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Individual differences and the multidimensional nature of face perception

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ABSTRACT

Face perception is critical to social interactions, yet people vary in how easily they can recognise their friends, verify an identification document, or notice someone's smile. There are widespread differences in people's abilities to recognise faces and research has particularly focused on exceptionally good or poor recognition performance. In this Review, we synthesise literature on individual differences in face processing across different tasks including identification and estimates of emotional state and social attributes. The individual differences approach has considerable untapped potential for theoretical progress in understanding the perceptual and cognitive organisation of face processing. This approach also has practical consequences — for example, in determining who is best suited to check passports. We also discuss the underlying structural and anatomical predictors of face perception ability. Furthermore, we highlight problems of measurement that pose challenges for the effective study of individual differences. Finally, we note that research in individual differences rarely addresses perception of familiar faces. Despite people's everyday experience of being 'good' or 'bad' with faces, a theory of how people recognise their friends remains elusive.

[H1] Introduction

Faces provide many types of information. Using faces, people can recognise others they know and also quite accurately estimate the age, gender or health of strangers and friends. Faces can also be used to judge transient states, for example someone's mood, focus of attention, or speech patterns. The multiple sources of information available in a face are critical for social behaviour, enabling people to identify someone as family, friend or colleague, and to decide whether they should speak to, hug, or stay away from them. These decisions are made quickly and easily, often without reflection. However, these remarkable abilities in face processing are not distributed equally across people.

Widespread differences in face perception between individuals have become an important research focus for three reasons. First, everyday experience suggests that some people are better at face perception than others, and some people have strong beliefs about whether they are 'good with faces'. Second, given the wide variety of information available in a face, much theoretical work focuses on whether the processes underlying different perceptual decisions are independent1[1]. Individual differences techniques are well-suited to addressing these questions in both face processing[2,3], and other areas of cognition research[4,5]. Third, face processing research has a good track record of using converging evidence to build theory[6–8]. Individual differences methodology can be recruited alongside evidence from experimental psychology, neuroscience, neuropsychology and computational modelling to make significant progress in the field.

Research on individual differences in face processing has tended to focus on identity processing. Tests have been designed that measure performance on a relatively small, narrowly defined set of tasks, which often do not capture the richness of daily life. Nevertheless, differences in performance reveal a multidimensional face processing system and its links to broader perceptual and cognitive processes.

In this Review, we explore why some people are better at certain face tasks than others, and whether this variation helps to uncover the fundamental processes involved. We summarise the approaches to measuring individual differences and the instruments developed across the broad range of face perception tasks. We then consider the notion of 'holistic' processing — the tendency for faces to be perceived as unitary objects rather than as a collection of parts[9] — and describe how studies of individual differences inform the representational codes supporting face perception. We highlight the differences between perceiving familiar and unfamiliar faces, and point out the relative dearth of individual differences studies of familiar face processing. Finally, we review the practical issues that emerge for face processing in professional settings. Overall, we provide a snapshot of an approach that contributes to our understanding of face perception and offers opportunities for insights that complement converging evidence in the field.

Throughout the Review, we use the term 'face recognition' to denote the process by which someone is identified from their face. Recognition of identity is just one component of 'face perception', a term that covers face processing for multiple purposes, including decisions about somebody's expression, age, or attractiveness, as well as their identity. We use the term 'face processing' to refer to any of the perceptual, cognitive or neural processes underpinning face perception for any purpose. Finally, person perception refers to the processing of perceptual information across a whole person including, for example, someone's voice or gait.

[H1] Converging research on face perception

Whereas the majority of individual differences research focuses on face recognition[10], there is also individual variation in other aspects of face perception[11,12]. Knowing how these different abilities co-vary in the population can help reveal the structural and processing constraints that shape the face processing system.

The traditional research emphasis in face perception has been on performance in clinical populations or group-level analysis of average measures, in particular to detect transient changes induced by experimental manipulation. By contrast, a focus on the natural variation between people's face processing abilities represents a fundamental shift in research focus. Although individual differences research presents challenges for measuring natural variation, it also adds novel tools. As in other areas of psychology, a single face perception study rarely fully resolves an issue through a conclusive experiment or simulation. Instead, converging evidence is highly valued, and this is the spirit in which individual differences techniques are becoming popular. Here we describe three major approaches taken by individual differences researchers.

[H3] Extreme abilities

Much of the individual differences research literature derives from the observation that there are some individuals who are unusually poor or unusually good at face recognition tasks. In addition to acquired prosopagnosia (the inability to recognise faces as a result of brain damage), there are also people who show poor recognition ability throughout life in the absence of known organic cause, a condition known as developmental prosopagnosia[13–15] (or sometimes 'congenital prosopagnosia': see Box 1). These individuals typically report an inability to recognise familiar people on the basis of their face alone, sometimes termed 'face blindness'. Research on developmental prosopagnosia is complemented by studies on 'super-recognisers'[16–18], individuals with extremely high face recognition ability relative to the average person. These people often report that they can recognise previously seen faces in challenging conditions, for example in poor lighting, and despite not having encountered them for many years.

Recruiting participant groups with extreme abilities enables group-level comparisons between these extreme profiles and average performers. This approach differs substantially from traditional neuropsychological case studies in which an individual is compared to a single control individual or a control group. Group studies on participants selected from extremes of the ability spectrum can offer high statistical power for detecting differences and have the potential to provide insight into the fundamental nature of that ability. This approach can be used to establish dissociations between different subtypes of face processing ability[19], or between face processing and other types of ability. However, the increased power gained by group comparisons relies on a degree of homogeneity within groups and people with developmental prosopagnosia can sometimes display rather diverse symptoms.

[H3] Variation within the normal range

There is growing awareness of the value of individual differences research across the entire range of face processing abilities. Whereas face perception variability is sometimes studied to identify target groups (for example, to establish a range of abilities from which one might select people to perform face-related tasks such as checking passports) it is more commonly used to establish associations or independence between variables of interest. The main tool for establishing the relationship between two tasks is correlation – deriving a quantitative measure of the association between performance on two or more different tasks. This method raises issues of the reliability and validity of particular scales of test processing. The composition of the tests themselves is critical to scientific progress.

Associations between tests of face perception and other performance measures provide an opportunity to understand the relationships between fundamental processes that are not easily uncovered using traditional group-level analysis. For example, if people who are good at face recognition also turn out to be good at voice recognition, that would provide evidence for some commonality in the processing required of these tasks. Association studies between face processing and broader cognitive tasks – for example IQ tests – can address the key question of whether individual differences in face processing reflect more domain-general differences in perceptual and cognitive abilities[20,21].

[H3] Structural Variation

The third major approach to individual differences in face perception is to link quantifiable structural variation – for example in genetic factors or brain physiology – to differences in face perception abilities. A series of twin studies has demonstrated that certain face perception abilities – particularly those related to recognition – are highly heritable[22–25]. Along with the evidence from extreme performers, the twin data has been taken to support a stable, trait-like ability underpinning performance on some face perception tasks. Interestingly, this heritability is not observed for some other face perception abilities, including those related to social attributions, for example ratings of perceived trustworthiness[12]. Patterns of findings in which certain abilities are strongly heritable but others are not are a good example of how individual differences research can be used to constrain models of the face processing network in general. For example, heritable face identity recognition abilities signal a structural basis that is consistent with this being a discrete processing module.

In addition to genetic factors, individual differences have also been instructive for understanding the relation between face processing abilities and variations in neural physiology. For example, better face processing abilities have been linked to increased grey matter volume in certain regions[26–28], as well as to neural activity[29–31] and connectivity between regions of the face processing network[30] (Box 2). Relatively small participant group sizes in neurophysiological studies means that some of this evidence is preliminary, but cumulative evidence from studies of individual differences provides a promising approach linking face processing abilities to their neural substrates.

Finally, researchers have examined the relationship between face processing and certain pathologies. For example, those with low levels of ability in social communication characteristic of Autism Spectrum Disorder tend to perform poorly on a variety of face perception tasks[32] including identity[33] and emotion recognition[34]. People with Autism Spectrum Disorder also show abnormal patterns of attention to faces[32], as well as divergence from typical cognitive[35] and neurophysiological[36] markers of face processing. Whether these are directly linked to reduced social communication abilities in Autism Spectrum Disorder, or to other symptomatic sensory atypicalities, is not clear[37]. Establishing the complex causal links between face processing and more general communicative abilities therefore remains a challenging task[25].

Many of the questions addressed in studies of individual differences remain unresolved. But accumulating evidence from the various strands we have outlined in this section demonstrates the power of this approach to bring together research from cognitive psychology, genetics neuroscience and psychopathology. By observing associations between these diverse measures of individual differences, a multidimensional system of related face processing abilities begins to emerge, and its mapping to structural properties can be revealed.

[H1] Face processing abilities

A longstanding issue in philosophy, psychology, and neuroscience is the extent to which individual differences in performance on cognitive tasks have a common underlying driver, for example IQ. Alternative 'modular' accounts hold that certain encapsulated processes such as early visual processing operate relatively independently[38]. Face perception provides an important example of modularity in higher-level processing, with converging evidence pointing to a degree of encapsulation: Individual differences in face recognition tasks are independent of general intelligence[39] and to some extent general visual processing[22,40–43]. These findings from the individual differences literature concur with long-established evidence from other research traditions including neuropsychology[44], neuroscience[45] and behavioural group studies[46] showing dissociations between face perception and other types of visual processing.

In the field of face perception the modularity issue arises in an often polarised debate about the functional specialisation of face processing relative to other high-level visual processing tasks[46–48]. In fact, individual difference studies show a moderate, rather than sharp, dissociation between face and visual object perception tasks[20,40]. Some studies report significant associations between face and general object perception ability (r ranging from .00 to .37)[20,40,42,49,50] whereas face recognition[42] and perception[21] do not correlate with non-visual aspects of intelligence. However, associations between face and object recognition are consistently weaker than those between different face (r ranging from .20 to .65)[20,22,50–54], or object recognition tasks (r ranging from .27 to .68)[42,49]. This pattern is consistent with the observations that two thirds of people with developmental prosopagnosia have impaired object recognition abilities[43] abilities[39] and super-recognisers outperform control groups on non-face object processing tasks[16]. Overall, these patterns of associations are not consistent with a strictly modular face processing system, suggesting a graded rather than absolute distinction between face and object perception abilities.

[H3] Measuring face processing

There is a range of face processing tasks used to study individual differences, including recognition of identity, facial expression, and inferences about personal characteristics (Table 1). Tasks measuring recognition of identity are highly over-represented compared to other aspects of face perception. Diverse task formats have been used to study aspects of face processing (Fig. 1). Probing a particular ability with a range of tests is valuable to gain converging evidence. High levels of convergence suggest an underlying common ability, in contrast to highly task-specific abilities. But diversity in task format can also pose problems for inferences about the relatedness between abilities – lack of association could be attributed to differences in superficial aspects of the tasks rather than the underlying abilities.

Three key psychometric properties constrain the individual differences approach. First, test-retest reliability, which is the correlation between test scores on the same test across two separate test sessions. This property is critical for interpretation because it places an upper bound on the associations between tests – associations between tests cannot exceed associations between a test and itself. However, estimates of test-retest reliability are not available for most tests. The second property, convergent validity, is the correlation between different tasks that ostensibly measure the same thing. This property is similarly critical[42] because it establishes that the common variance in test scores is attributable to an underlying ability recruited by the tests, rather than due to artifacts of any particular test – for example the specific images that were used to create it. Third, external validity relates to whether the tests measure what they are intended to measure, by correlating test scores with performance outside the laboratory. In the context of face processing, externally valid tests capture abilities as they are used in daily life, rather than reflecting the highly-specific context of psychological assessment. Thus, whereas test-retest reliability can be measured using a single test (Table 1), convergent and external validity are contingent on comparison with other tests.

[H3] Facial identity

The most common tests of face recognition require participants to remember previously seen faces (for example, ‘which of these faces did you see earlier?’) or to match faces (for example, ‘do these two photos show the same person?’). The results of facial identity processing tests show a wide diversity in abilities across people[55–57] but an individual’s score is highly stable over time, with test-retest correlations typically above .7 (Table 1)[22,51,58]. Face recognition is heritable[22–24], with correlations of 0.7 between scores of monozygotic twins, compared to 0.29 for dizygotic twins[22], and estimates of heritability ranging from 68 to 97%[22,24]. Thus, identity processing can be measured reliably and apparently taps a stable underlying dimension. Yet this evidence is based predominantly on a single test of unfamiliar face memory, the Cambridge Face Memory Test, CFMT[55]. It is therefore important to confirm that this trait generalises beyond a specific test.

Regarding convergent validity of face identification tests, associations persist despite substantial changes in task format. Similar results are observed despite differences in memory demands[20,56], retention interval[59], and types of response (for example, naming or multiple choice[42]). The term *f* – measured by associations between face tasks – is defined as a general factor underlying face identity processing ability[21]. The reported correlation between tests of face memory and matching is typically in the range of .5 to .7[21,51]. It has been estimated that f can account for up to 25% of the variance across face recognition tests – including the popular CFMT, Before They Were Famous Test (BFTWF), and Glasgow Face Matching Test (GFMT)[20] – and it has been linked to particular polymorphisms from a genome-wide association study[55,60].Whereas these face tasks tend to correlate, reports typically show no reliable associations between performance on these tasks and visual processing tasks for other objects. This pattern is consistent with research in object recognition reporting a general factor accounting for shared variance in novel object processing tasks (denoted *o*[49]). The general object factor shows relatively weak association with the CFMT (r = 0.28), providing converging evidence that face identity processing is somewhat isolated from more general object processing ability.

Another key question is whether face recognition is a unitary ability across familiar and unfamiliar faces. The study of identification commonly focuses on unfamiliar faces, despite the fact that recognition of familiar people is an important component of daily life (only 3 out of 17 face recognition tests use familiar faces, Table 1). This under-representation may be due to recognition of familiar faces being generally easier than recognizing unfamiliar faces, so it is challenging to design discriminating tasks. Furthermore, there is no common set of faces that are familiar to all individuals. People are highly bound to their cultures, age and social groups, each having distinct sets of familiar faces such as celebrities, politicians, and famous athletes[61]. There are large behavioural differences between the perception of familiar and unfamiliar faces, which have been argued to reflect qualitatively different processing[62–64].Some authors have reported an absence of correlation between familiar and unfamiliar face recognition using matching tasks[65] but these tests tend to give near-perfect results for familiar faces, limiting the measurement of their association. Studies using tests of familiar face naming tend to find significant associations between familiar and unfamiliar face recognition[20,42,66], consistent with the idea that face identity processing is a relatively coherent ability.

Self-report measures of face recognition ability correlate very highly with each other (r = .82)[67], but tend to predict test performance less well (r ranging from .14 to .52)[68–72]. Ad-hoc (non-psychometric) tests of people's insights into their face recognition abilities have reported even smaller associations to actual performance (r = .13 to .26)[71]. This modest relationship between self-report and face identity tests could be due to a general lack of metacognitive insight[73]. Another possibility is that tests of face recognition do not capture the processes involved in everyday recognition. This might also explain relatively low correlations between standardised tests and more naturalistic learning and recognition tasks, for example between CFMT scores and viewers' recognition of faces from the TV show Game of Thrones (r = 0.45)[74,75]. Thus, although face identity processing tests show good internal, convergent, and divergent validity, important questions remain regarding their external validity. Establishing external validity is critical if face identity tests are to be used for selecting good face recognisers in professional settings[18], and so we return to this issue later (see Practical Implications).

[H3] Expressions and impressions

The study of emotion perception in faces has been dominated by a debate about whether a few 'basic' emotions are expressed and perceived similarly by all humans[76–78]. However, using the individual differences approach, some studies of subtle variations in expression recognition show reliable between-person differences in the ability to judge emotion[11,79–81]. In contrast to identity processing, the pattern of correlation on tests of emotion recognition is highly sensitive to changes in the particular emotions being expressed[2] and the task format[11]. This pattern points to a lack of convergence onto a unitary process for the visual analysis of facial expression. Instead, it seems that the recognition of different emotions (for example, happiness or fear) call on somewhat different abilities[2,3,82].

One focus of individual differences research has been social and aesthetic judgments made to unfamiliar faces (that is, the faces of people unknown to the viewers). When asked to judge the trustworthiness or dominance of a face, viewers tend to agree with each other, even though these judgements are typically not accurate indicators of a person's true character[83–86]. People asked to judge the attractiveness of a face, show moderate levels of agreement, albeit lower than their ratings of trustworthiness/dominance[87–89]. Despite some agreements between people in making social judgments, there remains some variation, pointing to idiosyncrasies in individual perceptions, which appear to be relatively stable over time[12,89].

Unlike face identity processing, variation in social judgements is not associated with genotype. A large-scale twin study showed that trustworthiness judgements of unfamiliar faces vary more strongly with the viewers' personal experiences than their genetics[12]. Individual variation in aesthetic judgements of attractiveness is also associated more strongly with environment than genes[89]. The implication of current research is that social judgements are a product of social learning[78,84,90], and researchers are beginning to propose mechanistic accounts of this learning at an individual level. For example, trustworthiness and attractiveness judgments appear to be linked to transitory changes such as smiling or warm expressions[91–93]. This observation reflects an emerging view that social signals from faces are intertwined in real world tasks, limiting the external validity of many lab-based tasks that use artificial faces or highly standardised images[94–96].

[H3] Multimodal person perception

In daily life, people perceive information about each other using multiple sources, including cues from voices, bodies, clothing, and context. Lab-based experiments using isolated faces can obscure the fact that recognising or making a perceptual judgement about someone usually involves many cues presented together and often in redundant combinations. For example, a viewer might recognise a friend from their face, their walking style, a particular jacket, and the fact that they arrive at an arranged meeting on time (Fig. 2). Variation in real life person perception might incorporate differences in all these dimensions too – each requires cognitive and perceptual decisions, and so they may be subject to individual variation between people.

Within the visual domain, the ability to recognise facial identity is only weakly correlated with the ability to process cues from bodies and movement[97], suggesting somewhat separable processes. Beyond vision, there are widespread differences in people's ability to recognise voices[98-100] over and above general differences in auditory perception[101]. On tests of identity using matching and similarity tasks, there is some evidence for an association between recognising faces and recognising voices[102] and some individuals have high ability levels in both[103]. Associations are typically quite small (r ranging from .24 to .41)'[102] and so cross-modal mechanisms do not seem to underpin all voice recognition. The relatively weak association between face and voice recognition is further supported by the report of individuals with developmental prosopagnosia but intact familiar voice recognition[104].

There are also associations between decisions about attractiveness from voices and faces (r from .15 to .34)[105,106]. The perception of attractiveness appears to be multimodal and can be influenced by olfactory cues[107]. Well-established individual differences in olfactory sensory apparatus[108] and effects of scent on other impression judgments[107] highlight the potential for individual differences in the associations between olfactory and visual cues to social judgments.

Individual differences in judgements of emotion from faces and voices also appear to show common processing across modalities[3,11] and this association extends to tactile perception, elicited by the touch of another person[109]. Connolly and colleagues[2,3] identify shared variability for tests of expression recognition accuracy from both face and voice stimuli, which they describe as a 'supra-modal' factor underlying emotion perception. This factor is related to the ability to introspect on one's own emotional state, which varies dimensionally in the typical population[3]. The association between face processing and social abilities in the general population has implications for the diagnosis of pathology (Box 1), for example emotion processing impairments in psychopathy[110,111] and autism[112].

Studying individual differences in face processing abilities has contributed to a greater understanding of the subtle ways in which the different aspects of face processing are related. Associations between performance on multiple face tasks, including identity recognition and expression perception, points to some shared underlying processes. For emotion perception particularly, these processes appear to be multi-modal, incorporating vision, audition and touch. However, it has also been possible to establish some key differences between different face processing abilities, for example the strong genetic component underlying identity recognition, but not social judgements.

[H1] Underlying representations

Research on the associations between different abilities, as described in the previous section, is complemented by a parallel focus on the cognitive mechanisms. Models of face perception posit multiple (serial or parallel) processing stages between visual input and perceptual decisions[6]. Neural models instantiate these networks in connected brain regions[7] (Box 2). In the study of individual differences, these networks are revealed as systems of related abilities that provide converging sources of information to support perception. Individual differences research tends to report some overlap in people's abilities in recognition and emotion perception[2,3,11,113–115]. This pattern suggests some shared representational resource between abilities to recognise identities and emotions.

Patterns of association and dissociation help clarify the modular structure and representations of the face processing system. For example, research on developmental prosopagnosia has found that some individuals show impaired gender discrimination[116] but spared facial age estimation[19,117]. This pattern provides good evidence that perception of age is not dependent on identity or gender perception.

These studies begin from an observed data pattern to determine the underlying cognitive processes. Working in the reverse direction, an understanding of the underlying representations used by the face processing system can help to explain observed differences in performance. We examine this latter approach next.

[H3] Holistic processing

Holistic processing refers to the idea that perception of a whole object (or Gestalt) has precedence over perception of its parts. Faces are widely believed to be perceived more holistically than other types of objects[9]. Individual facial features (for example, eyes or noses) are easier to remember when embedded in a face than in isolation[118].Similarly, when the top and bottom halves of two different faces are aligned to form a new face, the composed face appears as a new identity[119].

The importance of holistic face processing has led to the hypothesis that the extent to which different people process faces holistically might underpin differences in their face processing ability[10,59,120,121]. However, this hypothesis is not well supported among individuals with face processing in the typical range. One of the most popular measures of holistic processing is the Composite Face Effect[119], a phenomenon in which the top and bottom halves of two different faces are aligned and tend to fuse perceptually into a single new face. This fusion impedes the separate processing of the face halves compared to when they are not aligned. Some studies show weak-to-moderate correlation between the composite face effect and performance on the CFMT[59,121,122], but others have found no association with CFMT[21,123] or other face recognition tasks[59,124].The performance of individuals with developmental prosopagnosia also provides mixed evidence for an association between holistic processing and face recognition ability. Some studies have found slightly poorer holistic processing in individuals with developmental prosopagnosia by comparison to controls[125–127] while others have found no difference[124,128–130].

Another challenge to the use of holistic representations as an explanation for differences in face processing is that a person's ability to perform face perception tasks from whole images is highly correlated with their ability to recognise isolated face features[131]. Some individuals with developmental prosopagnosia have equivalent impairment on face recognition from isolated features and from whole faces[104], and a hallmark of super-recognisers is their ability to identify faces from relatively limited local face information[132,133]. Furthermore, recognition is less impacted by distortions that change the spatial layout of facial features in high compared to low performers within the typical range[134], and those at the top of the typical range are less sensitive to changes in global shape of a face[135,136]. These findings suggest the need for a more sophisticated understanding of the representational differences underlying face processing ability[137].

Progress in this area also relies on a greater understanding of the tasks themselves. Problems of measurement have dominated research on holistic processing for over a decade[59,121,138,139] and the challenge of developing valid and reliable measures appears intractable[131]. Even the best-established measures of holistic processing suffer from very low reliability and do not correlate with differences in face recognition performance despite best practice in psychometric approach[131,140,141]. These observations might signal a problem with the construct of holistic processing itself. Other measures of holistic processing, including face inversion effects (faces are harder to process upside down) and part-whole effects (recognition of isolated features is easier when they are embedded in a face) also correlate very poorly with each other[124]. This pattern is perhaps symptomatic of a broader lack of clarity in operationalising processing mechanisms in the field[137,142]. Substantial methodological and conceptual challenges need to be overcome to understand how differences in underlying representations give rise to differences in ability.

[H3] Unfamiliar and familiar faces

Research on individual differences has overwhelmingly examined recognition of unfamiliar faces, yet the faces of familiar people comprise much of personal daily experience. Group-level evidence shows that familiarity is directly related to recognition success, viewers are much better at recognizing familiar than unfamiliar faces[8,143–145] and higher levels of familiarity exert more powerful modulating effects on neural responses[64,146–150]. If differences between familiar face representations are important for performance within an individual, these differences could also be important between individuals.

Performance in recognising famous faces is moderately related to performance on an unfamiliar face test (CFMT), with correlations ranging from .55[42] to .33[20]. There is also some evidence that the representations underlying familiar and unfamiliar face recognition tasks are distinct. Whereas high performers on a famous face test were less reliant on global face shape than low performers, high performers on the CFMT (unfamiliar faces) showed the opposite pattern and were more reliant on global face shape[136].

For familiar faces, idiosyncratic cues contribute to the representation of identity[151,152]. One face might be recognised from a characteristic smirk, another from distinctive facial speech movements. Analyses of multiple images of the same person reveal not only consistent differences between people, but also idiosyncratic within-person variability[153,154]. To become familiar with a new face, one needs to experience the range over which that face can vary[155,156]. This multidimensional view of familiar face representations has implications for individual differences in responses to unfamiliar faces too. People who are particularly skilled at unfamiliar face recognition recruit elaborate semantic and emotional representations more commonly used for familiar face processing[29,30]. In this way, the difficulty of unfamiliar face recognition may be alleviated to some extent in skilled viewers.

Representations of the same faces, both familiar and unfamiliar, also diverge considerably across individuals. For example, participants disagree entirely which images of unfamiliar faces look most similar to one another[157], and there are large differences in the photos that people report as showing the best likeness of a familiar face[158]. Research on the representations underlying these differences is rare and it remains puzzling why different viewers show different patterns of similarity between the same familiar faces.

In summary, researchers have sought to explain differences in performance on face tasks through differences in viewers' underlying representations. The degree to which people tend to use holistic processing was once thought to be a good candidate to explain variation in face recognition performance, but the evidence is weak. Differences between recognition of familiar and unfamiliar face recognition offer some promise for understanding the relationship between people's representations and their performance. Further exploration of this relationship will require detailed investigation of people's idiosyncratic representations of the faces they know.

[H1] Practical implications

In addition to providing theoretical understanding, studying individual differences brings practical implications. For example, face perception in disorders influencing social cognition has clinical relevance (Box 1) and social consequences for individuals with these disorders[159–162]. There are also clear societal implications of individual differences in face recognition. The outcomes of face identification decisions in security and forensic settings can often be profound – impacting civil liberties and even leading to wrongful convictions – and the science of individual differences can help address these problems.

Identity-checking

Tasks that involve checking the identity of unfamiliar people are known to be difficult and error-prone. Error rates of 20-30 percent are common in studies asking viewers to match two different photos of the same person, taken on different occasions, even when using high quality images taken in good lighting[163]. This difficulty extends to professionals who conduct daily face matching, such as in passport control or forensic face identification. In a meta-analysis of 29 comparisons between professional groups and participants from the general population on tests of unfamiliar face identity matching, 40% of tests showed equivalent face matching accuracy in these groups[164]. High error rates were found in staff performing a variety of important identity verification roles in border control[165], government offices[166], passport issuance[167,168], police departments[169], security firms[170] and banks[171]. Simply performing identification tasks in daily work is not sufficient for expertise. Furthermore, current approaches to training in many professional settings are ineffective (Box 3).

The discovery of reliable individual differences in face recognition provides one means of addressing this problem. It is becoming increasingly popular to select people for specialist face identification roles on the basis of their natural ability as measured by standard tests. This strategy has been used by the London Metropolitan Police[172,173] and the Australian Passport Office[168], with groups selected for high face performance showing 10-20% gains in accuracy over control groups.

Forensic face identification

Facial forensic examiners – who analyse similarities and differences between face images to provide evidentiary reports for police investigations and criminal trials – outperform standard participant groups by roughly the same margin[57,164,174,175] as selectively-recruited, but untrained, super-recognisers. In contrast to super-recognisers' quick and intuitive recognition ability, forensic abilities are founded on years of deliberate training in comparing images of unfamiliar faces[176] and involve slow, analytic comparison[174,175].

Forensic identifications are also made by eye-witnesses. These are highly vulnerable to error, with meta-analysis suggesting that 50% of eyewitness lineup selections are wrong[177]. Given the range of face recognition abilities in the general population, it is likely that a large proportion of errors are made by people with relatively poor face recognition abilities. Researchers have examined the use of tests of face identification to screen eyewitnesses, an approach that pre-dates broader interest in individual differences[178]. Face recognition tests can be used to predict eyewitness errors[179], by allowing law-enforcement officers to weigh witnesses' identifications against their objective abilities. Furthermore, eyewitnesses are often overconfident, and tests can establish whether particular individuals tend to over-estimate their recognition performance, providing a level of credibility to testimony[73,180,181].

The potential for individual difference research to improve accuracy in real-world tasks relies on reliable and valid tests. From an applied perspective, valid tests must correspond with real-world tasks. As a basic example, a face memory test might not be an optimal measure for professionals who are required to match but not remember faces. However, there is sufficient task diversity among relevant practitioners to present a nontrivial challenge in choosing tests for specific professional contexts[18]. Forensic identifications made from CCTV involve a complex set of cognitive demands[182] and might incorporate cues beyond the face including behaviour, gait, or clothing. The use of these cues these might each represent separate skills[97]. Preliminary evidence suggests that face recognition tests are not especially reliable predictors of performance on CCTV monitoring tasks[75,183]indicating that basic understanding of skills underpinning accuracy on different real-world identification tasks is lacking.

The challenges in forensic face identification echo the lack of diversity in measures for effectively capturing everyday abilities. Batteries of face tests that target distinct subskills provide an alternative to reducing ability to a single test score[18,52], and might provide the necessary flexibility to capture the multidimensional nature of person identification for both applied and theoretical use.

Human-AI collaboration

Face recognition in applied settings increasingly relies on combined processing by humans and technology. Deep neural network approaches to facial recognition have been highly successful and the best-performing systems are now as accurate as both super-recognisers and facial forensic examiners[57]. Such automated processes are used for passport control in some countries as well as police searches for suspects in image surveillance[184]. Critically, in many of these applications, the technology does not replace human processing but rather presents operators with arrays of potential matches for follow-up. This procedure automatically makes easy match decisions, leaving more difficult matches to human reviewers and error rates in human review can be as high as 50%[168]. Thus, this type of forensic identification can be problematic in the same way as traditional identification processes, such as eyewitness lineups[177].

Selecting people with the necessary skills to review matches generated by facial recognition technology is a potential way to reduce error rates. Moreover, it appears that personnel selection can be tailored to the specific face recognition algorithms that are being used. Statistical aggregation of the decisions made by algorithm and high performing humans produces accuracy that exceeds either algorithms or humans alone[57]. This statistical combination benefit is driven by independent processes recruited by algorithms and human perceivers. Given the present revival of interest in deep learning networks as models of face processing[185,186], evaluating similarities and differences between human and machine processing can also lead to theoretical advances.

[H1] Summary and future directions

Individual differences research is a complementary approach to traditional group studies for understanding face perception. In a field that has traditionally drawn on converging evidence, individual differences research enables new questions to be asked and can address some long-standing issues. Although there has been considerable research focusing on people with extreme levels of ability (individuals with developmental prosopagnosia and super-recognisers), there is considerable potential for broader scientific progress across the full scale of abilities.

The study of individual differences has also highlighted some major problems in the field of face perception. Perhaps the most significant of these is the problem of measurement. The construction of reliable and valid tests lies at the heart of an individual differences research programme, but tests of face perception remain comparatively weak in these properties. Without reliable tests, it is impossible to draw valid conclusions. Although the construction of new tests remains a challenge, it would be relatively straightforward for researchers to only use tests with published test-reliability measures. The problem of reliability in psychological measures is not specific to the study of face processing, but the problem seems particularly acute in this field because there are multiple tests for measuring each aspect of face processing (Table 1).

The issue of measurement has also highlighted another problem with the theory-led approach to some face recognition questions. A good example is the widespread view that holistic perceptual processing underlies face perception. However, the set of tests used to measure holistic processing correlate very poorly with each other[124] - a key finding that has perhaps not yet had the influence it deserves. Theoretical statements based on holistic processing are common and the field has perhaps been too willing to adopt these generalisations without clear operationalistationn[142]. At the very least, holistic processing accounts of face perception should specify the relevant measure of holistic processing[131].

Another major challenge remains in eliciting general principles of face perception while acknowledging that every person has different experience with faces. Developing methods for studying variation in familiar face recognition will be a major challenge, given the highly idiosyncratic set of personally familiar faces and the laborious processes required to tailor experimental materials to individual participants[64,148,149,187]. For example, one person might not recognise Barack Obama and another might not recognise Kim Kardashian – discrepancies that often lead to mutual disbelief. Approaches targeting specific cohorts of TV viewers who have comparable perceptual exposure could offer a promising solution to this methodological problem[74]. Most studies of familiar face perception treat familiarity as a binary categorisation (familiar/unfamiliar), a methodological constraint which has, to some extent, obscured our understanding using traditional experimental approaches[154]. It remains to be seen whether individual differences approaches, which conceptually differentiate between people, can be harnessed to capture natural idiosyncrasy.

In this Review, we have emphasised the implications of multiple sources of information for face perception. We have shown how individual differences approaches shed light on the perceptual architecture necessary to use faces in the flexible ways that humans do. Yet, the biggest unsolved problem in face perception remains how someone recognises the people they know.

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Table 1. Tasks used to measure individual differences in face processing abilities. Only tasks that were specifically developed to test individual differences in face processing are included, where normative accuracy data is available based on non-clinical adult samples of more than 80 participants. Test-retest reliability is presented, and ranges indicate variable reliability in sub-measures reported. This table signals a maturing field of individual differences in face processing with progress in testing a range of face processing abilities, albeit most heavily concentrated in identity processing.

Target ability	**Task type**	**Task**	**Test-retest reliability**
Identity	Perceptual matching	BFRT, Benton Face Recognition Test[188, 189]	-
		Glasgow Face Matching Test[56]	.77[54]
		Glasgow Face Matching Test 2[58]	.79[58]
		Kent Face Matching Test[190]	.67[52]
		Models Matching Test[191, 52]	-
		Oxford Face Matching Test[54]	.75[54]
		Yearbook Test[192]	-
		1-in-10 Matching Test[52]	-
	Perceptual discrimination	Cambridge Face Perception Test[53, 193]	-
		Facial Identity Card Sorting Test[52, 192]	-
	Recognition memory	Adult/ Infant Face recognition Test[194]	-
		Cambridge Face Memory Test[55]	.70[22]
		Cambridge Face Memory Test Extended[17, 53]	-
		UNSW Face Test[50]	.59[50]
	Naming	Bielefelder famous faces test (BFFT)[195]	-
		Before They Were Famous Test[17, 20]	-
		Familiar Faces Memory Test[42, 72]	-
	Self report	Cambridge Face Memory Questionnaire[72]	-
		Hong Kong Prosopagnosia Questionnaire[196, 67]	-
		Prosopagnosia Index[197]	.89[54]
		Stirling Face Recognition Scale[68]	-
Expressions	Perceptual matching	Emotion Matching Task[11]	-
	Naming	Ekman 60 Faces[198]	-
		Emotion Hexagon Test[199]	-
		Facial Expression Labelling Test[200]	.39 - .85[200]
		Karolinska Directed Emotional Faces[201]	-
		Reading the Mind in the Eyes Test[202]	.63[203]
Impressions	Rating	Facial Impression Tests (Trustworthiness)[12]	.73[12]
		Facial Impression Tests (Dominance)[12]	.58[12]
		Facial Impression Tests (Attractiveness)[12]	.50[12]
		Individual Preference Test (Attractiveness)[89]	.75[89]
		Philadelphia Face Perception Battery (Attractiveness) [117]	.50[117]
Demographics	Perceptual matching	Philadelphia Face Perception Battery (Age)[117]	.49[117]
	Naming	Philadelphia Face Perception Battery (Gender)[117]	.37[117]

Figure 1. Taxonomy of tasks used to measure face processing abilities. (A) Perceptual matching involves deciding whether two or more images match on a given dimension (here: identity). (B) Perceptual discrimination requires comparing two or more images on a given dimension and either choosing most/least, or ranking from high to low (here: expression). (C) Recognition memory requires studying faces and some time later memory for the faces is tested. (D) Naming tasks require naming a person or labelling an expression, sometimes from a set of predefined labels. (E)Rating tasks ask participants to rate a single image on a dimension using a Likert scale. (F) Self-report measures ask participants about their face processing experiences in everyday life. Correlation of tests measuring the same ability across different task formats establishes convergent validity, but differences in task format can also interfere with measurement of association between different abilities.

Figure 2. Everyday decisions depend on rapid decoding of multidimensional facial cues. Everyday decisions are made in rich and dynamic environments where multiple cues from multiple senses are integrated and linked with complex social contexts. Coloured boxes list some of the ambient visual cues that might influence perceptual judgments on given dimensions in real world tasks. For example, a decision about where to sit on a bus might be contingent on both identifying your colleague and on whether her mood would be conducive to casual conversation (is she upset?). Indeed those cues might not be independent, if for example you have only encountered your colleague in a happy mood then her expression might influence the identity judgment itself. Situational contexts such as the bus route, and the clothes worn by the men who might be arguing, are also likely to influence judgments.

Box 1: Defining developmental prosopagnosia

Acquired prosopagnosia is characterised by impairment of face processing resulting from brain damage, but developmental prosopagnosia is not linked to known structural or genetic pathology. Nevertheless, poor face processing abilities can have severe negative impacts on social interactions[159–162]. The problem of diagnosis is therefore critical. It is unclear whether developmental prosopagnosia is better conceptualised as the low-end of the range of typical ability or as a condition in its own right, independent of typical variability[204,205]. Understanding the dimensional structure of individual differences in face processing can help better define developmental prosopagnosia and its association with other conditions.

No genetic markers have yet been identified for developmental prosopagnosia, and reported neural abnormalities vary between studies (Box 2). In the absence of reliable markers, the definition of developmental prosopagnosia is purely based on behavioural performance on tests of face identity processing or questionnaires probing everyday face recognition. Accurate diagnosis is therefore conditional on the psychometric properties of these measures.

That some people with developmental prosopagnosia show impaired holistic processing but others do not might reflect 'cognitive heterogeneity' of the condition[116,206], which could signal a family of related subtypes of prosopagnosia rather than a unitary condition[207]. This proposal would be consistent with a genetic basis for the condition, despite the current absence of markers: many inherited disorders are end-points of quantitative dimensional traits determined by multiple genes exerting small effects, resulting in heterogeneity across a group of individuals[196,204,208].

Defining developmental prosopagnosia as a condition is further complicated by age-related declines in ability[50,209], and the need to exclude the contributions of associated conditions . Some of these conditions do have a clear organic basis (for example, macular degeneration[210], Alzeimer's pathoogies[211], frontotemporal dementia[212,213]) and produce associated progressive deficits in face perception and memory abilities. The basis of other conditions is less well understood, for example Autism Spectrum Disorder (ASD)[32,33,37,] and Schizophrenia[215]. The complexity of these disorders involve social and perceptual deficits that are not specific to faces[25] and manifests as heterogeneity in the patterns of face processing impairment.

When symptomatic of broader conditions, patterns of impairment reflect the multidimensionality of face processing abilities. Some disorders are associated with both impaired emotion and identity processing (Autism[34], Schizophrenia[215], Anxiety[82]). Other conditions selectively impair expression recognition (Parkinsons[216], Psychopathy[110]). Individual difference studies can improve understanding of the links between emotion processing deficits[82] and face abilities in the typical population. Aside from

Parkinson's, these conditions involve traits that vary dimensionally in the typical population[81,217,218] and so associated face processing impairments have implications for non-pathological variation[3,25,219–221].

Box 2: Neural bases of face recognition

Examining anatomical brain differences and their relation to different ability levels can help improve understanding of functional aspects of face processing abilities. Most studies on this topic have focused on differences in blood flow within face-selective regions, measured using functional Magnetic Resonance Imaging (fMRI). Some regions have been functionally defined as ‘face-selective’, and differential activation to faces and non-face objects can then be measured to capture face-selective responses at the individual level[222]. Individual differences are found in the precise locations of these regions[223,224], and they are mostly stable over time within individuals[225,226].

The Fusiform Face Area (FFA) is a functionally defined area that selectively responds to images of faces across repeated brain scans (figure panel a, dark blue). Some studies show correlations between scores on face identification performance and FFA activation strengthh[?,29,30] and region size[30,227]. However a number of studies report no association[228–230]. This inconsistency might be due in part to small sample sizes, which are not well suited to individual difference analysis. Some comparisons of FFA activation in people with developmental prosopagnosia to controls show reduced activity[229,231,232], but others show no difference[233]. Inconsistency might also arise from poor reliability of brain responses[234]. Test-retest reliability of FFA activation has not been examined rigorously, although one study does show relatively high stability in this measure over different presentations of faces in the same experimental session[230].

An association has also been found between FFA grey matter volume and performance in face recognition[26–28]. A small number of studies using electrophysiological recordings from the scalp (ERPs), have also reported correlations between face-specific components and face recognition performance[115,235,236]. Despite high reliability of some ERP measures over repeated testing[237], in each of these studies correlations between multiple face-selective ERP components were low (r = .3), and the degree to which the components were face-selective did not reliably distinguish developmental prosopagnosia from typical recognition abilities[238].

The FFA is just one part of the neuronal network that has been identified as responding selectively to faces (see figure). But outside the FFA, the association between individual differences in face recognition and brain response in specific regions are relatively inconsistent across studies (light blue and gray in figure: Occipital Face Area, OFA; Anterior Temporal Lobe, ATL; Amygdala, AMG; Superior Temporal Sulcus, STS)[29,30,239]. The degree of network connectivity, both within this core set of regions and beyond, correlates with measures of face recognition[30] and reduced communication between areas has been implicated in developmental prosopagnosia[239–241]. The importance of interconnection is also supported by structural investigations of white matter connections between cortical areas (figure panel b, dark blue), with structural deficits of these fibre tracts reported in developmental prosopagnosia[242–244].

Box 3: Training face recognition

The extent to which face recognition abilities can be improved with training has implications for understanding individual differences and plasticity. Face recognition ability does not develop fully until after the age of 30[50,209] and people's history of perceptual exposure to faces influences their abilities[245,246]. This flexibility in the face processing system could support training, and hence benefit people with developmental prosopagnosia and those using face recognition professionally.

[H1] Training impaired face abilities

Attempts to train face recognition abilities of adults with developmental prosopagnosia have been largely unsuccessful. One approach has been to train a holistic processing strategy when learning previously unfamiliar faces, but accuracy benefits from these methods are rarely found. Where they are reported, the benefits generalise poorly to faces not included in the training, and do not transfer to superficially different faces, for example photos taken with different cameras or lighting[247]. This poor generalisation limits the clinical benefit of training and is consistent with earlier failed attempts to improve face recognition performance in patients with acquired prosopagnosia[248,249].

Another approach is to encourage use of individual face features for identification of familiar faces. Many people with developmental prosopagnosia report using distinguishing facial features to identify familiar faces[162]. In a case study, researchers were able to teach children with developmental prosopagnosia to recognise familiar faces by memorising three distinctive features of each person's face[250] and anecdotal evidence suggests that these improvements carried into daily life. Other studies have also produced promising results training children with developmental prosopagnosia[251], suggesting that treatment in early development could confer some benefit. However, training does not transfer well to more naturalistic task conditions, a finding that is consistent with attempts to train face recognition in the broader population[252].

[H1] Training typical face abilities

Training in applied settings tends to be tailored to the specific task of matching unfamiliar faces[176]. A large-scale evaluation of professional training courses showed no learning beyond the specific faces used in each course[169]. In laboratory studies, collaborative face matching decisions with another person[253,254], and accuracy feedback on decisions[255] produce small benefits to accuracy. Improvements were specific to individuals with poorer recognition skills and were small in comparison to individual differences. A common element might be participants' realization that the task is more difficult than they expect it to be, leading them to more careful analysis. Some paradigms have successfully improved accuracy by directing participants’ attention to diagnostic features[175,256], which would be consistent with the benefit of additional analysis.

Given the very large benefits of familiarity for face recognition[62,257], another approach has been to develop familiar face representations. Substantial improvements are found when participants view multiple different photos of the same face[155,156,258–260], encouraging the formation of a coherent representation across variability. However, these benefits do not generalise to new faces[155,258], limiting their value in applied settings.