feedback prevented a decline in performance suggests that the benefits of feedback may be driven by attentional mechanisms rather than increased perceptual sensitivity to identity information in faces. However, this explanation does not hold true for White et al.'s (2014) study, where feedback training increased sensitivity to task-relevant information and did not change participants' response criterion (c.f., Papesh, Heisick, & Warner, 2018). Further research is necessary to resolve these mixed findings. Until then, the benefits of feedback training, and the mechanisms driving those benefits, remain unclear.

The training paradox

For face matching training to be useful in forensic settings, training benefits must generalise to previously unseen identities. A review of the literature on professional training, remedial and compensatory strategy interventions for prosopagnosia patients, and lab-based experiments on the general population reveals only *two* studies employing two different training approaches that have shown training effects which generalise to new unfamiliar faces (see Dowsett & Burton, 2014; White, Kemp, Jenkins, & Burton, 2014). Even so, these procedures only improve the accuracy of people who were initially poor at the task and have not been demonstrated to have consistent effects over repeated tests.

These underwhelming effects of face identification training might lead us to conclude that face identification *cannot be trained*. Indeed, some psychologists have recommended that training for unfamiliar face matching accuracy be abandoned in favour of recruiting 'super-recognisers', people who are naturally talented at face recognition, for facial image comparison

roles (e.g., see Bobak, Dowsett, & Bate, 2016; Noyes, Phillips, & O'Toole, 2017; Ramon, Bobak, & White, 2019; Robertson, Noyes, Dowsett, Jenkins, & Burton, 2016).

However, there is one specialist group of facial image comparison practitioners whose performance indicates that face matching ability *can* be trained. Facial examiners conduct slow, systematic analysis of facial features in order to reach face matching decisions, and this process can take up to several hours or days to complete. They are often referred challenging cases by less specialised practitioners, and can be called upon to provide expert identification evidence in court. While individual performance varies, as a group, facial examiners consistently outperform novices, sometimes by as much as 25% (see Phillips et al., 2018; Towler, White, & Kemp, 2017; White, Phillips, Hahn, Hill, & O'Toole, 2015; White, Towler, & Kemp this volume). This observation gives rise to the *training paradox*: how do facial examiners acquire their expertise, if not through training?

We have discussed potential alternative contributions to the superior performance of facial examiners in another chapter in this volume (White et al., this volume). There, we conclude that other factors, summarised below, cannot entirely account for examiners' superior performance. First, it is unlikely that examiners' expertise developed as a consequence of performing identification tasks in their daily work because length of employment does not predict face matching accuracy (White, Dunn, et al., 2015; White, Kemp, Jenkins, Matheson, et al., 2014; Wirth & Carbon, 2017). Second, motivation cannot explain examiners' expertise because they outperform other similarly motivated practitioner groups (Phillips et al., 2018; White, Phillips, et al., 2015). Finally, it is possible that facial examiners are naturally better at face matching, and that they simply choose the profession because they have a talent for it. However, this possibility is inconsistent with evidence that facial examiners perform face matching tasks in a *qualitatively* different manner to untrained participants.

For example, White, Phillips, et al. (2015) compared facial examiners to untrained student novices on a 1:1 face identification task. When given just two seconds to view the images there was no evidence of examiners' expertise – both groups performed equally well (see Figure 6). Critically however, when given 30 seconds to view the images examiners outperformed novices by nearly 10%. Examiners benefitted more from the additional time than students, indicating that their expertise lies in slow, careful analysis of faces.

Figure 6. Performance data from White, Phillips, et al. (2015) of untrained students and facial examiners performing a 1:1 face identification task after seeing the face images for 2 seconds vs. 30 seconds. Examiners' expertise is apparent when the images were visible for 30 seconds but not 2 seconds, indicating that their expertise lies in slow, careful analysis of faces.

In Towler, White, et al. (2017) we showed that the slow, systematic, feature-based comparison strategy used by facial examiners produces higher face matching accuracy than just making 'gut instinct' decisions. Importantly, facial examiners are experts at using this strategy. Not only do examiners outperform novices when using a feature-by-feature comparison strategy, but they extract more diagnostic identity information from facial features. We calculated the extent to which examiners' similarity ratings for each facial feature predicted the ground truth, and found that examiners' feature similarity ratings were far more diagnostic of identity than those of novices (Cohen's $d = 1.44$; see Towler, White, et al., 2017). Underlying examiners' expertise is therefore an enhanced ability to extract identity information from facial features.

Comparison between examiners and super-recognisers provides further evidence that examiners' expertise is acquired through training and not just a consequence of naturally occurring superior performance. Super-recognisers are born with natural expertise in face identification, and because they show quantitative differences to novices, they are thought to represent the very top end of the normal distribution of face recognition ability rather than a distinct group (see Noyes et al., 2017). Super-recognisers experience larger face inversion effects than novices (Bennetts, Mole, & Bate, 2017; Bobak, Bennetts, Parris, Jansari, & Bate, 2016; Russell, Duchaine, & Nakayama, 2009), whereas facial examiners experience smaller or no inversion effects compared to novices (Towler, White, et al., 2017; White, Phillips, et al., 2015). Inversion is thought to disrupt normal holistic face recognition processes, leaving observers to rely on piecemeal, feature-based processes (see McKone & Yovel, 2009; Rossion, 2008; Yin, 1969). The finding that examiners' performance is resistant to inversion therefore suggests that, unlike super-recognisers, their expertise does not rely on normal face recognition processes, but instead relies on piecemeal feature-based processes.

Examiners achieve very high levels of accuracy using a different strategy to novices and super-recognisers. These findings provide strong evidence that it is possible to learn skills that improve face matching ability, indicating that this ability can be trained. However, these findings also reinforce the training paradox. Examiners are experts at identifying faces because of their reliance on slow, systematic facial feature comparison. Professional training courses encourage practitioners to use a feature-by-feature comparison strategy, and yet, the evidence indicates that professional training courses do not work (see Towler et al., 2019). How then, do examiners learn their skills?

In Towler et al. (2019), we argued that examiners probably learn their skills through extensive on-the-job practice and mentoring from other examiners, and this is certainly consistent with anecdotal reports by examiners. For example, it may not be enough to simply tell trainees to conduct feature-by-feature comparison, as is typical in professional training courses (see Towler et al., 2019). Inhibiting natural holistic face processing in favour of piecemeal analysis of facial features would likely require extensive practice. Further, working alongside another examiner, learning about the strategies they use and receiving their feedback (e.g., “Yes, the noses do look similar, but notice the subtle differences in nostril shape”) could help refine examiners’ ability to search for and extract useful identity information from facial features.

Evidence for learning via this kind of mechanism comes from the Metropolitan Police’s 3-day professional training course we evaluated in Towler et al. (2019). This is the only training course we tested which showed any evidence of improving matching accuracy. Unlike the other courses, a considerable proportion of this course involved group discussion of facial features which may have conferred some small immediate benefit. Further, on-the-job training may serve as a more elaborate and information-rich version of the paired decision-making task (Dowsett & Burton, 2014) and feedback training (Alenezi & Bindemann, 2013; White, Kemp, Jenkins, & Burton, 2014) reported in the psychology literature as providing some benefit. Further research is necessary to understand exactly how examiners acquire their feature-based expertise on-the-job but, for now, it appears that they develop their expertise through professional training.

Two routes to face identification expertise

On the basis of the evidence reviewed above, it appears that facial examiners derive at least part of their expertise in facial image comparison through extensive on-the-job training in feature comparison. This is in contrast to unsuccessful attempts to train face recognition through perceptual tasks that involve holistic perceptual processing. For instance, there is almost no evidence that remedial holistic training for prosopagnosia patients can rehabilitate normal face recognition functioning (see Bate & Bennetts, 2014; DeGutis, Chiu, et al., 2014). Similarly, the evidence for improving face matching ability in the general population using procedures inspired by the processes supporting familiar face recognition have had limited success in producing generalised improvements in accuracy (see Bate & Bennetts, 2014; DeGutis, Chiu, et al., 2014). These findings indicate that the core face recognition system – responsible for recognising faces in daily life – is not amenable to training. This conclusion is consistent with evidence that our face recognition abilities are largely predetermined by genetics (Shakeshaft & Plomin, 2015; Wilmer et al., 2010), and that performance in

challenging face memory tasks reaches asymptote in adulthood (Germine, Duchaine, & Nakayama, 2011).

In contrast, training methods that promote feature-based strategies have had much more success. The most promising approach for training prosopagnosia patients to recognise familiar faces is to teach them compensatory strategies, such as relying on distinctive facial features, voice and hairstyle (Brunsdon et al., 2006; Schmalzl et al., 2008). It also seems that the most reliable way to improve face matching accuracy in the general population is to adopt the feature-based comparison strategy used by facial examiners (Towler, White, et al., 2017).

To account for these findings, we propose that there are *two routes to expertise in face identification*. One route is the core face recognition system that supports familiar face recognition by matching visual input to stored holistic face representations. Our skill at employing this route appears to be acquired through normal development, and resistant to training. The other route is feature-based and draws on piecemeal, feature-by-feature matching processes that bypass the core face recognition system and is better suited to unfamiliar face matching tasks. Importantly, the feature-based mechanisms driving performance in this route appear to be trainable.

We are not the first to argue that there are two separable routes involved in face identification. In her seminal work explaining patterns of co-occurrence in associative agnosias, Farah (1991) argued that face, word and object recognition rely on two levels of perceptual processing: one where ‘complex parts’ are recognised as a single unified object, and another where ‘numerous parts’ are decomposed further into multiple elementary parts. Further, Bartlett, Searcy, and Abdi (2003) conducted a thorough literature review and concluded that face recognition involves two distinct but complementary routes: a fast, holistic processing route and a slow, feature-based processing route.

Bruce and Young’s (1986) functional model of face recognition also distinguishes between two separable routes involved in face identification. The ‘core’ face recognition system, built to recognise familiar faces, proceeds along the right-hand route highlighted in blue in Figure 7. The structural properties of the face are encoded, these in turn activate face recognition units (cognitive face representations) which allow us to recognise familiar faces quickly and with almost perfect accuracy. However, the model also describes ‘directed visual processing’, the left-hand route highlighted in red in Figure 7, which allows us to selectively and strategically attend to aspects of the face in order to encode particular information (e.g., to carefully search for distinctive features in order to remember someone’s face in the future). Bruce and Young (1986) suggested that this type of processing may play a particularly important role in unfamiliar face matching. In support of this, Megreya and Burton (2006) demonstrated that familiar face recognition and unfamiliar face matching recruit qualitatively different cognitive mechanisms. Unlike familiar faces, unfamiliar faces are matched more like objects than faces, recruiting piecemeal, feature-based processing.

Figure 7. Bruce and Young's (1986) functional model of face recognition. The two routes to face identification are overlaid – the blue right-hand route is the core face recognition system that allows us to recognise familiar faces, the red left-hand route is a feature-based alternative that permits reliable face matching decisions in facial examiners, and familiar face recognition in prosopagnosia patients.

While there has been compelling evidence for two routes to face identification for some time now, featural face processing has historically been associated with poorer performance compared to holistic face processing (e.g., see Tanaka & Farah, 1993; Yin, 1969). This probably reflects the fact that research has paid much more attention to face *recognition* memory than to perceptual matching tasks. As it turns out, this route can be especially useful in face matching tasks. It appears that facial examiners are able to achieve very high levels of performance by deliberately employing a feature-by-feature comparison strategy and directing their attention to specific facial features in order to detect and analyse similarities and differences between faces (Phillips et al., 2018; Towler, White, et al., 2017; White, Phillips, et al., 2015). This feature-based face processing strategy does not align with the holistic processes we typically think of as ‘normal’ face recognition, and yet, they use this strategy to achieve very high levels of accuracy in face matching tasks. We therefore argue that both routes can lead to expert-level face identification performance.

Acquiring expertise in each route appears to require quite different experiences. Expertise in the core face recognition route likely develops naturally as a consequence of needing to recognise familiar faces in our daily lives. Because of this, most of us would already be considered experts in this route (see Young & Burton, 2018), the exception of course being prosopagnosia patients. Interestingly, super-recognisers appear to be ‘super-experts’ at using this route because they seem to use it for unfamiliar face identification tasks, not just familiar face recognition. Their unfamiliar face identification performance mirrors many of the characteristics of familiar face recognition – quick, automatic, and highly accurate. This may

indicate that super-recognisers are particularly skilled at extracting stable perceptual representations, which benefit accuracy in both memory and matching tasks.

Unlike expertise in the core face recognition route, which appears to develop naturally, acquiring expertise in the feature-based route appears to require deliberate effort. Prior to the invention of photography some 200 years ago, unfamiliar face matching was not performed *at all*. Unfamiliar face matching only exists because of our modern-day customs of identifying unfamiliar people from photo-ID and CCTV footage. Even so, only a very small proportion of the population regularly undertake this task. It is therefore unsurprising that our cognitive and perceptual systems have not developed the necessary feature-based adaptations that are required to perform unfamiliar face matching tasks accurately. Developing expertise in this feature-based route is likely to involve significant cognitive effort, not only to fine-tune the skill itself, but also to learn to override automatic holistic face processing strategies.

We propose that each route is recruited to varying extents for familiar face recognition and unfamiliar face matching tasks, and depending on the person making the identification decision. For example, while the core face recognition route is best suited for recognising familiar faces, this system is not necessarily an option for prosopagnosia patients, so they are able to switch to the feature-based route to use compensatory strategies to recognise familiar faces with reasonable success. Similarly, facial examiners report forming an intuitive initial impression of a facial comparison, but then deliberately switch to engaging a slower, feature-by-feature comparison strategy in order to reach their final identification decision.

Without some level of awareness of the most useful strategies for the particular face identification task at hand, people are likely to recruit these two routes in suboptimal ways. For example, a novice may attempt to make an unfamiliar face matching decision by garnering a holistic overall impression of each face, rather than taking a feature-by-feature approach. To illustrate why the holistic approach can lead to inaccurate decisions, consider the faces in Figure 8. Do they show the same person or different people? At first glance, the faces appear very dissimilar suggesting that they are two different people. However, upon closer inspection of the facial features – particularly the ears, eyelids, freckle to the left of the mouth, and the sideburn-cheek contours – we can see striking similarities that point to the correct answer, that the photos are of the same person. Relying on an initial holistic impression of the faces would mean that informative cues to identity such as these would be missed. Recruiting the core face recognition system for an unfamiliar face matching task, rather than the feature-based route, could therefore contribute to poor performance on unfamiliar face matching tasks (see Towler, White, et al., 2017). Training people to use the feature-based route for unfamiliar face matching tasks, rather than the core face recognition system, may help boost face matching accuracy.

Figure 8. Do these faces show the same person or different people? Your initial impression may be that these faces look very different and thus show different people. Upon closer inspection of the facial features however – particularly the ears, eyelids, freckle to the left of the mouth, and the sideburn-cheek contours – we see striking similarities that indicate these photos are actually of the same person, which is the correct answer.

Conclusion

We have argued that there are two routes to expertise in face identification. One route is our core face recognition system, which is built to recognise familiar faces using quick, intuitive, holistic judgements. The second route is feature-based, and suited to performing unfamiliar face matching tasks using a slow, feature-by-feature comparison strategy. Importantly, it appears that only the feature-based route can be trained. Expertise in the core face recognition system is largely resistant to training.

Training to improve unfamiliar face matching ability in facial image comparison practitioners should therefore focus on improving their ability to extract identity information from facial features, rather than attempt to train the processes that support familiar face recognition. For now, it seems the only way to train this feature-based route is to undergo the extensive on-the-job training experienced by facial examiners. However, this type of training is extremely time and resource intensive. We therefore encourage practitioners and academics to work together to identify efficient evidence-based training methods to replace current training practices.

References

- Adams, A., Hills, P. J., Bennetts, R. J., & Bate, S. (2019). Coping strategies for developmental prosopagnosia. *Neuropsychological Rehabilitation*, 1-20. doi:10.1080/09602011.2019.1623824
- Alenezi, H. M., & Bindemann, M. (2013). The effect of feedback on face-matching accuracy. *Applied Cognitive Psychology*, 27(6), 735-753. doi:10.1002/acp.2968
- Andrews, S., Jenkins, R., Cursiter, H., & Burton, A. M. (2015). Telling faces together: Learning new faces through exposure to multiple instances. *The Quarterly Journal of Experimental Psychology*. doi:10.1080/17470218.2014.1003949
- Avidan, G., Tanzer, M., & Behrmann, M. (2011). Impaired holistic processing in congenital prosopagnosia. *Neuropsychologica*, 49(9), 2541-2552. doi:10.1016/j.neuropsychologia.2011.05.002
- Bartlett, J. C., Searcy, J. H., & Abdi, H. (2003). What are the routes to face recognition? In M. Peterson & G. Rhodes (Eds.), *Perception of faces, objects, and scenes: Analytic and holistic processes* (pp. 21-52). Oxford: Oxford University Press.
- Bate, S., & Bennetts, R. J. (2014). The rehabilitation of face recognition impairments: A critical review and future directions. *Frontiers in Human Neuroscience*, 8, 1-30. doi:10.3389/fnhum.2014.00491
- Behrmann, M., Avidan, G., Thomas, C., & Humphreys, K. (2010). Congenital and acquired prosopagnosia: Flip sides of the same coin? In I. Gauthier, M. Tarr, & D. Bub (Eds.), *Perceptual expertise: Bridging brain and behavior*: Oxford Scholarship Online.
- Bennetts, R. J., Mole, J., & Bate, S. (2017). Super-recognition in development: A case study of an adolescent with extraordinary face recognition skills. *Cognitive Neuropsychology*, 34(6), 357-376. doi:10.1080/02643294.2017.1402755
- Benton, A. L., & Van Allen, M. W. (1972). Prosopagnosia and facial discrimination. *Journal of the Neurological Sciences*, 15(2), 167-172. doi:10.1016/0022-510X(72)90004-4
- Bertillon, A. (1896). *The Bertillon System of Identification*: The Werner company.
- Beyn, E. S., & Knyazeva, G. R. (1962). The problem of prosopagnosia. *Journal of Neurology, Neurosurgery, and Psychiatry*, 25, 154-158. doi:10.1136/jnnp.25.2.154
- Bobak, A. K., Bennetts, R. J., Parris, B. A., Jansari, A., & Bate, S. (2016). An in-depth cognitive examination of individuals with superior face recognition skills. *Cortex*, 82, 48-62. doi:10.1016/j.cortex.2016.05.003
- Bobak, A. K., Dowsett, A. J., & Bate, S. (2016). Solving the border control problem: Evidence of enhanced face matching in individuals with extraordinary face recognition skills. *PLoS ONE*, 11(2), 1-13. doi:10.1371/journal.pone.0148148
- Bruce, V., Henderson, Z., Newman, C., & Burton, A. M. (2001). Matching identities of familiar and unfamiliar faces caught on CCTV images. *Journal of Experimental Psychology: Applied*, 7(3), 207-218.
- Bruce, V., & Young, A. W. (1986). Understanding face recognition. *British Journal of Psychology*, 77(3), 305-327. doi:10.1111/j.2044-8295.1986.tb02199.x
- Brunsdon, R., Coltheart, M., Nickels, L., & Joy, P. (2006). Developmental prosopagnosia: A case analysis and treatment study. *Cognitive Neuropsychology*, 23(6), 822-840. doi:10.1080/02643290500441841
- Bukach, C. M., Bub, D. N., Gauthier, I., & Tarr, M. J. (2006). Perceptual expertise effects are not all or none: Spatially limited perceptual expertise for faces in a case of prosopagnosia. *Journal of Cognitive Neuroscience*, 18(1), 48-63. doi:10.1162/089892906775250094

- Busigny, T., Joubert, S., Felican, O., Ceccaldi, M., & Rossion, B. (2010). Holistic perception of the individual face is specific and necessary: Evidence from an extensive case study of acquired prosopagnosia. *Neuropsychologia*, 48(14), 4057-4092. doi:10.1016/j.neuropsychologia.2010.09.017
- Coin, C., & Tiberghien, G. (1997). Encoding activity and face recognition. *Memory*, 5(5), 545-568. doi:10.1080/741941479
- Dalrymple, K. A., Corrow, S., Yonas, A., & Duchaine, B. (2012). Developmental prosopagnosia in childhood. *Cognitive Neuropsychology*, 29(0), 393-418. doi:10.1080/02643294.2012.722547
- DeGutis, J. M., Bentin, S., Robertson, L. C., & D'Esposito, M. (2007). Functional plasticity in ventral temporal cortex following cognitive rehabilitation of a congenital prosopagnosic. *Journal of Cognitive Neuroscience*, 19(11), 1790-1802. doi:10.1162/jocn.2007.19.11.1790
- DeGutis, J. M., Chiu, C., Grosso, M. E., & Cohan, S. (2014). Face processing improvements in prosopagnosia: Successes and failures over the last 50 years. *Frontiers in Human Neuroscience*, 8. doi:10.3389/fnhum.2014.00561
- DeGutis, J. M., Cohan, S., Kahn, D., Aguirre, G., & Nakayama, K. (2013). Facial expression training improves emotion recognition and changes in neural tuning in a patient with acquired emotion recognition deficits and prosopagnosia. *Journal of Vision*, 13, 993. doi:10.1167/13.9.993
- DeGutis, J. M., Cohan, S., & Nakayama, K. (2014). Holistic face training enhances face processing in developmental prosopagnosia. *Brain*, 137(6), 1781-1798. doi:10.1093/brain/awu062
- Dowsett, A. J., & Burton, A. M. (2014). Unfamiliar face matching: Pairs out-perform individuals and provide a route to training. *British Journal of Psychology*, 106(3), 433-445. doi:10.1111/bjop.12103
- Dowsett, A. J., Sandford, A., & Burton, A. M. (2015). Face learning with multiple images leads to fast acquisition of familiarity for specific individuals. *The Quarterly Journal of Experimental Psychology*, 69(1). doi:10.1080/17470218.2015.1017513
- Drost, M. (2016). The unique method for face recognition of the Stasis. *Volkskrant*.
- Duchaine, B. C., & Nakayama, K. (2004). Developmental prosopagnosia and the Benton Facial Recognition Test. *Neurology*, 62(7), 1219-1220. doi:10.1212/01.wnl.0000118297.03161.b3
- Duchaine, B. C., & Nakayama, K. (2006). The Cambridge Face Memory Test: Results for neurologically intact individuals and an investigation of its validity using inverted face stimuli and prosopagnosic participants. *Neuropsychologia*, 44(4), 576-585. doi:10.1016/j.neuropsychologia.2005.07.001
- Ellis, H. D., & Young, A. W. (1988). Training in face-processing skills for a child with acquired prosopagnosia. *Developmental Neuropsychology*, 4(1), 283-294. doi:10.1080/87565648809540412
- Facial Identification Scientific Working Group. (2011). Guidelines and recommendations for facial comparison training to competency (Version 1.1). Retrieved from https://fiswg.org/FISWG_Training_Guidelines_Recommendations_v1.1_2010_11_18.pdf
- Farah, M. J. (1991). Patterns of co-occurrence among the associative agnosias: Implications for visual object representation. *Cognitive Neuropsychology*, 8(1), 1-19. doi:10.1080/02643299108253364
- Farah, M. J., Wilson, K. D., Drain, M., & Tanaka, J. W. (1998). What is "special" about face perception? *Psychological Review*, 105(3), 482-498. doi:10.1037/0033-295x.105.3.482

- Germine, L. T., Duchaine, B., & Nakayama, K. (2011). Where cognitive development and aging meet: face learning ability peaks after age 30. *Cognition*, 118(2), 201-210. doi:10.1016/j.cognition.2010.11.002
- Grother, P., & Ngan, M. (2014). *Face Recognition Vendor Test (FRVT)*. Retrieved from Information Access Division, National Institute of Standards and Technology
- Grother, P., Ngan, M., & Hanaoka, K. (2018). Ongoing Face Recognition Vendor Test (FRVT) Part 1: Verification. *National Institute of Standards and Technology*.
- Grother, P., Ngan, M., & Hanaoka, K. (2019). Ongoing Face Recognition Vendor Test (FRVT) Part 1: Verification. *National Institute of Standards and Technology*.
- Jeckeln, G., Hahn, C. A., Noyes, E., Cavazos, J. G., & O'Toole, A. J. (2018). Wisdom of the social versus non-social crowd in face identification. *British Journal of Psychology*, 109(4), 724-735. doi:10.1111/bjop.12291
- Kramer, R. S. S., & Reynolds, M. G. (2018). Unfamiliar face matching with frontal and profile views. *Perception*, 47(4), 1-18. doi:10.1177/0301006618756809
- Levine, D. N., & Calvanio, R. (1989). Prosopagnosia: A defect in visual configural processing. *Brain and Cognition*, 10(2), 149-170. doi:10.1016/0278-2626(89)90051-1
- Matthews, C. M., & Mondloch, C. J. (2018). Finding an unfamiliar face in a line-up: Viewing multiple images of the target is beneficial on target-present trials but costly on target-absent trials. *British Journal of Psychology*, 109(4), 1-18. doi:10.1111/bjop.12301
- Mayer, E., & Rossion, B. (2007). Prosopagnosia. In J. Bogousslavsky & O. Godefroy (Eds.), *The Behavioral and Cognitive Neurology of Stroke* (pp. 315-334). Cambridge: Cambridge University Press.
- McKone, E., & Yovel, G. (2009). Why does picture-plane inversion sometimes dissociate perception of features and spacing in faces, and sometimes not? Toward a new theory of holistic processing. *Psychonomic Bulletin and Review*, 16(5), 778-797. doi:10.3758/PBR.16.5.778
- Megreya, A. M., & Burton, A. M. (2006). Unfamiliar faces are not faces: Evidence from a matching task. *Memory and Cognition*, 34(4), 865-876. doi:10.3758/bf03193433
- Menon, N., White, D., & Kemp, R. I. (2015). Variation in photos of the same face drives improvements in identity verification. *Perception*, 44(11), 1332-1341. doi:10.1177/0301006615599902
- Murphy, J., Ipser, A., Gaigg, S., & Cook, R. (2015). Exemplar variance supports robust learning of facial identity. *Journal of Experimental Psychology: Human Perception and Performance*, 41(3), 577-584. doi:10.1037/xhp0000049
- National Research Council. (2009). Strengthening forensic science in the United States: A path forward.
- Noyes, E., Phillips, P. J., & O'Toole, A. J. (2017). What is a super-recogniser? In M. Bindemann & A. M. Megreya (Eds.), *Face Processing: Systems, Disorders and Cultural Differences*: Nova Science.
- Palermo, R., Riolta, D., Wilson, C. E., & Jeffery, L. (2011). Adaptive face space coding in congenital prosopagnosia: Typical figural aftereffects but abnormal identity aftereffects. *Neuropsychologia*, 49(14), 3801-3812. doi:10.1016/j.neuropsychologia.2011.09.039
- Papesh, M. H., Heisick, L. L., & Warner, K. A. (2018). The persistent low-prevalence effect in unfamiliar face-matching: The roles of feedback and criterion shifting. *Journal of Experimental Psychology: Applied*, 24(3), 416-430. doi:10.1037/xap0000156
- PCAST. (2016). Forensic science in criminal courts: Ensuring scientific validity of feature-comparison methods.
- Phillips, P. J., Yates, A. N., Hu, Y., Hahn, C. A., Noyes, E., Jackson, K., . . . O'Toole, A. J. (2018). Face recognition accuracy in forensic examiners, super-recognisers and

- algorithms. *Proceedings of the National Academy of Sciences*, 115(24). doi:10.1073/pnas.1721355115
- Piazza, P. (2016). Alphonse Bertillon and the identification of persons (1880-1914). *Suspects, Defendants, Gilty*. Retrieved from <https://criminocorpus.org/en/exhibitions/suspects-defendants-guilty/alphonse-bertillon-and-identification-persons-1880-1914/>
- Piepers, D. W., & Robbins, R. A. (2012). A review and clarification of the terms "holistic," "configural," and "relational" in the face perception literature. *Frontiers in Psychology*, 3, 1-11. doi:10.3389/fpsyg.2012.00559
- Powell, J., Letson, S., Davidoff, J., Valentine, T., & Greenwood, R. (2008). Enhancement of face recognition learning in patients with brain injury using three cognitive training procedures. *Neuropsychological Rehabilitation*, 18(2), 182-203. doi:10.1080/09602010701419485
- Ramon, M., Bobak, A. K., & White, D. (2019). Super-recognizers: From the lab to the world and back again. *British Journal of Psychology*, 110(3), 461-479. doi:10.1111/bjop.12368
- Ramon, M., Busigny, T., & Rossion, B. (2010). Impaired holistic processing of unfamiliar individual faces in acquired prosopagnosia. *Neuropsychologia*, 48(4), 933-944. doi:10.1016/j.neuropsychologia.2009.11.014
- Ritchie, K. L., & Burton, A. M. (2016). Learning faces from variability. *The Quarterly Journal of Experimental Psychology*, 70(5), 1-9. doi:10.1080/17470218.2015.1136656
- Ritchie, K. L., Mireku, M. O., & Kramer, R. S. S. (2019). Face averages and multiple images in a live matching task. *British Journal of Psychology*, 1-11. doi:10.1111/bjop.12388
- Robertson, D. J., Noyes, E., Dowsett, A. J., Jenkins, R., & Burton, A. M. (2016). Face recognition by metropolitan police super-recognisers. *PLoS ONE*, 11(2). doi:10.1371/journal.pone.0150036
- Rossion, B. (2008). Picture-plane inversion leads to qualitative changes of face perception. *Acta Psychologica*, 128(2), 274-289. doi:10.1016/j.actpsy.2008.02.003
- Russell, R., Duchaine, B., & Nakayama, K. (2009). Super-recognizers: People with extraordinary face recognition ability. *Psychonomic Bulletin and Review*, 16(2), 252-257. doi:10.3758/PBR.16.2.252
- Schmalzl, L., Palermo, R., Green, M., Brunsdon, R., & Coltheart, M. (2008). Training of familiar face recognition and visual scan paths for faces in a child with congenital prosopagnosia. *Cognitive Neuropsychology*, 25(5), 704-729. doi:10.1080/02643290802299350
- Shakeshaft, N. G., & Plomin, R. (2015). Genetic specificity of face recognition. *Proceedings of the National Academy of Sciences*, 112(41), 12887-12892. doi:10.1073/pnas.1421881112
- Tanaka, J. W., & Farah, M. J. (1993). Parts and wholes in face recognition. *The Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, 46(2), 225-245. doi:10.1080/14640749308401045
- Towler, A., Kemp, R. I., Burton, A. M., Dunn, J. D., Wayne, T., Moreton, R., & White, D. (2019). Do professional facial image comparison training courses work? *PLoS ONE*, 14(2), e0211037. doi:10.1371/journal.pone.0211037
- Towler, A., Kemp, R. I., & White, D. (2017). Unfamiliar face matching systems in applied settings. In M. Bindemann & A. M. Megreya (Eds.), *Face Processing: Systems, disorders and cultural differences*. New York: Nova Science Publishers Inc.
- Towler, A., White, D., & Kemp, R. I. (2014). Evaluating training methods for facial image comparison: The face shape strategy does not work. *Perception*, 43, 214-218. doi:10.1068/p7676

- Towler, A., White, D., & Kemp, R. I. (2017). Evaluating the feature comparison strategy for forensic face identification. *Journal of Experimental Psychology: Applied*, 23(1), 47-58. doi:10.1037/xap0000108
- U.S. National Library of Medicine. (2014). The Bertillon system. *Visible proofs: Forensic views of the body*. Retrieved from <https://www.nlm.nih.gov/exhibition/visibleproofs/galleries/technologies/bertillon.html>
- White, D., Burton, A. M., Jenkins, R., & Kemp, R. I. (2014). Redesigning photo-ID to improve unfamiliar face matching performance. *Journal of Experimental Psychology: Applied*, 20(2), 166-173. doi:10.1037/xap0000009
- White, D., Dunn, J. D., Schmid, A. C., & Kemp, R. I. (2015). Error rates in users of automatic face recognition software. *PLoS ONE*, 10(10), 1-14. doi:10.1371/journal.pone.0139827
- White, D., Kemp, R. I., Jenkins, R., & Burton, A. M. (2014). Feedback training for facial image comparison. *Psychonomic Bulletin and Review*, 21(1), 100-106. doi:10.3758/s13423-013-0475-3
- White, D., Kemp, R. I., Jenkins, R., Matheson, M., & Burton, A. M. (2014). Passport officers' errors in face matching. *PLoS ONE*, 9(8), 1-6. doi:10.1371/journal.pone.0103510
- White, D., Phillips, P. J., Hahn, C. A., Hill, M., & O'Toole, A. J. (2015). Perceptual expertise in forensic facial image comparison. *Proceedings of the Royal Society of London B: Biological Sciences*, 282, 1814-1822. doi:10.1098/rspb.2015.1292
- White, D., Rivolta, D., Burton, A. M., Al-Janabi, S., & Palermo, R. (2017). Face matching impairment in developmental prosopagnosia. *The Quarterly Journal of Experimental Psychology*, 70(2), 287-297. doi:10.1080/17470218.2016.1173076
- White, D., Towler, A., & Kemp, R. I. (this volume). Understanding professional expertise in unfamiliar face matching. In M. Bindemann (Ed.), *Forensic face matching: Research and practice*: Oxford University Press.
- Wilmer, J. B., Germine, L., Chabris, C. F., Chatterjee, G., Williams, M., Loken, E., . . . Duchaine, B. (2010). Human face recognition ability is specific and highly heritable. *Proceedings of the National Academy of Sciences*, 107(11), 5238-5241. doi:10.1073/pnas.0913053107
- Wirth, B. E., & Carbon, C. C. (2017). An easy game for frauds? Effects of professional experience and time pressure on passport-matching performance. *Journal of Experimental Psychology: Applied*, 23(2), 138-157. doi:10.1037/xap0000114
- Woodhead, M. M., Baddeley, A. D., & Simmonds, D. C. V. (1979). On training people to recognize faces. *Ergonomics*, 22(3), 333-343. doi:10.1080/00140137908924617
- Yardley, L., McDermott, L., Pisarski, S., Duchaine, B., & Nakayama, K. (2008). Psychosocial consequences of developmental prosopagnosia: A problem of recognition. *Journal of Psychosomatic Research*, 65(5), 445-451. doi:10.1016/j.jpsychores.2008.03.013
- Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology*, 81(1), 141-145. doi:10.1037/h0027474
- Young, A. W., & Burton, A. M. (2018). Are we face experts? *Trends in Cognitive Sciences*, 22(2), 100-110. doi:10.1016/j.tics.2017.11.007
- Young, A. W., Hellawell, D. J., & Hay, D. C. (1987). Configurational information in face perception. *Perception*, 16(6), 747-759. doi:10.1068/p160747