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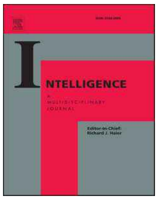

The association between intelligence and face processing abilities: A conceptual and meta-analytic review

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ABSTRACT

Whether there is an association between intelligence and face processing ability (i.e., face detection, face perception and face memory) is contentious, with some suggesting a moderate, positive association and others contending there is no meaningful association. The inconsistent results may be due to sample size differences, as well as variability in the quality of intelligence measures administered. The establishment of a moderate, positive correlation between face processing and intelligence would suggest it may be integrated within the Cattell-Horn-Carroll model of intelligence. Additionally, developmental prosopagnosia, a specific impairment of the recognition of facial identity, may be assessable in a manner similar to a learning disability. Consequently, we employed a psychometric meta-analytic approach to estimate the true score correlation between intelligence and face processing ability. Intelligence was positively and significantly correlated with face detection ($r' = 0.20$; $k = 2$, $N = 407$), face perception ($r' = 0.42$, $k = 11$, $N = 2528$), and face memory ($r' = 0.26$, $k = 23$, $N = 9062$). Additionally, intelligence measurement quality moderated positively and significantly the association between intelligence and face memory ($\beta = 0.08$). On the basis of both theoretical and empirical considerations, we interpreted the results to suggest that face processing ability may be plausibly conceptualised within the Cattell-Horn-Carroll model of intelligence, in a manner similar to other relatively narrow dimensions of cognitive ability, i.e., associated positively with intelligence, but also distinct (e.g., reading comprehension). Potential clinical implications for the assessment of developmental prosopagnosia are also discussed.

1. Introduction

On theoretical and empirical grounds, some researchers claim that face processing ability is essentially independent of general intelligence[1] (Bowles et al., 2009; Shakeshaft & Plomin, 2015; Wilmer, Germine, & Nakayama, 2014), whereas others contend that it is associated positively and meaningfully with other well-known cognitive abilities, including general intelligence (Connolly, Young, & Lewis, 2019; Gignac, Shankaralingam, Walker, & Kilpatrick, 2016; Hildebrandt, Wilhelm, Schmiedek, Herzmann, & Sommer, 2011). Thus, there is currently no consensus on whether individual differences in face processing ability may be considered a conventional cognitive ability or not.

In order to advance the area forward, in this review, we refer to abstract and operational definitions of intelligence, alongside descriptions of some of the key theories and models of cognitive ability, and we note connections with face processing ability and its measurement. We also conduct meta-analyses on the association between intelligence and face processing ability. To foreshadow, we will suggest that several face processing abilities may be plausibly conceptualised within the broadly accepted model of cognitive abilities, the Cattell-Horn-Carroll (CHC) model (McGrew, 2009). We will also contend that there are potential benefits with such an integration, both theoretical and practical.

1.1. *Abstract definition of intelligence*

Several abstract definitions of intelligence have been provided. For example, echoing Pintner (1923), Sternberg (1997, p.1) defined intelligence as "…the mental abilities necessary for adaptation to, as well as shaping and selection of, any environmental context" (see also

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[1] Throughout this manuscript, use of the word 'intelligence' refers to overall intellectual functioning (general intelligence; general cognitive ability). An intelligence may also refer to a narrower ability (e.g., fluid reasoning; numerical memory span; ideational fluency); however, we use the specific cognitive ability term wherever possible, when it is appropriate, so as to distinguish the context from more general intellectual functioning.

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McIntosh, Dixon, & Pierson, 2012). Gignac (2017, p. 465) defined intelligence somewhat less abstractly as "…an entity's maximal capacity to achieve a novel goal successfully using perceptual-cognitive abilities." As will be noted in more detail below, face processing ability may be conceptualised as an adaptive capacity relevant to achieving novel goals using perceptual-cognitive abilities, suggesting face processing abilities may be integrated within conventional intelligence conceptualisations. Although abstract definitions of intelligence are useful, especially in the context of theory, they are limited with respect to the generation of psychometric measures. By contrast, operational definitions, which are more concrete than abstract definitions, facilitate psychometric measurement.

1.2. *Operational definition of intelligence*

In more operational terms, Gignac (2017, p. 465) defined intelligence as "…an entity's maximal capacity to complete a novel, standardised task with veridical scoring using perceptual-cognitive abilities." Thus, intelligence tests have scoring that is objective and verifiable. For example, the word 'ambiguous' has an agreed upon definition and a person can be asked to define the word ambiguous as part of a vocabulary test. Another example is Digit Span Forward (Kaplan, 1991), a short-term memory test where participants are asked to repeat a series of numbers sequentially. As a final example, participants can complete the Trails-B task (Corrigan & Hinkeldey, 1987), a measure of processing speed, by connecting numbers and letters, within a limited time, in an alternating progressive sequence, 1 to A, A to 2, 2 to B, and so on. Thus, intelligence tests can be administered in a way that is objective and performance is verifiable. To foreshadow, published face processing ability tests can also be regarded as objective tasks of performance, much like typical tests of intelligence.

1.3. *Intelligence tests and inter-correlations*

It is important to note that performance on intelligence tests correlate with each other positively, a phenomenon known as the positive manifold, i.e., ubiquitous positive correlations between cognitive abilities (Carroll, 1993; Spearman, 1904). Consider, for example, that the correlation between verbal comprehension and working memory is $r = 0.64$, based on the Wechsler Adult Intelligence Scale-IV (WAIS-IV) normative sample (Wechsler, 2008). Furthermore, Digit Span, a measure of short-term memory, is correlated at $r = 0.50$ with Vocabulary, a measure of crystallised intelligence (Wechsler, 2008). Additionally, Matrix Reasoning is correlated with Symbol Search, a measure of processing speed, at $r = 0.39$ (Wechsler, 2008). In fact, the average inter-subtest correlation across all 10 subtests of the WAIS-IV is 0.43; and none of the inter-correlations are negative or zero. The inter-correlations between cognitive ability measures have facilitated the development of models of intelligence via techniques such as factor analysis.

1.4. *Models of intelligence and the CHC model of intelligence*

Over the years, several models of intelligence have been proposed. For example, Spearman's two-factor model (Spearman, 1904) emphasised the prominence of the general factor on the basis of the positive manifold; Cattell/Horn's model that emphasised the distinction between fluid and crystallised intelligence (Cattell, 1941; Horn & Cattell, 1966); and Carroll's (1993) extensive factor analytic work that has culminated into the CHC model of intelligence (McGrew, 2009).

The CHC model of intelligence is an amalgamation of Horn and Cattel's (1966) model and Carroll's model (Carroll, 1993). The first generation of the CHC model aimed to reconcile the differences between the two models (McGrew, 1997). The first CHC model was based substantially upon Carroll's hierarchical three-factor model, although it included a unique broad ability (reading and writing, *Grw*) and new narrow abilities, such as reading comprehension and reading speed (see Flanagan & Dixon, 2013). The CHC model has been refined based upon current factor analytic research, as well as developmental, neurocognitive, and heritability evidence (Flanagan & Dixon, 2013).

Today, the structure of the CHC model consists of a general factor (known as *g*), which is referred to as a Stratum III ability within the model. The model also includes 16 broad abilities, called Stratum II abilities, that appear under *g* (Newton & McGrew, 2010). The Stratum II abilities include: fluid reasoning (*Gf*),[2] comprehension–knowledge (*Gc*),[3] reading and writing (*Grw*), visual processing (*Gv*), long-term storage and retrieval (*Glr*), processing speed (*Gs*), short-term memory (*Gsm*), reaction and decision speed (*Gt*), and quantitative knowledge (*Gq*; see Table 1). As described by McGrew (2009), the CHC model includes additional possible Stratum II abilities that have not yet been validated fully, including Auditory processing (*Ga*), General (domain specific) knowledge (*Gkn*), Tactile abilities (*Gh*), Kinesthetic abilities (*Gk*), Olfactory abilities (*Go*), Psychomotor abilities (*Gp*), and Psychomotor speed (*Gps*).

Each Stratum II (broad) ability is divided further into narrower abilities (i.e., Stratum I abilities) that define the depth and breadth of a broad Stratum II ability. For example, memory span (MS) and working memory (WM) are Stratum I abilities and each measures a different aspect of *Gsm* (a Stratum II ability). In a comprehensive review, Newton and McGrew (2010) listed all nine broad (Stratum II) abilities and nearly 100 Stratum I abilities, with the latter being very narrow in scope. Examples of Stratum I abilities include writing ability (WA), mathematical achievement (A3), simple reaction time (R1), closure speed (CS), and reading comprehension (RC).

Although the CHC model of intelligence is a relatively comprehensive model of individual differences in cognitive abilities, several authors have contended that additional factors may be seriously considered for inclusion into the CHC model, including social and emotional intelligence (Wilhelm & Kyllonen, 2021). Additionally, it has been suggested that face processing abilities may be advantageously considered within the CHC model of intelligence (Meyer, Sommer, & Hildebrandt, 2021). As we detail below, commonly measured dimensions of face processing ability, including face detection, face perception and face memory, may be linked theoretically and empirically to several of the CHC model dimensions (see Table 1 for summary; see also Table S1 in supplementary materials).

Stratum I abilities are correlated positively with *g* (McGrew, 2009). For example, the correlation between general intelligence and reading comprehension, a Stratum I ability, has been reported to range between ≈ 0.40 and ≈ 0.55 (Jensen, 1998; Joshi & Hulme, 1998; Naglieri & Ronning, 2000; Tiu Jr, Thompson, & Lewis, 2003). Importantly, while reading comprehension is correlated moderately with general intelligence, it is not considered isomorphic with *g*. In fact, intelligence researchers recognise reading comprehension as a specific ability that can predict various outcomes, above and beyond general intelligence (Gersten, Fuchs, Williams, & Baker, 2001). Such an observation will be important for the theorised role of face processing ability within the context of cognitive abilities more broadly, as described in more detail further below.

1.5. *Face processing ability: defined*

Human face processing may be defined simply as the abilities necessary to process facial information, including the ability to detect, match, and recognise faces accurately (Fysh, 2018; Meyer et al., 2021). As mentioned previously, intelligence may be viewed as how well an individual adapts to an environment successfully using cognitive

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[2] Historically, the term 'fluid intelligence' has been used, however, the CHC model uses the term 'fluid reasoning'.

[3] Historically, the term 'crystallised intelligence' has been used, however, the CHC model uses the term 'comprehension-knowledge'.

Table 1
Stratum II abilities of the CHC model and possible associations to face processing abilities.

Ability	Definition	Example of a common test	Theoretical face processing ability links?		
			Face detection	Face perception	Face memory (short-term)
Fluid reasoning (*Gf*)	Deliberate and controlled mental operations employed to solve novel problems, that can't be solved automatically	Raven's Progressive Matrices (Raven, 1983)		✓	✓
Comprehension-knowledge (*Gc*)	The accumulation of the knowledge of information, language, and one's culture	Vocabulary subtest (Wechsler, 2008)			
Reading and writing (*Grw*)	The acquired knowledge of basic and complex reading and writing skills	Woodcock Reading Mastery Test—Revised (WRMT-R; Woodcock, 1987)			
Visual processing ability (*Gv*)	The ability to use mental imagery, often in conjunction with currently perceived images, to solve problems	Picture Completion subtest (Wechsler, 2008)	✓	✓	✓
Long-term storage and retrieval (*Glr*)	The ability to effectively store and fluently retrieve information from long-term memory	Information subtest (Wechsler, 2008)			
Processing speed (*Gs*)	The ability to fluently and automatically perform a task that is relatively easy or over-learned, especially when attention and concentration are required	Symbol Search subtest (Wechsler, 2008)	✓		
Short-term memory (*Gsm*)	The ability to apprehend and maintain information in an immediate situation and then use within less than a minute	Digit Span Forward (Wechsler, 2008)			✓
Reaction and decision speed (*Gt*)	Making simple decisions when items are presented at one time	Deary-Liewald Reaction Time task (Deary, Liewald, & Nissan, 2011)		✓	✓
Quantitative knowledge (*Gq*)	A person's declarative and procedural knowledge of numbers	Number Series (Gwenith, John, Ryan, Amanda, & David, 2013)			

Note. Definitions derived from Schneider and McGrew (2014) and McGrew (2009); the check marks indicate which cognitive abilities may be associated with specific face processing abilities on similarity/theoretical grounds.

abilities (McIntosh et al., 2012; Pintner, 1923; Sternberg, 1997). Face processing ability, a construct that includes face detection, face perception and face recognition as dimensions (described in more detail below), are all abilities that may be suggested to facilitate successful adaptation. For example, individual differences in face processing ability correlate positively with cooperative interactions ($r = 0.25$; Corbett, Newsom, Key, Qualls, & Edmiston, 2014) and quality of social networks ($r = 0.21$; McLaughlin Engfors, Palermo, & Jeffery, 2019). Therefore, face processing ability could be defined as an adaptive ability, as per cognitive intelligence more generally. Furthermore, face processing tasks require perceptual-cognitive skills to solve novel problems. Finally, the tasks are scored objectively – again, as per conventional IQ tests. As one example, face perception tasks (e.g., Cambridge Face Perception Test, CFPT; Duchaine, Germine, & Nakayama, 2007) show a line-up of faces that need to be matched to a target face, based on the degree of visual similarity to the target face. The task is scored based upon the number of accurate matches (quantitative similarity). Therefore, in general terms, face processing ability could be defined operationally as an individual's capacity to use cognitive faculties to complete a novel task involving faces and for which there is a clear procedure to evaluate successful completion of the task (i.e., veridical scoring).

1.6. *Inter-correlations between face processing abilities*

Like cognitive abilities more generally, there is evidence that face processing abilities yield a positive manifold. Verhallen et al. (2017) referred to the face processing general factor as *f*. McCaffery, Robertson, Young, and Burton (2018) and Verhallen et al. (2017) reported moderate to relatively large correlations ($r \approx 0.20$ to 0.50) between measures of face detection, face perception, and face memory (defined below). Although not all of the empirical research is consistent (e.g., Fysh, 2018), the observation of positive correlations between face processing abilities is similar to the observation of positive correlations between cognitive abilities more generally (Carroll, 1993). It should be noted that although detection, matching and recognising faces may be considered positively inter-related processes, they are also considered to be, at least to some degree, distinct. That is, the relatively large correlations (by individual differences research standards; Gignac & Szodorai, 2016) are not large enough to suggest construct redundancy. We discuss each face processing dimension in further detail next.

1.7. *Face detection*

Face detection is the ability to detect a face generally within a visual scene (Bindemann & Lewis, 2013; Verhallen et al., 2014). Studies show that humans are quicker at detecting a face than any other non-face object (Lewis & Ellis, 2003), implying that faces are an important object to detect for humans. It has been suggested that there may be a dedicated neurophysiological system that mediates the process of face detection, a system distinct from the detection of other objects (Lewis & Ellis, 2003). Individuals with prosopagnosia, the inability to recognise faces, can have impairments in their ability to detect faces (Garrido, Duchaine, & Nakayama, 2008). In fact, de Gelder and Stekelenburg (2005) proposed that some cases of developmental prosopagnosia may originate from deficits in face detection. Furthermore, they proposed that the face detection system is crucial for the normal development of more specialised face processing abilities, such as face memory. Thus, face detection may be considered a relatively more primary face processing ability.

A commonly used test of face detection is the Mooney test (Mooney, 1957), whereby a participant must view degraded images and determine whether an image contains a face or not (e.g., Fig. 1, left-side). Each Mooney face detection image has obstructions of the important local, featural and relational information (e.g., eyes, nose, mouth). Specifically, an individual would have to construct a specific, three-dimensional model of both the face and lighting in order to detect the face (Verhallen & Mollon, 2016). The underlying processes likely draws,

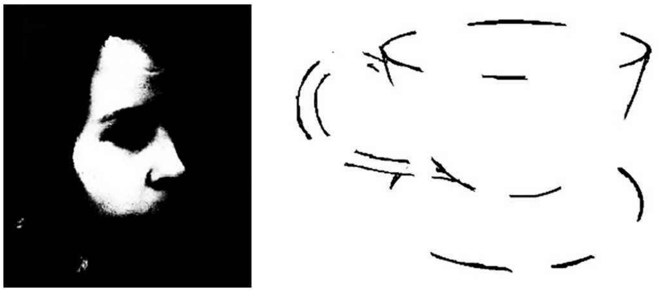

Fig. 1. Illustrative examples of a mooney test item (left-side) and a gestalt figure completion item (right-side).

to some degree, upon the observer's stored knowledge of faces acquired over their lifetime (Verhallen et al., 2017). Other tasks of face detection involve finding face-like images (see Robertson, Jenkins, & Burton, 2017) and actual face images (see Fysh, 2018) within a visual scene. Both of these tasks require participants to search visual scenes for concealed face images. Comparatively, the forementioned tasks involve visual searching of scenes to detect a real face, in comparison to the Mooney test which involves detection of a face from black and white ambiguous and non-ambiguous images. Some researchers argue that the Mooney test incorporates limited visual searching, a suggested essential component of face detection (Bindemann & Lewis, 2013; Fysh, 2018). Nonetheless, the Mooney test has been shown to be a reliable and valid measure of face detection (Schwiedrzik, Melloni, & Schurger, 2018; Verhallen et al., 2014; Verhallen & Mollon, 2016).

Overall, face detection is a holistic process whereby information is processed in a more general, "big picture" way, compared to local processing. Local processing involves attending to specific details, or processing information in a narrower and more detail orientated way (Navon, 1977). At a superficial level, the Mooney test has seemingly unrelated patches of white and black. An individual completing the task would need to look at the picture as a whole and decide whether the patches of white and black converge together to form the percept of a face. Thus, the Mooney test involves global judgments that are somewhat dependent upon the integration of local elements (Mooney, 1957). This process of organisation is often referred to as *closure* (or figure closure).

Arguably, the Mooney test may be considered a relatively narrow instantiation of more general figure closure tasks. For example, the Gestalt Figure Completion Task (Eliot & Czarnolewski, 1999; Goodwin, 2012; Street, 1931) is a commonly used measure of general figure closure ability: an ability regarded as a subdimension of intelligence (Closure Speed, CS; McGrew, 2009). Gestalt perception tasks tend to include incomplete figures of familiar objects, animals, or humans. In a manner similar to the Mooney test, an individual must first recognise the ambiguous stimuli and then label it (see Fig. 1, right-side). Arguably, with respect to both the Mooney test and Gestalt Figure Completion Task, an individual would have to create a mental image of the face/object, drawing upon their experience and knowledge of objects observed within their lifetime. Thus, drawing from the CHC model of cognitive abilities, performance on both tasks likely draws upon *Gv* (visual processing) and to some degree *Gc* (comprehension-knowledge). Thus, a positive correlation between face detection ability and general figure closure ability would be expected on theoretical grounds. Correspondingly, small-scale ($N = 63$) empirical research suggests that general figure closure and face detection tasks load onto the same cognitive ability factor (Wasserstein, Barr, Zappulla, & Rock, 2004). Therefore, whether figure closure tasks that include only face stimuli, as per the Mooney test, draw upon unique visual processing ability (i.e., somewhat distinct from general figure closure ability) remains to be determined, convincingly. Theoretically, the observation of some face detection specific (unique) variance would align with current research, suggesting that the ability to detect faces may be a process that is, at least to some degree, distinct from the ability to detect other objects (Lewis & Ellis, 2003).

Despite the fact that the Mooney test was published many years ago, little research has examined the association between intelligence and face detection ability. In one study, Vigen, Goebel, and Embree (1982) estimated the association between IQ (WAIS-R) and face detection ability (Mooney test) at $r = 0.25$, based on a diverse sample of college, vocation and community member participants ($N = 300$). By contrast, in another study with a primarily community sample ($N = 104$), McCaffery et al. (2018) reported a non-significant correlation ($r = 0.06$) between executive functioning (Card Sorting Task) and face detection ability (Mooney test). McCaffery et al. (2018) suggested that there was little association between face detection ability and other cognitive abilities. Thus, a meta-analysis may be required to help generate a consensus view on this issue.

1.8. Face perception

Theoretically, face perception is an important ability that would be expected to occur after a face has been detected. That is, once a face has been detected, it is possible to discriminate or individualise faces from each other. Face perception ability, at a basic level, involves scanning faces within a group and identifying faces as distinct/similar. Correspondingly, in typical face perception tasks, participants must discriminate, or tell apart, one face from another. Face perception tasks usually require the face stimuli to remain visible, in order to ensure that the task is focused on the visual processing required to perceive faces, with minimal memory requirements. The Warrington Recognition Memory for Faces test (Warrington, 1984) has participants view two photos and make the judgement of whether the identity of the person portrayed is the same or different (see Fig. 2). By contrast, the Benton Face Recognition Test (Benton, Sivan, Hamsher, Varney, & Spreen, 1983) has participants look at a target photo and asks them to choose the target individual from six simultaneously displayed photos (see Fig. 3). In recent years, other face perception tasks have been designed, including the relatively popular CFPT (Duchaine, Yovel, & Nakayama, 2007), the Kent Face Matching Test (Fysh & Bindemann, 2018), the Glasgow Face Matching Test (Burton, White, & McNeill, 2010; White, Guilbert, Varela, Jenkins, & Burton, 2021) and the Faces Card-Sorting Task (Andrews, Jenkins, Cursiter, & Burton, 2015). Arguably, these face perception tasks involve visual processing of faces with minimal memory requirements, thus rendering them relatively pure face perception tasks.

Higher levels of face perception ability have been linked to positive outcomes, whereas lower levels of face perception ability haven been linked to social difficulties. For example, the ability to tell faces apart, or individualise a face, is an important social skill (Fysh, Stacchi, & Ramon, 2020). From a professional perspective, many common professions require at least adequate performance in the ability to perceive and differentiate faces. For example, police officers may have to match a photo of a suspect with video footage of a crime scene (White et al., 2015). Additionally, border control officers and airport security personnel often check identification by matching a passport photo with the face of the person who presents with the identification (White et al., 2015). Similarly, people who work in banks, post offices, and establishments that sell alcohol must often match photo identification to a face.

Not everyone can perceive faces well. For example, individuals with prosopagnosia are often impaired in their face perception ability (Behrmann & Avidan, 2005; Duchaine, Germine, & Nakayama, 2007).

Fig. 2. An example item from the warrington recognition memory for faces (Warrington, 1984).

Note. Copyright Elizabeth K. Warrington, 1984. Reproduced by permission of Elizabeth K. Warrington.

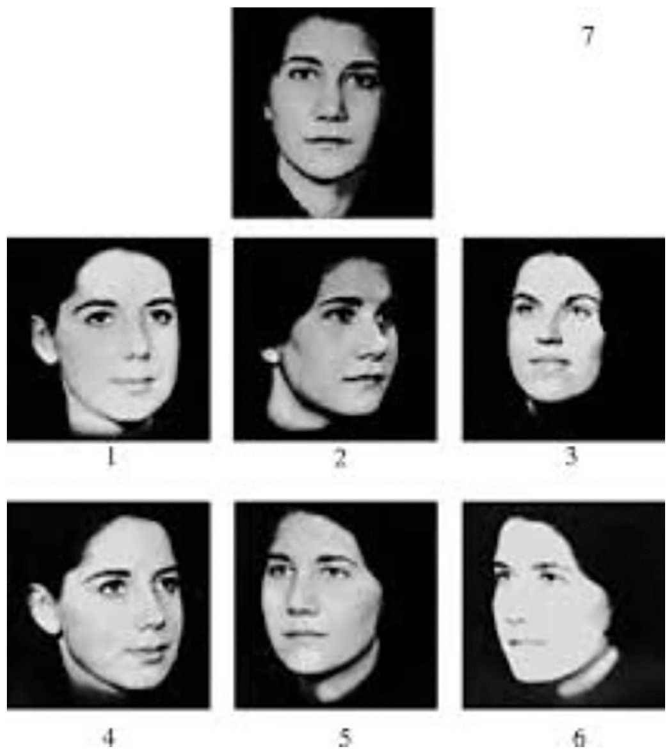

Fig. 3. An example item from the benton face recognition test (Benton et al., 1983).

Duchaine, Yovel, and Nakayama (2007) found that healthy controls averaged statistically significantly fewer errors than people with developmental prosopagnosia (Cohen's $d = -2.13$). Correspondingly, people with developmental prosopagnosia often report socialisation difficulties due to their poor face processing abilities and become anxious in public locations (Dalrymple et al., 2014). Therefore, a greater understanding of face perception ability is not only important theoretically, but also practically.

Face perception requires the ability to accurately discern facial configurations and features (Hildebrandt, Schacht, Sommer, & Wilhelm, 2012). More specifically, individuals must detect similarities, or differences, between faces. It could be argued that many visual processing and fluid reasoning tasks require similar detection of image similarities and differences. Consider, for example, the Raven's Progressive Matrices Test (Raven, Raven, & Court, 1998), a measure of fluid reasoning. In this task, participants are presented with a 3 × 3 matrix of geometric figures. Fig. 4 includes an example progressive matrices item from the International Cognitive Ability Resource (ICAR, 2017); it can be seen that the bottom right geometric figure is missing and must be selected from eight multiple choice response options. Interestingly, McGreggor, Kunda, and Goel (2010) found that a computer program designed solely to compare the similarity of images (akin to face perception tasks) was able to accurately complete over half of the Raven's Progressive Matrices Test. Arguably, the computer program exhibited processes related primarily to visual processing (*Gv*), and perhaps specifically visual matching, in addition to fluid reasoning (*Gf*). Correspondingly, Raven's Progressive Matrices has been found to measure general intelligence, as well as *Gf* and *Gv* (Gignac, 2017). Therefore, it is plausible to suggest that there is a positive association between a person's ability to perceive and differentiate faces and an individual's *Gf* and *Gv* ability. Stated alternatively, face perception ability may be considered, in part, a cognitive ability imbued with visual processing and fluid reasoning variance, within the context of the CHC model of cognitive abilities, at least theoretically.

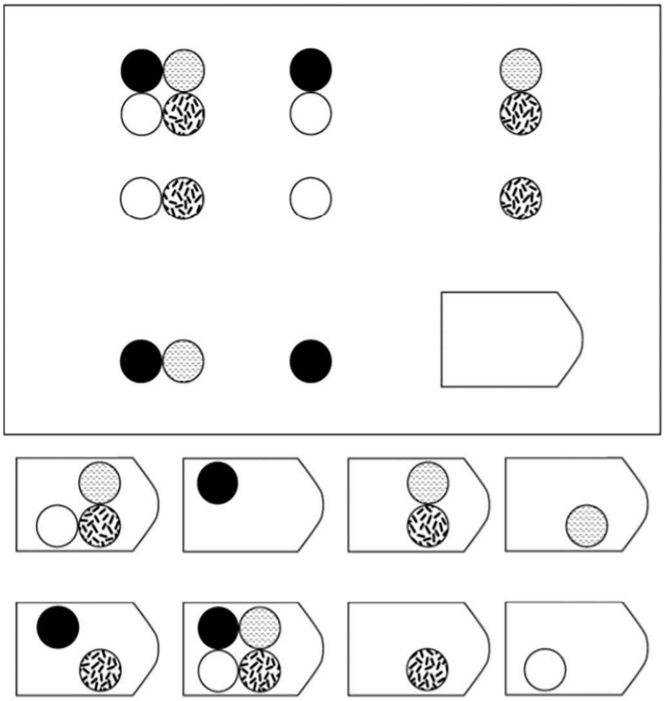

Fig. 4. An example of a progressive matrices item (ICAR).

Empirically, the evidence also suggests the possibility of a positive association. For example, Wilhelm et al. (2010) found a significant, positive association ($r = 0.56$) between their measure of face perception, a custom-made task based upon the part-whole paradigm, and composite intelligence scores defined by multiple cognitive ability subtests (community sample: $N = 209$). They interpreted their findings as supportive of the hypothesis of an association between intelligence and face perception ability. By contrast, Slone, Brigham, and Meissner (2000) investigated the association between the Benton Face Recognition Task, a measure of face perception ability, and a digit span task, a measure of short-term memory. They reported a small, non-significant correlation ($r = 0.09$); however, their study was based on a relatively small and restricted sample of university students ($N = 129$). As per face detection, the inconsistent results in the literature suggest that a meta-analysis may be beneficial.

1.9. *Face memory*

Face recognition is a term often used in the literature to describe different concepts. Some authors use the term face recognition for a task that involves perceiving faces (Oruc, Balas, & Landy, 2019). Additionally, the term face recognition has been used as a label for tasks and processes that are face perception or memory in nature. For example, the Benton Face Recognition Test (Benton et al., 1983) is a face perception test. Within this review, the term 'face memory' will be used, rather than the more ambiguous term 'face recognition'.

Face memory is the ability to perceive a face, encode that face into memory, and then recall that face, in order to determine if it has been seen previously (Dalrymple & Palermo, 2016). Many face memory tasks have a short interval between viewing the face and recalling the face (e.g., Cambridge Face Memory Test; CFMT; Duchaine & Nakayama, 2006). The CFMT requires participants to recognise six learnt faces across three test stages (see Fig. 5). In the learning stage, the participants learn the faces of six identities in frontal and side-on views. The first test stage requires participants to select which image contains a learnt face amongst two distractors. The images in this stage are identical to the learning stage. The second test stage employs the same three-alternative force choice paradigm, however, the images shown are different to the learning stage, i.e. novel images where the faces have different

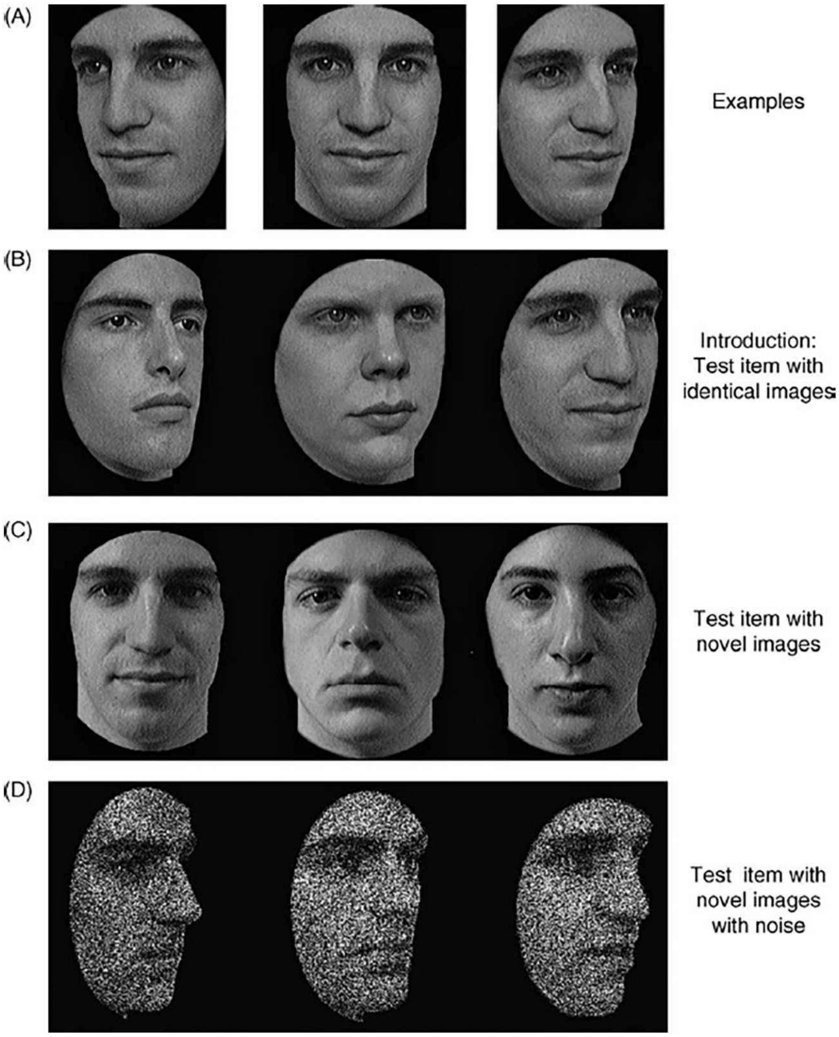

Fig. 5. The CFMT stages (Duchaine & Nakayama, 2006).

viewpoint and/or lighting. The third test phase is the same as the second stage, however, participants must recognise a learnt face in novel images covered by heavy visual noise.

There are also face memory tasks that test an individual's ability to recall the identity of a face over a longer period, for example, a time-delayed CFMT (McKone et al., 2011). The standard CFMT and time-delayed CFMT (both 20 min and 24 h) are correlated at 0.84 (McKone et al., 2011). Even though the CFMT is the most popular face memory test used by researchers, there are other valid tasks developed to measure face memory (see Hildebrandt et al., 2011).

Arguably, face memory is an important skill for successful social interaction, as the successful recognition of another person would be expected to determine how we may interact with the person in an appropriate manner. For example, recognising a colleague compared to a family member, will impact the interaction and appropriate socialisation. Correspondingly, individuals with clinical developmental prosopagnosia report that they avoid social situations where face memory is important (Murray, Hills, Bennetts, & Bate, 2018; Yardley, McDermott, Pisarski, Duchaine, & Nakayama, 2008). Furthermore, they also report long-term, negative consequences, as a result, including (but not limited to) dependency on others, restricted social circle, more limited employment opportunities and low self-confidence (Murray et al., 2018; Yardley et al., 2008). The interpersonal struggles shown by people with developmental prosopagnosia, linked to their inability to recognise faces, highlights the importance of face memory for everyday situations.

Theoretically, face memory may be considered to be associated with multiple cognitive abilities. The ability to recognise and remember faces over a short period of time may be linked to an individual's short-term memory (*Gsm*). Consider that the Digit Span Forward task from the Wechsler scales is similar in structure and task design to the CFMT. In Digit Span Forward, participants must recall a series of numbers previously learnt, whereas the CFMT requires participants to recall the identity of six faces previously learnt. The two tasks arguably tap into a similar process, notably short-term memory (*Gsm*). By contrast, the ability to recognise and remember faces over a long period of time could be linked to an individual's long-term storage and retrieval (*Glr*).

Interestingly, the Wechsler Memory Scale –Third Edition (WMS-III) includes two face memory tasks. These tasks, labelled Faces I and Faces II, form part of the Visual Immediate or Visual Delayed indices. In Faces I, participants are shown 24 target faces, and each face is displayed one at a time for 2 s. Then, participants are shown 48 faces (24 targets and 24 distractors) and are asked to identify the target faces by responding either "yes" or "no" to each face. Participants are prompted to keep the target faces in mind. In Faces II, participants are shown 48 faces (24 targets and 24 distractors) after a 30-min delay and are asked again to identify the target faces. Faces I and Faces II correlated with other subtests within the WMS-III. For example, Faces I correlated at 0.14 with Logical Memory I, and also correlated with another Visual Memory Immediate index task (Family Pictures I) at 0.30 (Psychological Corporation, 1997). Ultimately, the correlations between the Faces tasks and the other tasks within the WMS-III were deemed too low (insufficient convergent validity), which led to the removal of these tasks from the WMS-IV (Hawkins & Tulsky, 2004).

On the one hand, the low correlations may be due to methodological considerations. For example, the measure itself differs from the free recall methodology employed by the WMS-III. Moreover, the recognition format of the faces subtest without a recall component may make the test easier than other nonverbal memory tests (Tulsky, Chiaravalloti, Palmer, & Chelune, 2003). On the other hand, it may be acknowledged that facial memory may require a special (unique) type of visual processing. For example, research into face recognition ability has found that recognition of faces activates a cortical region in the brain specialised to the perception of faces, known as the Fusiform Face Area (Kanwisher & Yovel, 2006; Tsao, Freiwald, Tootell, & Livingstone, 2006). Consequently, memory for faces would not necessarily be expected to be meaningfully correlated with intelligence, and some researchers contend that it is not (Bowles et al., 2009; Shakeshaft & Plomin, 2015; Wilmer et al., 2014).

The empirical results on the association between intelligence and face memory are inconsistent. For example, Gignac et al. (2016) reported a positive, significant association between intelligence, as measured by multiple subtests, and the CFMT, a measure of face memory ($r = 0.35$; $N = 211$). They interpreted their findings as supportive of an association between intelligence and face memory ability. By contrast, Richler, Wilmer, and Gauthier (2017) failed to find a significant association between intelligence (Matrices from the Wechsler Abbreviated Scale of Intelligence) and face memory (CFMT), based on a community sample ($N = 279$). It is noted that Richler et al.'s measurement of intelligence would not be considered good or excellent, based on Gignac and Bates (2017) guidelines, whereas several studies that did use good or excellent intelligence measurement (i.e., several subtests; multiple dimensions) did find a significant and positive association between intelligence and face memory ability (Gignac et al., 2016; Herlitz & Yonker, 2002; Zhu et al., 2010). Thus, a meta-analysis may be useful to help synthesise the empirical results and possibly identify intelligence measurement quality as a positive moderator of the effect between intelligence and face processing ability.

1.10. *Emotion recognition and other types of face processing*

In addition to identity, people glean lots of information from faces, such as eye gaze, attractiveness, trustworthiness, speech decoding, first impression and emotion. These face processing abilities are beyond the scope of this review; however, it is important to review briefly the recent research on individual differences in face emotion recognition and intelligence. Face emotion recognition is the ability to accurately and efficiently recognise facial expressions (Palermo, Connor, Davis, Irons, & McKone, 2013). Empirically, individual differences in face emotion recognition have been found to be associated positively with intelligence (Borod et al., 2000; Connolly et al., 2019; Hildebrandt, Sommer, Schacht, & Wilhelm, 2015). Furthermore, a meta-analysis estimated the association between face emotion recognition and cognitive abilities at $r \approx 0.19$ (Schlegel et al., 2019); however, the correlations were not corrected for measurement error and range restriction, nor was intelligence measurement quality taken into consideration. Thus, the reported 0.19 correlation is likely a substantial underestimate.

1.11. *Face processing ability and intelligence: definitional similarities*

It is plausible to postulate that face processing abilities facilitate successful adaptation and involves goal/problem solving using cogntive-perceptual abilities. Stated alternatively, we define face processing ability as an adaptive cognitive-perceptual ability to detect, match or recognise facial identity and facial expressions. Such a definition aligns with abstract definitions of intelligence that focus upon successful environmental adaptation (McIntosh et al., 2012; Pintner, 1923; Sternberg, 1997).

Beyond theoretical similarities, face processing tests have characteristics that align with operational measures of cognitive abilities. That is, in more operational terms, face processing abilities can be defined as an individual's ability to complete a novel, standardised visual task involving faces and for which there is veridical scoring. For example, the CFMT is a standardised visual face task that includes novel problems/stimuli and is scored objectively; i.e., in line with conventional operational definitions of intelligence (Gignac, 2017).

2. Summary

Face processing abilities represent the ability to detect, perceive, and recognise facial identity and expressions. Furthermore, face processing abilities are important for many different social and professional situations. The previous sections highlighted how face detection, face perception and face memory are important, how these abilities are measured and how these abilities may be related to other cognitive abilities within the CHC model. Finally, face processing abilities can be defined and conceptualised in a manner congruent with intelligence definitions and conceptualisations. However, to date, research pertinent to the empirical estimation of the association between intelligence and face processing abilities has not been examined meta-analytically. Consequently, the purpose of this investigation was to estimate meta-analytically the true score (corrected for measurement error) correlation between intelligence and three face processing abilities: face detection, face perception, and face memory. We also investigated the possibility that the magnitude of the correlations would be moderated positively by intelligence measurement quality.

3. Methods

3.1. *Literature search*

The literature search reported in this review was conducted on 12th October 2021. The literature search aimed to identify any study that measured cognitive abilities and either face detection, face perception or face memory ability. In line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; see Fig. 6), the review methodology involved four steps—identification, screening, eligibility, and inclusion. In the identification step, the following electronic databases were searched, without restricting the publication date or language: Education Resource Information Centre (ERIC), PsychINFO, ProQuest, Medline, PubMed, and CINAHL. Unpublished literature was also searched through Dissertations in Proquest.

The database search (titles, abstracts, and keywords) included the following terms: ("Intelligence" OR "IQ" OR "Visual Memory" OR "verbal intelligence" OR "non-verbal intelligence" OR "Cognit* abilit*" OR "Fluid intelligence" OR "Fluid abilit*" OR "processing speed" OR "reasoning" OR "Raven's" OR "Raven" OR "Wechsler" OR "Cultural Fair") AND ("face recognition" OR "Face Identity recognition" OR "Face memory" OR "Face perception" OR "Benton Face" OR "Face cognition" OR "Mooney N3 Task" OR "Holistic processing N3 Mooney" OR "Visual closure N3 Mooney" OR "Holistic perception N3 Mooney" OR "Mooney N3 Test"). Different search techniques were used to help eliminate irrelevant articles and help locate relevant articles. For example, truncation (*) allows different forms of a search term to be included (e.g. cognit* will include search terms such as cognition and cognitive) and wildcards (e.g. N) indicated that the search terms needed to be near/adjacent within a specified number of words (e.g. Mooney N3 Test means the search term Mooney and Test need to be near to each other within three words, which identifies articles with the term Mooney Test, Mooney Face Test, Mooney Face Closure Test and any other variation of this). The database search identified 545 unique records (15 were duplicates). Two additional records were identified: one through citation search, and one (via A. Hildebrandt) by emailing 37 authors in the area

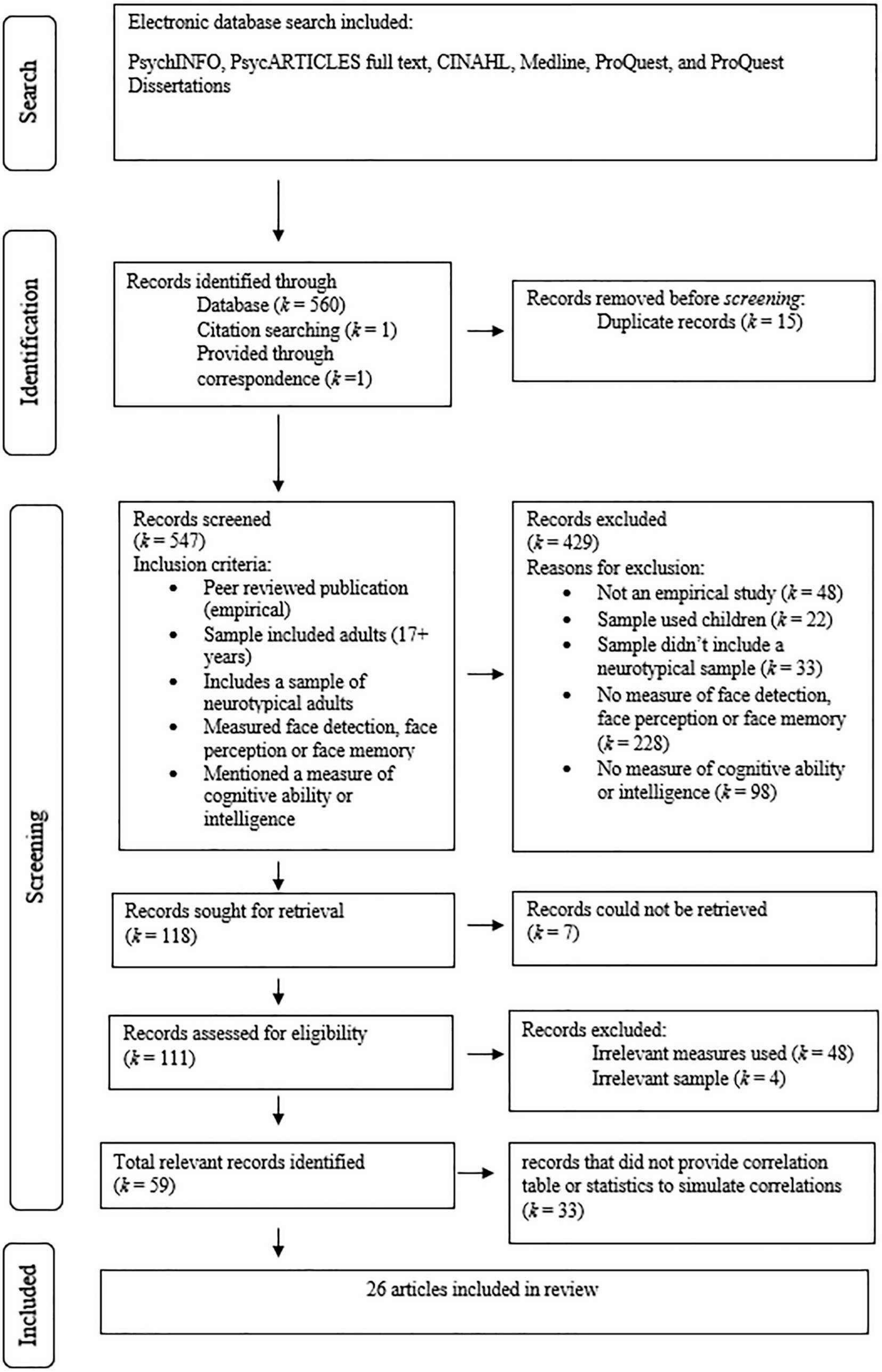

Fig. 6. Flow diagram for the search and inclusion criteria for studies in the present review.

about potentially relevant unpublished data (thus, 547 unique records for screening).

3.2. Study selection

Studies were selected for further review based on the following inclusion criteria:

1. Sample: Neurotypical adults over the age of 18. Some studies of special populations also included neurotypical control participants, the latter of which were included in this investigation.
2. Measures: studies were included if they administered a valid intelligence test (e.g., Wechsler Adult Intelligence Scale, Wechsler Adult Intelligence Scale-Revised, Cattell Culture Fair Intelligence Test), or a valid intelligence subtest (e.g., Digit Span, Card Sorting Task, etc.). Studies must also have included a measure of face processing ability, on the basis of either the following search terms: face memory, face recognition, face perception, face identity recognition, or face detection, or a commonly regarded task (e.g., CFMT or Benton Face Recognition Task).

Once all potentially useful records were identified, the initial screening commenced by reviewing the abstract, keywords and titles through an online article review platform, Rayyan (Ouzzani, Hammady, Fedorowicz, & Elmagarmid, 2016). To reduce bias, all studies selected were reviewed by the authors DW and ZC. Disagreements were discussed until an agreement was reached. The initial screening excluded 429 articles for one or more of the following reasons: (1) it was not an empirical study; (2) studies were conducted on children (17 years or younger); (3) the study had no sample of neurotypical adults; (4) the study did not include a measure of face detection, face perception or face memory; (5) the study did not mention any measure of cognitive ability.

After the initial screening, a total of 118 articles remained for full-text screening. Seven of the articles could not be retrieved, therefore, the full-texts of the 111 articles were screened for relevance and correlation results by author DW. Fifty-nine articles were identified as having relevance for the review based on methodology and sample characteristics (e.g., neurotypical adults). Of these articles, 37 articles contained one or more relevant measured variables, however, the correlation(s) were not reported. The corresponding author of the relevant articles was sent an email, requesting the correlation between their cognitive ability measure(s) and their face memory, face perception or face detection measure(s), or to provide the raw data for our own analysis. Ten authors provided the requested correlational results, six authors were unable to provide the results or the data, and 21 authors did not respond.

Wilhelm et al. (2010) and Olderbak, Hildebrandt, and Wilhelm (2015) were included in the meta-analysis as representative of two different samples. The corresponding author confirmed that other potentially relevant studies used the same samples (Hildebrandt et al., 2011; Sommer, Hildebrandt, Kunina-Habenicht, Schacht, & Wilhelm, 2013), therefore, these were not included to avoid duplication. Similarly, the same corresponding author confirmed that two identified studies used the same sample (Kaltwasser, Hildebrandt, Recio, Wilhelm, & Sommer, 2013; Kiy, Wilhelm, Hildebrandt, Reuter, & Sommer, 2013). Finally, the corresponding author provided an additional published study and relevant data to represent the sample (Hildebrandt et al., 2015) that avoided duplication. Furthermore, the sample in Connolly, Young, and Lewis (2021) and Connolly et al. (2019) appeared to be the same. In order to avoid duplication, only the Connolly et al. (2019) was included in the meta-analysis.

Finally, one corresponding author provided the relevant data for their study (Danielsson et al., 2006), however, upon further evaluation, a severe ceiling effect was apparent for the Raven's Coloured Matrices test scores. Specifically, a score of 97.2% or higher was achieve by 83.3% of the participants. As the ceiling effect was so acute (perhaps to be expected, as the Coloured Matrices is a test for children), Danielsson et al. (2006) was not included in the meta-analysis.

3.3. Characteristics of the meta-analytic dataset

A total of 26 relevant articles with available correlation results (reported or supplied) were included in the meta-analyses. Of these, one study used a face detection measure, four studies used a measure of face perception, and 14 studies used a measure of face memory. Furthermore, six studies included both a face perception and a face memory measure, and one study included measures of face detection, face perception, and face memory. Two face memory studies reported correlations across two separate samples (Wilmer et al., 2010 twin and non-twins, and Hills, Lowe, Hedges, & Teixeira, 2020 experiment 1 and 2). Thus, the number of included samples/correlations corresponded to: face detection $k = 2$; face perception $k = 11$; and face memory $k = 23$.

Finally, for each included study, we extracted the following study characteristics: sample size, intelligence measure(s), face processing ability measure(s), the means and standard deviations of the measures, proportion of male to female, mean age, demographics of sample (e.g., university students, community sample), the source of the correlation (e.g., from article, from corresponding author), test score reliabilities, reference details and additional notes specific to the investigation.

3.4. Quality of intelligence measures

Gignac and Bates (2017) provided guidelines to help researchers partially quantify the degree of intelligence measurement quality (poor, fair, good, and excellent) associated with various combinations of tests. In summary, the criteria outlined in Gignac and Bates (2017) are as follows: (1) number of subtests (poor: 1, fair: 1–2, good: 2–8 and excellent: 9+); (2) number of dimensions (poor: 1, fair: 1–2, good: 2–3 and excellent: 3+); (3) testing time (poor: 3–9 min, fair: 10–19 min, good: 20–39 min and excellent: 40 + min); and (4) correlation with g (poor: < 0.49, fair: 0.50–0.71, good: 0.72–0.94 and excellent: ≥ 0.95). The final criterion requires some judgement on the part of the researcher, and in the absence of empirical evidence, the first three criteria may be used exclusively. Furthermore, in cases where there were inconsistencies across the first three rated criteria, judgement was again required. For example, a study that administered three subtests (good), but all measured the same dimension of IQ (poor), and required only nine minutes of testing (e.g., short-forms; poor) would require some judgement (likely poor). Based on our review of the included 26 studies and Gignac and Bates' (2017) guidelines, 33% of the studies used poor quality, 14% of studies used fair quality, 44% of studies used good quality, and 8% used excellent quality intelligence measures. Across the three types of studies, the IQ measurement quality percentages corresponded to: face detection, 50% poor, 50% good; face perception: 36% poor, 64% good; and face memory: 30% poor, 22% fair, 35% good, 13% excellent (see Fig. 7).

3.5. Sample restriction

The face detection, face perception and face memory studies were assessed for sample restriction and categorised accordingly. The two face detection studies had mixed samples of either university and community, or university and vocational participants. Furthermore, 27% of the face perception studies were considered restricted (i.e., university sample), 18% of studies used a mixed sample of university and community participants, and 55% of studies were community based. Moreover, only 46% of studies ($k = 5$) used a good measurement of intelligence and a non-restricted sample (i.e., community sample). With respect to the face memory studies, 30% of studies were considered restricted (i.e., university sample), 13% of studies used a mixed sample of university and community participants, and 57% of studies were community based. Finally, only 30% of face memory studies ($k = 7$) used at least a good/excellent measure of intelligence and a non-restricted

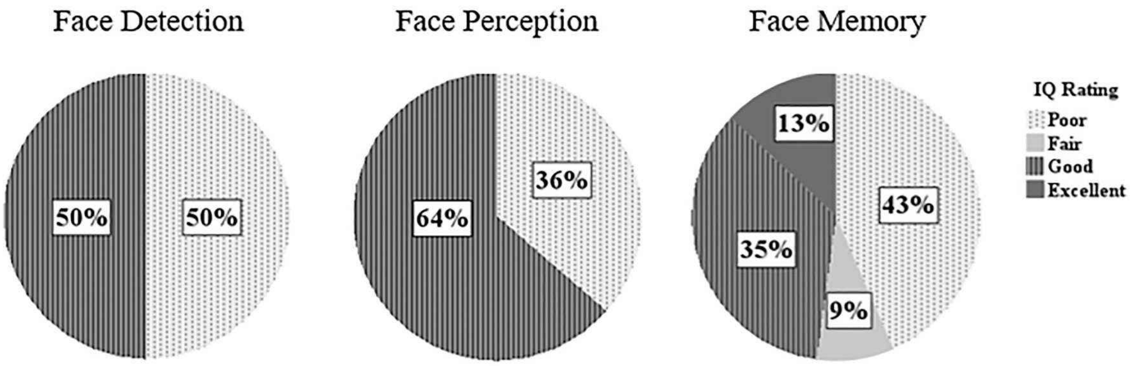

Fig. 7. Pie chart representing the percentage of studies across intelligence measurement quality categories for the included studies.
Note. Face detection $k = 2$; face perception $k = 11$; face memory $k = 23$.

community sample. As we revisit in the discussion, the relatively small number of studies with good quality intelligence measures and non-restricted samples suggests that many of the effect sizes reported in the literature are likely meaningful underestimates.

3.6. Data analysis

Across several studies, the process by which we calculated/estimated the relevant bivariate correlation and/or internal consistency reliability involved multiple steps, including the simulation of data, in some cases. Consequently, for each study included in the meta-analyses, we created a folder with detailed method related descriptions, scripts, data files, and output files (access here: https://osf.io/6ae3v/). Below, we include some details associated with some of the more common procedures we used, in order for the general reader to appreciate.

3.7. Correlations

For some studies, the relevant bivariate correlation between intelligence and the face processing task was reported in the results section and we included those correlations in Tables 2, 3 and 4. In the event that studies included more than one cognitive ability test/subtest, we typically selected the relevant correlation associated with the overall indicator of intelligence (e.g., full scale intelligence quotient; FSIQ). When no overall indicator correlation was available, but the correlations between the intelligence subtests and face processing test(s) were reported, we simulated the data[4] to enable the calculation of a total intelligence composite score, which then allowed for the estimation of the correlation between overall intelligence and the face processing ability of interest. In other cases, the correlations between cognitive ability tests were not reported/available, therefore, we averaged the cognitive ability subtest correlations with the face processing ability of interest via Fisher's z transformation and back-transformation ('DescTools' package developed for *R*; Signorell, 2021). Finally, if a study reported correlations across conditions or groups (e.g., Herlitz & Yonker, 2002), the correlations were also averaged with the same procedure to represent an overall correlation. Finally, although one-tailed tests of the correlations could have been used, we used two-tailed tests of the correlations to be on the conservative side.

With respect to Meinhardt-Injac, Daum, Meinhardt, and Persike (2018), an investigation that reported only latent variable results, we used the path tracing rule (Wright, 1934) in order to derive the correlations between the observed variables. Once these correlations were calculated via the path tracing rule, it facilitated the simulation of the data, the derivation of total intelligence scores, and, finally, the estimation of correlations between overall intelligence and face processing abilities.

Olderbak et al. (2015) included a covariance matrix for the correlations between all of the observed variables. We converted the covariance matrix into a correlation matrix, in order to simulate the data. The full correlation matrix created a non-positive defined matrix. Notably, the Olderbak et al. study included nine cognitive ability tests, eight of which were memory tests. Therefore, the cognitive ability battery was considered biased toward a single-dimension of ability(i.e., memory), one that may be expected to associate highly with face memory. Therefore, in order to obtain a relatively balanced representation of overall intelligence, only one task from each of the cognitive ability dimensions was selected: reasoning 1 (REA1), working memory 1 (WM1), and immediate and delayed memory 6 (IDM6). The IDM6 task was selected out of all the immediate-delayed memory tasks because it was based on both numbers and letters, and represented delayed memory, rather than immediate (short-term) memory (i.e., was less similar to the WM1 task).

Finally, Wilhelm et al. (2010) reported latent variable coefficients between their intelligence measures, face perception measure and face memory measure. As the latent variable coefficients were already disattenuated for imperfect measurement reliability, it was possible to calculate the corresponding observed score correlation between the subtests by reverse calculating the disattenuated correlation, on the basis of the reliability coefficients (estimated via coefficient omega) and the disattenuation formula (Nunnally & Bernstein, 1994). The 36 reported/estimated observed score correlations included in our investigation can be found in Tables 2, 3 and 4 for face detection, face perception and face memory, respectively.

3.8. Reliability

The test score reliabilities were required for the purposes of disattenuating the correlation coefficients for imperfect reliability, based on the classical test theory disattenuation formula (Nunnally & Bernstein, 1994). Only three articles reported the reliabilities of both their face test scores and cognitive ability test scores: Gignac et al. (2016); Wilmer et al. (2010); Zhu et al. (2010). For several studies (e.g., Richler et al., 2017; Zhu et al., 2010), we estimated internal consistency based on an analysis of the inter-subtest correlations (i.e., coefficient omega), as such a level of analysis represents the reliable variance attributable to overall composite scores (Gignac, 2017).

For the remaining studies that did not report the test score reliabilities (cognitive ability and face processing), internal consistency reliability was often estimated with the Kuder-Richardson formula 21

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[4] We used a method to simulate correlated data described here: https://cran.r-project.org/web/packages/faux/vignettes/rnorm_multi.html

Table 2

Descriptive statistics, sample characteristics, and key correlation associated with systematic review: face detection.

Source	Age: *M* (*SD*)	Face processing measure	*α*	IQ measure	*α*	# IQ tests	IQ quality	*N*	Sample	Restricted	% Female	*r*	*p*	r'	Age adjusted?
Vigen et al. (1982)	33.07 (N/A)	Mooney test	0.73	WAIS-R	0.91	11	Excellent	300	University, Vocation, Community	2	49.7	0.25	0.001	0.31	No
McCaffery et al. (2018)	53 (15)	Mooney test	0.84	Card Sorting Task	0.81	1	Poor	107	Online and minimal university	2	52.3	0.06	0.539	0.07	No

Note. WAIS-R = Wechsler Adult Intelligence Scale - Revised; IQ quality was assessed using the criteria described in Gignac and Bates (2017); Vigen et al. mean age calculated by averaging across all participant groups; *α* = coefficient alpha or coefficient omega (reliability); restricted = degree of range restriction in the sample (1 = minimal restriction; 2 = moderate restriction; 3 = substantial restriction); *r* = observed Pearson correlation; *p*-values calculated via Excel (see supplementary materials); r' = disattenuated correlation coefficient for imperfect reliability.

(KR-21′), as the test scores were based on dichotomously scored items (i.e., answers that are right or wrong).[5] The formula requires raw scores, therefore, test sores reported as a percentage were first converted into raw scores, before inputted into the KR-21′ formula. This was achieved by simulating the data using *R* and converting the percentage correct scores into raw scores (see 'Data Guide' associated with each study folder). The most common measures in this investigation that required this procedure for the calculation of reliability was the CFMT and the Benton Face Recognition Task.

Additionally, a few test score reliabilities were calculated using a coefficient omega Excel sheet (McNeish, 2018), as the authors reported standardised factor solutions, or the Spearman-Brown Prophecy formula (de Vet, Mokkink, Mosmuller, & Terwee, 2017), as documented in the supplementary materials. No reliabilities or intelligence subtest correlations were reported for Vigen et al. (1982) who used the Satz-Mogel abbreviated form of the WAIS-R (Smigielski & Jenkins, 1984). Therefore, the WAIS-R coefficient omega hierarchical reported by Gignac (2005), based on an analysis of the WAIS-R normative sample inter-subtest correlation matrix (Wechsler, 2008), was used as the internal consistency reliability estimate.

Similarly, no reliabilities or intelligence subtest correlations were reported for Andric, Maric, Mihaljevic, Mirjanic, and van Os (2016) or Caldiroli et al. (2018). These two studies both used the same combination of subtests from the WAIS-R. The corresponding author for Andric et al. (2016) provided the relevant data to estimate overall intelligence composite score reliability, however, the corresponding data were not made available for the Caldiroli et al. (2018) sample. Therefore, we used the Andric et al. overall intelligence internal consistency reliability estimate for the Caldiroli et al. study.

Additionally, Slone et al. (2000) did not report reliability for the Benton Face Recognition Task, therefore, we used the Benton Face Recognition Task reliability reported in Rossion and Michel (2018). Similarly, Shakeshaft and Plomin (2015) did not report the reliability or correlation between their two cognitive ability measures. Therefore, the correlation between the Mill-Hill Vocabulary Test and Raven's Progressive Matrices, as reported by Raven (1983; $r = .75$), was used to help simulate data from which coefficient omega for the total scores could be estimated. Finally, Palermo et al. (2013) cited the reliability of the Cattell Culture Fair Intelligence Test-III from Cattell and Cattell (2008), therefore, that reliability coefficient was used in this investigation. Again, all of the reliability estimation details associated with each study are included in the relevant publicly accessible study folders (access here: https://osf.io/6ae3v/). All of the test score reliabilities, as well as the disattenuated correlations, used in the psychometric portion of this investigation's meta-analysis are reported in Tables 2, 3, and 4 for face detection, face perception and face memory, respectively.

3.9. Meta-analytic data analysis strategy

All meta-analyses were conducted via a random effects model using the 'metafor' package version 3.0.2 (Viechtbauer, 2010) for *R* version 4.1.0 (R Core Team, 2021). The commands and results can be accessed here: https://osf.io/6ae3v/. Both barebones and psychometric meta-analyses were conducted in this investigation. Therefore, the Hunter-Schmidt estimation method with a small sample size correction ('HSk') was used, as it was developed for both barebones and psychometric meta-analyses (Hunter & Schmidt, 2004). The barebones meta-analysis is required for the evaluation of publication bias, while the psychometric meta-analysis yields more accurate estimation of true effects, as it takes into account imperfect reliability in the test scores.

The study correlations/sample sizes were examined in accordance with the nine outlier evaluation statistics described by Viechtbauer (2010). If any outliers and/or influential case were identified, the leave-one-out method was consulted, where the study/effect size is removed from the meta-analysis to evaluate the degree to which it influences the overall estimate (Viechtbauer, 2010). If the re-estimated correlation was different by $|0.09|$ or greater, then the study was deemed excessively influential and excluded from further analyses.

Heterogeneity of correlations was evaluated with I^2, mainly because its magnitude is not influenced by the number of included studies (Borenstein, Higgins, Hedges, & Rothstein, 2017). As a general rule, low, moderate and high heterogeneity is associated with I^2 values of 25%, 50%, and 75%, respectively. We note that with $k \approx 10$ heterogeneity (i.e., I^2) is difficult to evaluate statistically in a valid manner (von Hippel, 2015). Nonetheless, for completeness, the I^2 and corresponding 95% confidence intervals were estimated. We also reported the forest-plots to facilitate visual evaluations of effect size heterogeneity.

In order to evaluate the possibility of publication bias, counter-enhanced funnel plots were consulted for each meta-analysis. The funnel plots were evaluated for asymmetry, whereby all of the studies' standard errors were plotted against their respective correlations. The Egger's regression test (Egger, Smith, Schneider, & Minder, 1997) was also conducted to test for publication bias statistically.

Finally, previous meta-analytic research suggests that quality of intelligence measurement may moderate the magnitude of the correlation between intelligence and another variable (Gignac & Bates, 2017). Consequently, a meta-regression was conducted to evaluate whether quality of intelligence measurement moderated the magnitude of the correlations between intelligence and face memory. In order to conduct this meta-regression, the quality of intelligence measurement variable (coded: 1 = poor; 2 = fair; 3 = good; 4 = excellent) was specified as a moderator variable in the relevant metafor command line. Only the face memory studies were evaluated, in this context, as 11 and two studies (i.e., face perception and face detection, respectively) were considered manifestly insufficient to evaluate statistically a hypothesised

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[5] We used a slightly modified version of the KR-21 formula (i.e., KR-21′) developed by Wilson (1979), a version that has been found to be more accurate than the original formulation (as cited in Frisbie, 1988).

Table 3

Descriptive statistics, sample characteristics, and key correlation associated with systematic review: face perception.

Source	Age: *M* (*SD*)	Face processing measure	*α*	IQ measure	*α*	# IQ tests	IQ quality	*N*	Sample	Restricted	% Female	*r*	*p*	*r'*	Age adjusted?
Andric et al. (2016)	29.8 (6.3)	Benton FRT	0.43	WAIS-III Arithmetic, Digit Symbol Coding, Information, and Block Design (FSIQ)	0.72	4	Good	51	Community	1	54.9	0.29	0.039	0.52	No
Boutet and Meinhardt-Injac (2021)	41.44 (22.21)	GFMT	0.76	Short version of Raven's SPM	0.89	1	Poor	243	University	3	69.1	0.33	<0.001	0.40	No
Caldiroli et al. (2018)	29.76 (8.0)	Benton FRT	0.73	WAIS-III Arithmetic, Digit Symbol Coding, Information, and Block Design (FSIQ)	0.72	4	Good	113	Community	1	52.2	0.13	0.170	0.18	No
Connolly et al. (2019)	54 (18.2)	Benton FRT	0.48	CFIT, Scale 2, Form A (overall)	0.84	1	Poor	605	Community	1	51.9	0.42	<0.001	0.67	No
Hildebrandt et al. (2015)	26 (5.92)	Custom Task	0.69	WM & REA = Memory Updating, Rotation Span Raven's APM; IDM (Name, Verbal, Address)	0.87	6	Good	269	Community	1	52	0.42	<0.001	0.54	No
McCaffery et al. (2018)	53 (15)	GFMT	0.74	Card Sorting Task	0.81	1	Poor	107	Online and minimal University	2	52.3	0.20	0.039	0.26	No
Meinhardt-Injac et al. (2018)	22.2 (3.4)	GFMT	0.75	Reasoning ability = Raven's short-form, Dice Task, Digit Sequence Verbal ability = Vocabulary, Verbal Analogies and Orthography	0.68	6	Good	343	University and Community	2	71.1	0.07	0.196	0.10	No
Olderbak et al. (2015)	48.5 (20.3)	Custom Task	0.72	WM & REA = Memory Updating, Rotation Span Raven's APM; IDM (Name, Verbal, Address)	0.75	6	Good	443	Community	1	51	0.56	<0.001	0.76	No
Rigby, Stoesz, and Jakobson (2018)	27.3 (7.5)	SIMT	0.76	WASI - Block Design, Vocabulary, Matrix Reasoning, Similarities (FSIQ reported as total of these subtests)	0.97	4	Good	16	University	3	31.2	0.39	0.135	0.46	Yes
Slone et al. (2000)	N/A	Benton FRT	0.61	Digit Span (WAIS-R)	0.64	1	Poor	129	University	3	72.9	0.09	0.310	0.14	No
Wilhelm et al. (2010)	25 (4.1)	Custom Task	0.73	Raven's APM, Memory updating, Rotation span, IDM (Name, Verbal, Address)	0.77	4	Good	209	Community	1	52.1	0.42	<0.001	0.56	No

Note. Benton FRT = Benton Face Recognition Test; GFMT = Glasgow Face Memory Task; SIMT = Simultaneous Identity Matching Task; CFIT = Cattell's Culture Fair Intelligence Test; FSIQ = Full Scale Intelligence Quotient; IDM = Immediate and Delayed Memory task; Raven's APM = Raven's Advanced Progressive Matrices; Raven's SPM = Raven's Standard Progressive Matrices; WAIS = Wechsler Adult Intelligence Scale; WASI = Wechsler Abbreviated Scale of Intelligence; WM & REA = Working Memory and Reasoning Tasks; Vocab = Vocabulary; *α* = coefficient alpha or coefficient omega (reliability); restricted = degree of range restriction in the sample (1 = minimal restriction; 2 = moderate restriction; 3 = substantial restriction); *r* = observed Pearson correlation; *r'* = correlation disattenuated for imperfect reliability; IQ quality was assessed using the criteria described in Gignac and Bates (2017); *p*-values calculated via Excel (see supplementary materials).

Table 4
Descriptive statistics, sample characteristics, and key correlation associated with systematic review: face memory.

Source	Age: *M* (*SD*)	Face Processing Measure	*α*	IQ Measures	*α*	# IQ tests	IQ quality	*N*	Sample	Restricted	% Female	*r*	*p*	*r'*	Controlled for age
Anstey, Dain, Andrews, and Drobny (2002)	70.8 (7.1)	Faces subtest (WMS III)	0.71	Raven's PM, Similarities, DSB	0.68	3	Good	90	Community	1	60	0.34	0.001	0.49	Yes
Batterham, Bunce, Cherbuin, and Christensen (2013)	76.19 (4.70)	Faces subtask based on Rivermead Behavioural Memory Test	0.45	Speed of processing, verbal fluency, episodic memory	0.66	3	Good	590	Community	1	51	0.22	<0.001	0.40	No
Boutet and Meinhardt-Injac (2021)	41.44 (22.21)	CFMT	0.88	Short version of Raven's SPM	0.89	1	Poor	243	University	3	69.1	0.36	<0.001	0.41	No
Davis et al. (2011)	21.9 (4.1)	CFMT	0.67	CFIT III	0.74	1	Poor	66	University	3	63.6	−0.08	0.523	−0.11	Yes
Gignac et al. (2016)	19.8 (2.9)	CFMT	0.83	CFIT Scale 3, Form A (series & Matrices), Quick *Gf*, mental rotation, DSB, WSB, VSB, Vocab	0.69	8	Excellent	211	University	3	67.8	0.26	<0.001	0.34	Yes
Hedley, Brewer, and Young (2014)	24.9 (9.9)	Custom Task	0.77	WASI – Vocab and Matrix Reasoning (FSIQ)	0.39	2	Good	33	University	3	42.4	0.17	0.344	0.31	Yes
Herlitz and Yonker (2002)	27.6 (5.7)[6]	Custom Task	0.81	WAIS-R – Information, Vocab, Comprehension, Similarities, Picture Completion, Picture Arrangement, Block Design, Figure Completion, Digit Symbol	0.91	9	Excellent	187	Community	1	52.9	0.26	<0.001	0.30	Yes
Hildebrandt et al. (2015)	26 (5.92)	Custom Task	0.89	WM & REA = Memory Updating, Rotation Span Raven's APM; IDM (Name, Verbal, Address)	0.87	6	Good	269	Community	1	52	0.39	<0.001	0.44	No
Hills et al. (2020) Experiment 1	21.6 (5.8)	Custom Task	0.91	CFIT II, Form A	0.58	1	Poor	229	Community and University	2	57.2	0.22	<0.001	0.30	No
Hills et al. (2020) Experiment 2	20.0 (2.9)	Custom Task	0.91	CFIT II, Form A	0.58	1	Poor	233	Community	1	53.0	0.07	0.287	0.10	No
McCaffery et al. (2018)	53 (15)	CFMT	0.90	Card Sorting Task	0.81	1	Poor	107	Online and minimal University	2	52.3	0.12	0.218	0.14	No
Meinhardt-Injac et al. (2018)	22.2 (3.4)	CFMT	0.89	Reasoning ability = short-form Raven's Test, Dice Task, Digit Sequence Verbal ability = Vocab, Verbal Analogies and Orthography	0.68	5	Good	343	University and Community	2	71.1	0.08	0.139	0.10	No
Murphy, Millgate, Geary, Catmur, and Bird (2018)	54.9 (19.5)	Emotion-Identity task	0.71	WASI-II (matrix and vocab); WAIS-IV (coding & symbol search)	0.68	4	Good	134	Community	1	63.4	0.26	0.002	0.37	Yes
Olderbak et al. (2015)	48.5 (20.3)	Custom Task	0.91	WM & REA = Memory Updating, Rotation Span Raven's APM; IDM (Name, Verbal, Address)	0.75	2	Good	443	Community	1	51	0.52	<0.001	0.63	No
Palermo et al. (2013)	23.2 (5.3)	CFMT	0.90	CFIT III, Form A	0.74	1	Poor	80	University	3	63.8	−0.01	0.930	−0.01	Yes
Richler et al. (2017)	32.2 (15.5)[9]	CFMT	0.90	Raven's APM, Vocab	0.40	2	Fair	279	Online	1	60.7	0.13	0.030	0.22	No
Shakeshaft and Plomin (2015)	19.5 (0.3)	CFMT	0.89	Mill Hill Vocab Scale & Raven's APM	0.86	2	Fair	1068	Community	1	58	0.16	<0.001	0.18	Yes
Slone et al. (2000)	60.2 (12.1)	Custom Task	0.92	Digit span (WAIS-R)	0.64	1	Poor	129	University	3	72.9	−0.01	0.910	−0.01	No

(*continued on next page*)

Table 4 (*continued*)

Source	Age: *M* (*SD*)	Face Processing Measure	α	IQ Measures	α	# IQ tests	IQ quality	*N*	Sample	Restricted	% Female	*r*	*p*	*r'*	Controlled for age
Susilo, Germine, and Duchaine (2013)	24.2 (4.3)	CFMT	0.89	VPAM	0.80	1	Poor	2031	Online	1	53.7	0.14	<0.001	0.17	No
Wilhelm et al. (2010)	25 (4.1)	Custom Task	0.79	Raven's APM, Memory Updating, Rotation Span, IDM (Name, Verbal, Address)	0.77	2	Good	209	Community	1	52.1	0.16	0.021	0.21	No
Wilmer et al. (2010) Twins	38 (11)	CFMT	0.89	VPAM	0.72	1	Poor	120	Community	1	74.2	0.15	0.012	0.19	No
Wilmer et al. (2010) Non-Twins	27.5 (11.5)	CFMT	0.90	VPAM	0.80	1	Poor	1532	Community	1	64.3	0.17	<0.001	0.20	No
Zhu et al. (2010)	19.7 (0.94)	CFMT	0.85	Raven's APM, WAIS-R(C)-V, WAIS-R (C)-P, WMS-RCA, WMS-RCG, 2-Back-WM	0.58	9	Excellent	436	University	3	54.9	0.27	<0.001	0.38	Partly

Notes. 2-Back-WM = 2-Back Working Memory Task; CFIT = Cattell's Culture Fair Intelligence Test; CFMT = Cambridge Face Memory Test; DSB = Digit Span Backwards; FSIQ = Full Scale Intelligence Quotient; IDM = Immediate and Delayed Memory task; Raven's APM = Raven's Advanced Progressive Matrices; Raven's SPM = Raven's Standard Progressive Matrices; WM = Working Memory; Vocab = Vocabulary; VPAM = Verbal paired-associates memory test; VSB = Visual Span Backwards; WMS = Wechsler memory scale; WMS-RCA = WMS Recall subtest; WMS-RCG = WMS Recognition Subtest; WAIS = Wechsler Adult Intelligence Scale; WAIS-R(C)-P = Wechsler Adult Intelligence Scale-Revised (Chinese Version) three performance subtests; WAIS-R(C)-V = Wechsler Adult Intelligence Scale-Revised (Chinese Version) three verbal subtests; WASI – Wechsler Abbreviated Scale of Intelligence; WSB = Word Span Backwards; WM & REA = Working Memory and Reasoning Tasks; IQ quality was assessed using the criteria described in Gignac and Bates (2017); Herlitz and Yonker (2002) mean age averaged across men and women; Richler et al. (2017) age and gender descriptive statistics derived from sample that completed the IQ battery; Slone et al. (2000) average mean and *SD* for age was calculated across all sessions and gender; α = coefficient alpha or coefficient omega (reliability); restricted = degree of range restriction in the sample (1 = minimal restriction; 2 = moderate restriction; 3 = substantial restriction); *r* = observed Pearson correlation; *r'* = correlation disattenuated for imperfect reliability; IQ quality was assessed using the criteria described in Gignac and Bates (2017); *p*-values calculated via Excel (see supplementary materials).

moderator with reasonable power (Hedges & Pigott, 2004). A statistically significant and positive regression coefficient would suggest that the quality of intelligence measurement moderated (positively) the association between intelligence and face memory.

4. Results

4.1. Face detection

As can be seen in Table 2, the two face detection studies yielded observed correlations equal to 0.06 and 0.25 (summed $N = 407$). One study was based on a good measure of intelligence and one study was based on a non-restricted sample. We note that neither study was based on both a good measure of intelligence and an unrestricted sample. As two studies were considered insufficient to conduct a full meta-analysis (i.e., heterogeneity, publication bias), we simply calculated the meta-analytic correlation and confidence intervals,[6] which yielded a positive and statistically significant observed score correlation, $r = 0.17$, $p = .044$, 95%CI [0.01, 0.34]. The corresponding psychometric meta-analytic correlation was also positive, but only significant as a one-tailed test, $r = 0.20$, $p = .058$, 95%CI [−0.01, 0.42]; one-tailed $p = .029$.

4.2. Face perception

4.2.1. Meta-analysis: barebones

As can be seen in Table 3, the eleven observed score correlations ranged in size from 0.07 to 0.56. The barebones meta-analytic correlation between intelligence and face perception ability was estimated at $r = 0.30$, $z = 5.56$, $p < .001$, 95%CI: [0.20, 0.41], $k = 11$, $N = 2528$. An examination of the influential case diagnostics (e.g., studentised residuals, Cook's distance values) did not reveal any influential cases (see supplementary Fig. S1). The degree of heterogeneity in the correlations was statistically significant, $Q^2(10) = 88.40$, $p < .001$, and high from an effect size perspective, $I^2 = 88.1\%$, 95%CI: [71.3, 95.4%]. Additionally, an examination of the forest plot suggested non-random heterogeneity in the observed score correlations (see Fig. 8). It was noted that four of the five largest correlations were associated with good intelligence measurement quality.

Next, we evaluated publication bias. First, Egger's regression test of funnel plot asymmetry was not significant, $z = -0.45$, $p = .656$. Furthermore, though the funnel plot was asymmetric, suggesting the possibility of publication bias, four of the correlations were non-significant statistically and seven were significant (see Fig. 9). Additionally, the largest correlations tended to be associated with the largest sample sizes (i.e., smallest standard errors). Thus, overall, we interpreted the results to suggest a relative absence of evidence for publication bias.

4.2.2. Meta-analysis: psychometric

The psychometric meta-analytic correlation between intelligence and face perception ability was estimated at $r' = 0.42$, $z = 5.49$, $p < .001$, 95%CI: [0.27, 0.57], $k = 11$, $N = 2528$. An examination of the influential case diagnostics (e.g., studentised residuals, Cook's distance values) did not reveal any influential cases (see supplementary Fig. S2). The degree of heterogeneity in the correlations was statistically significant, $Q^2(10) = 241.38$, $p < .001$, and high from an effect size perspective, $I^2 = 95.6\%$, 95%CI: [88.8, 98.2%]. Additionally, an examination of the forest plot suggested non-random heterogeneity in the true score correlations (see Fig. 8).

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[6] Meta-analysis is considered the best method to combine quantitatively the results of studies, including two studies (Goh et al., 2016).

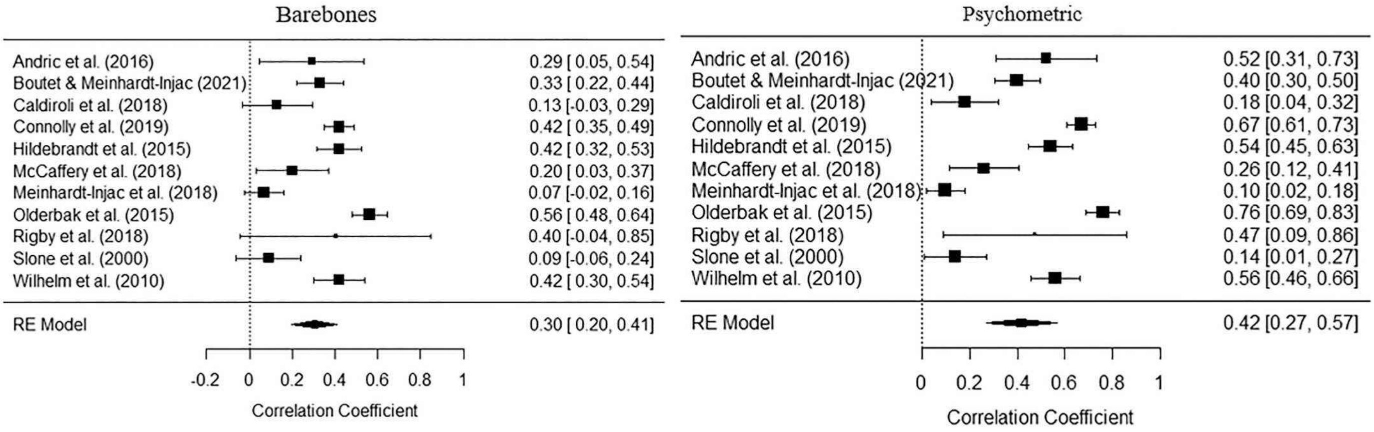

Fig. 8. Forrest plots: face perception.

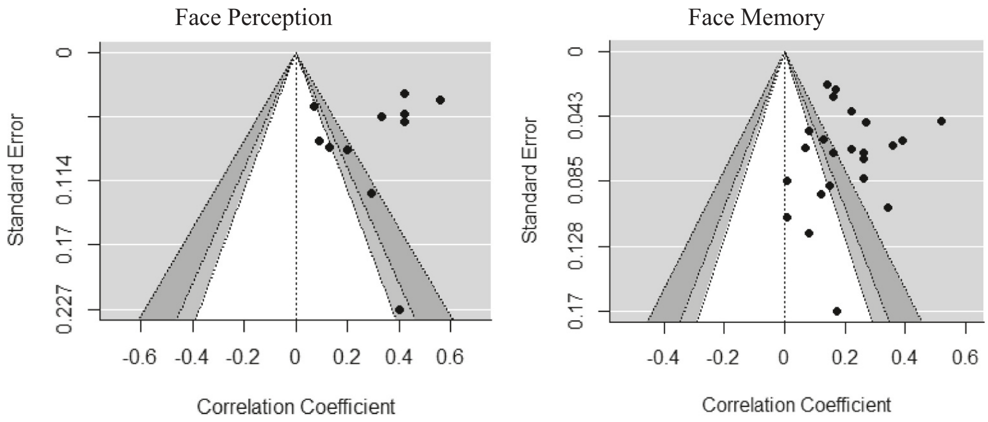

Fig. 9. Contour enhanced funnel plots: barebones meta-analysis (observed correlations).
Note. White region, $p > .10$; grey region, $p = .10$ to 0.05; dark grey region $p = .05$ to 0.01; region outside funnel $p < .01$.

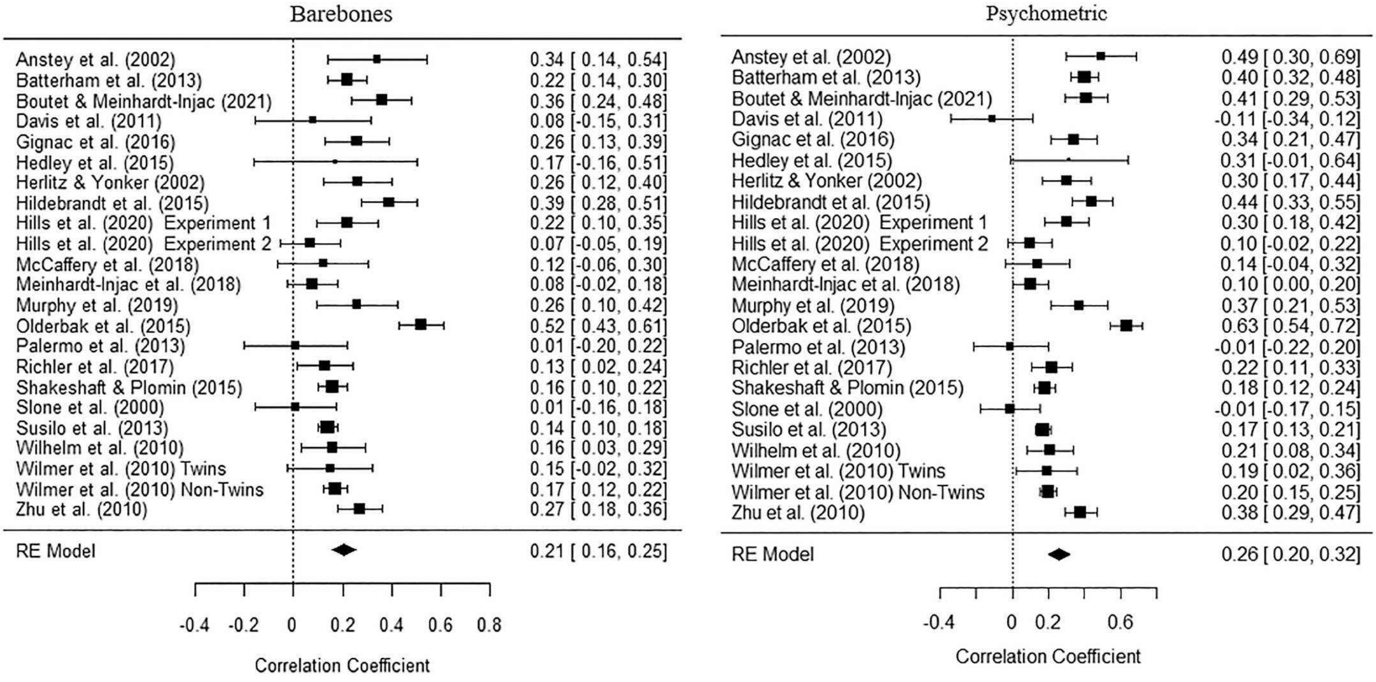

Fig. 10. Forrest plots: face memory.

4.3. Face memory

4.3.1. Meta-analysis: barebones

As can be seen in Table 4, the observed score correlations ranged in size from −0.08 to 0.52. The barebones meta-analytic correlation between intelligence and face memory ability was estimated at $r = 0.21$, $z = 8.50$, $p < .001$, 95%CI: [0.16, 0.25], $k = 23$, $N = 9062$. An examination of the influential case diagnostics (e.g., studentised residuals, Cook's distance values) revealed that one study (i.e., Olderbak et al., 2015) was possibly an influential case (see supplementary Fig. S3). However, based on the leave-one-out analysis, the re-estimated meta-analytic correlation (i.e., $r = 0.19$) did not differ appreciably from the whole group meta-analytic correlation, therefore, the meta-analytic correlation that included Olderbak et al. (2015) result was considered interpretable. The degree of heterogeneity in the correlations was statistically significant, $Q^2(22) = 105.43$, $p < .001$, and high from an effect size perspective, $I^2 = 77.9\%$, 95%CI: [66.4, 91.2%]. As can be seen in Fig. 10, the forest plot also suggested a non-trivial amount of heterogeneity in the observed correlations.

Next, we evaluated publication bias. First, Egger's regression test of funnel plot asymmetry was not significant, $z = -0.78$, $p = .435$. Furthermore, the contour enhanced funnel plot showed an appreciable spread of observed correlations across the three regions of statistical significance (see Fig. 9). Thus, there was little evidence to suggest publication bias.

4.3.2. Meta-analysis: psychometric

The psychometric meta-analytic correlation between intelligence and face memory ability was estimated at $r' = 0.26$, $z = 8.29$, $p < .001$, 95%CI: [0.20, 0.32], $k = 23$, $N = 9062$. As per the barebones meta-analysis, an examination of the influential case diagnostics revealed that one study (i.e., Olderbak et al., 2015) was a potential influential case (see Fig. S4). However, based on the leave-one-out analysis, the re-estimated meta-analytic correlation (i.e., $r' = 0.24$) did not differ appreciably from the whole group meta-analytic correlation, therefore, the meta-analytic correlation that included Olderbak et al. (2015) result was considered interpretable. The degree of heterogeneity in the correlations was statistically significant, $Q^2(22) = 193.10$, $p < .001$, and high from an effect size perspective, $I^2 = 87.9\%$, 95%CI: [83.9, 95.8%]. As can be seen in Fig. 10, the forest plot also suggested a non-trivial amount of heterogeneity in the true score correlations.

We noted that six of the seven smallest correlations (0.17 or lower) were from investigations that used a 'poor' measure of intelligence (see Table 4; IQ quality). By contrast, six of the seven largest correlations (0.37 or greater) were from investigations that used 'good' to 'excellent' intelligence measurement. Such a pattern of results suggested intelligence measurement quality moderated the magnitude of the correlation between intelligence and face memory, a possibility that could be tested via meta-regression.

4.4. Meta-regression

The meta-regression (mixed-effects model) was conducted on the reliability corrected correlations for face memory, in order to control for measurement error. As the moderator variable was associated with ordinal measurement, the beta-weight (β) statistical significance and confidence intervals were estimated via 2000 random permutations of the data (metafor command: 'permutest'). The quality of intelligence measurement rating variable was found to be a statistically significant contributor to the model, $\alpha = 0.084$, $\beta = 0.081$, $p = .005$, 95%CI: [0.02, 0.13]. Thus, larger correlations between intelligence and face memory were associated with higher intelligence measurement ratings (i.e., better quality). Specifically, a one unit increase in intelligence measurement quality was associated with, on average, a 0.081 increase in the corrected correlation between intelligence and face memory. The nature of the intelligence measurement quality moderator effect can be appreciated further by an examination of the corresponding bubble plot (see Fig. 11). As the mean intelligence measurement quality rating for the face memory data corresponded to approximately 'fair' ($M = 2.17$, $SD = 1.15$), we estimated that the population level true score correlation between intelligence and face memory may be closer to ≈ 0.41, based exclusively upon excellent intelligence measurement (i.e., 0.084 + (4*0.081) = 0.41).

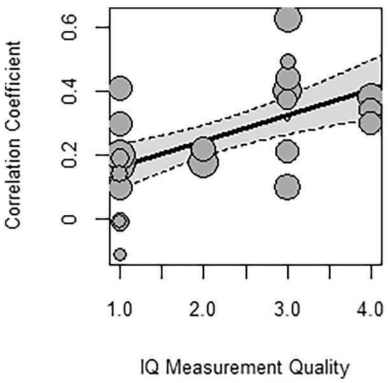

Fig. 11. Bubble plot depicting the positive association between IQ measurement quality and magnitude of the correlation between intelligence and face memory.
Note. IQ measurement quality ratings: 1 = poor; 2 = fair; 3 = good; 4 = excellent; shaded area represents corresponding 95% confidence interval bounds.

5. Discussion

The purpose of this investigation was to provide a conceptual and meta-analytic review of the association between intelligence and three face processing abilities: face detection, face perception and face memory. First, we estimated the meta-analytic observed score and true score correlations between intelligence and face detection at $r = 0.17$ and $r' = 0.20$, respectively. Secondly, we estimated the observed and true score correlations between intelligence and face perception at $r = 0.30$ and $r' = 0.42$, respectively. Thirdly, we estimated the observed and true score correlations between intelligence and face memory at $r = 0.21$ and $r' = 0.26$, respectively. Finally, we also found intelligence measurement quality moderated positively the effect between intelligence and face memory.

The results of the publication bias analyses suggested that publication bias was unlikely to be a meaningful influence on our results. Correspondingly, we note that there is no consistent notion within the face recognition literature that the null hypothesis would be expected to be rejected. That is, there are some researchers who posit that face recognition is essentially unrelated to cognitive abilities (e.g., Bowles et al., 2009; Shakeshaft & Plomin, 2015; Wilmer et al., 2014). Consequently, in this context, publication bias is less likely to be a factor. Furthermore, several investigations included in the meta-analysis were not primarily interested in testing the hypothesis of an association between intelligence and face processing. For example, some research compared clinical and typical developing samples (i.e., schizophrenia, autism), some pertained to test development, or assessment of other human abilities (i.e., emotion recognition, object recognition) and human physiology (i.e., brain function). Therefore, as the majority of the included studies did not specifically examine the association between face processing abilities and cognitive abilities, the potential for publication bias, in this context, may be regarded as less likely, consistent with our publication bias results.

5.1. Comparisons to other meta-analyses

To our knowledge, there are no meta-analyses that have investigated the association between cognitive abilities and any of the face processing abilities examined in this study (i.e., face detection, face perception or face memory). There is one meta-analysis reported in the face processing literature that has examined cognitive abilities and a face processing ability not investigated here – face emotion recognition. Schlegel et al. (2019) reported a meta-analytic (barebones) effect size of $r = 0.19$, suggesting that higher levels of intelligence correspond to higher levels of face emotion recognition ability. The magnitude of the meta-analytical correlation found by Schlegel et al. (2019) compares well with the observed score effects reported in this meta-analytic investigation. Individual investigations have examined the intercorrelation between face emotion recognition and face memory. The correlation between these abilities has been found to range from 0.38 and 0.52 (Connolly et al., 2019; Palermo et al., 2013; Rhodes et al., 2015), suggesting that these abilities may share similar processing mechanisms, and yet remain distinct abilities. In future research, it would be useful to estimate the unique predictive effects of various cognitive abilities and face memory as predictors of emotion recognition ability.

Additionally, a previous large-scale quantitative review of meta-analyses in the field of differential psychology found that the median observed correlation reported in the literature was $r = 0.19$ (Gignac & Szodorai, 2016). Therefore, the uncorrected correlations for face detection ($r = 0.17$), face perception ($r = 0.30$) and face memory ($r = 0.21$) reported in this investigation are in line with what is typically reported in the field of differential psychology. To help contextualise our results further, we note that the uncorrected correlation between two face processing abilities, i.e., face perception and face memory, is $r \approx 0.50$ (McCaffery et al., 2018; Verhallen et al., 2017). Given face processing ability tasks share method variance (face stimuli), the correlations we reported between intelligence and face processing abilities may be considered substantive, relatively speaking. Additionally, the corrected correlation associated with face memory ($r' = 0.26$) found in this investigation would be considered relatively typical for individual differences research (i.e., 50 to 55th percentile; Gignac & Szodorai, 2016). Furthermore, the corrected correlation for face perception ($r' = 0.42$) found in this investigation could be considered relatively large for individual differences research (i.e., 80th percentile; Gignac & Szodorai, 2016). Overall, it may be suggested that higher levels of intelligence are associated with higher levels of face processing ability, and that a non-trivial percentage of their true score variance is shared (i.e., as much as 18%; also, see below for a moderator of the effect).

5.2. Potential moderators

The meta-analytic results suggested a non-negligible amount of heterogeneity in effect sizes across studies. Such an observation suggests that there may be one or more moderators impacting the magnitude of the correlation between intelligence and face processing. Although the number of studies included in the face detection and face perception meta-analyses reported in this investigation was considered manifestly insufficient to test any moderator hypotheses statistically (i.e., insufficient power; Schmidt, 2017), we tested whether the quality of intelligence measures was a moderator in the meta-analysis for face memory (see Supplementary Materials for two additional moderator analyses).

Based on a meta-regression, we found that intelligence measurement quality was a significant, positive moderator of the correlation between intelligence and face memory ($\beta = 0.08$). Thus, a one unit increase in measurement quality corresponded to a 0.08 increase in the true score correlation. Correspondingly, previous research found intelligence measurement quality to be a significant, positive moderator of the correlation between brain volume and intelligence (Gignac & Bates, 2017). Specifically, Gignac and Bates (2017) also found that a one unit increase in intelligence measurement quality corresponded to a 0.08 unit increase in the correlation. Thus, these findings reinforce the benefits of including a quality of intelligence measurement variable in a meta-analysis, when estimating the effect between intelligence and another variable, as the quality of intelligence measurement across studies in an area can vary substantially. In fact, as the mean intelligence measurement quality rating for the face memory data corresponded to ‘fair’, we suggest that the population level true score correlation between intelligence and face memory may be closer to ≈ 0.40, based exclusively on excellent intelligence measures.

Currently, there are no guidelines for evaluating the quality of face processing measures, as per those developed for the measurement of intelligence (see Gignac & Bates, 2017). It may be postulated that the quality of the face processing measures may also moderate the magnitude of the correlations reported within this study. Future research may benefit from the development of guidelines for the quality of face processing measures.

A potential moderator not examined in this investigation was type of cognitive ability dimension. It is reasonable to expect that some dimensions of cognitive ability may associate with face processing more substantially than others. Such a suggestion is plausible, as Schlegel et al. (2019) meta-analysis suggested that particular narrow dimensions of cognitive abilities may contribute uniquely to better emotion recognition ability. For example, visual processing, fluid reasoning, comprehension-knowledge and long-term storage and retrieval. With respect to face processing dimensions examined in this investigation, we note that Rigby et al. (2018) reported (via personal communication) verbal IQ and performance IQ correlations of −0.02 and 0.57, respectively, with a face perception measure, suggesting that face perception may be more substantially associated with visual processing abilities, in comparison to verbal abilities. As theorised in the introduction, it is plausible to suggest that certain cognitive abilities would be more substantially associated with certain face processing abilities (see Table 1). For example, face detection is likely associated more substantially with *Gv* and *Gc*. For the purposes of thoroughness, we provide in the supplementary materials (see Table S1) an overview of the correlations between individual cognitive ability tests and face processing measures, as reported by the studies included in our meta-analysis, where two or more subtests of cognitive abilities were administered. We note briefly that Table S1 suggests that certain cognitive abilities may be more strongly associated with specific face processing abilities. For example, memory-based tasks (e.g., Immediate and Delayed memory task) are associated with numerically larger correlations with face memory than verbal-based tasks (e.g., vocabulary task). Table 1 in the introduction of this review proposed possible theoretical links between the face processing abilities (i.e., face detection, face perception and face memory) and specific cognitive abilities. Table S1 provides some empirical evidence for some of these theoretically proposed associations (e.g., an association with visual processing, short-term memory and fluid reasoning). In order to evaluate the sub-dimension moderator hypothesis statistically, more studies would have to be conducted with a variety of intelligence subtests. Consequently, we recommend that further research be conducted to investigate whether individual differences in face processing abilities are explained primarily by general intelligence or more substantially by narrower cognitive abilities (e.g., *Gv*). Furthermore, such research would facilitate situating face processing abilities within the CHC model more precisely.

5.3. Theoretical and practical implications

Face processing abilities are not yet included in established models of cognitive abilities, such as the CHC model of intelligence (McGrew, 2009). Overall, the findings of our meta-analysis suggest that face processing abilities may be regarded as a cognitive ability, as they share a moderate amount of variance with general intellectual functioning ($r \approx 0.20$ to 0.40). Furthermore, the types of tests used to measure face processing ability share several characteristics with conventional cognitive ability tests, as described in the introduction. Correlations of 0.20 to 0.40 compare well with the correlations between other narrow CHC Stratum I dimensions and general intelligence. For example, across several meta-analyses, the following Stratum I ability associations with general intelligence have been reported: numerical memory span (stratum I ability MS) $r = 0.35$ (Mukunda & Hall, 1992); ideational fluency (Stratum I ability FI) $r \approx 0.20$ (Kim, 2005); reading comprehension (Stratum I ability RC) $r = 0.38$ (Peng, Wang, Wang, & Lin, 2019)[7]; mathematics ability (Stratum I abilities KM and A3) $r = 0.41$ (Peng, Wang, Wang, & Lin, 2019); divergent thinking (Stratum I ability FO) $r \approx 0.25$ (Gerwig et al., 2021); and a candidate Stratum I ability (set-shifting) $r \approx 0.45$ (Kopp, Maldonado, Scheffels, Hendel, & Lange, 2019).

Thus, theoretically and empirically, it may be time to seriously consider face processing abilities, such as face detection, perception and memory, sub-dimensions of intelligence, contrary to previous suggestions that suggest face memory to be essentially unrelated to intelligence (e.g., Shakeshaft & Plomin, 2015; Wilmer et al., 2014). With only two empirical studies that have examined the association between intelligence and face detection ability, no firm conclusions can be made, however, our results are suggestive. Furthermore, face detection ability, as measured by the Mooney test, shares substantial similarities to conventional figure closure tests (Eliot & Czarnolewski, 1999; Goodwin, 2012; Street, 1931), a dimension regarded as a cognitive ability (Ekstrom, French, Harman, & Dermen, 1976).

It is important to note that the observation of a moderate to large correlations of around 0.20 to 0.50 between intelligence and each of the face processing abilities suggests, on the one hand, meaningful shared variance, however, on the other hand, face processing ability is arguably also distinct from general intelligence. In fact, as much as 80% of the true score variance in face processing may be independent of general intelligence. This suggests that face processing ability is not considered isomorphic with general intelligence, and may predict outcomes over and above general intelligence, such as social anxiety, for example (Davis et al., 2011). The notion of face processing abilities as, to some degree, materially distinct from other cognitive abilities is consistent with research into the Fusiform Face Area (Kanwisher & Yovel, 2006) and heritability research (Wilmer et al., 2010).

Finally, there are possible implications with respect to our results and the assessment of developmental prosopagnosia. On the basis of the positive correlation between face memory and intellectual functioning, developmental prosopagnosia may be conceptualised as a learning disability. A learning disability may be defined as a substantial difference between a specific ability and general intellectual functioning (Wilmshurst, 2012). For example, dyslexia is operationally defined as a substantially lower performance (e.g., two standard deviations) in Reading Comprehension (a specific CHC ability, RC) and general intellectual functioning (Vellutino, Fletcher, Snowling, & Scanlon, 2004). The correlation between Reading Comprehension and general intelligence has been reported to range between ≈ 0.40 and ≈ 0.55 (Jensen, 1998; Joshi & Hulme, 1998; Naglieri & Ronning, 2000; Tiu Jr et al., 2003), i.e., approximately the same magnitude as the association between general intelligence and face perception, and to a somewhat lesser degree between general intelligence and face memory, found in this investigation. Currently, substantial difficulty in face identity recognition ability, i.e., developmental prosopagnosia, is commonly diagnosed through examination of performance on face recognition and perception tasks (most commonly: the CFMT, the CFPT and the Famous Faces Test). The recommendation for impaired face recognition ability is any score that is two standard deviations from the control mean on any two of the three tasks (Dalrymple & Palermo, 2016), although such a recommendation has been scrutinised (Murray & Bate, 2020). On the basis of our results, and consistent with approaches to the diagnosis of reading disabilities (Wilmshurst, 2012), developmental prosopagnosia may be more validly diagnosed when a person's performance on a valid measure of face memory is two standard deviations (or more) below a person's FSIQ performance (CFMT < FSIQ), rather than simply two standard deviations below the CFMT normative sample mean.[8] Face processing researchers may also profit from including intelligence measures in their studies, in order to control for individual differences in intelligence. In practice, a respectable estimate of general intelligence can be obtained by administering four diverse subtests of cognitive ability (≈ 20–25 min; e.g., Gignac, Walker, Burtenshaw, & Fay, 2020).

5.4. Recommendations for methodological improvements and further research

A clear area in need of further research is face detection. That is, only two studies (i.e., McCaffery et al., 2018 and Vigen et al., 1982) examined the association between face detection and intelligence, and only one is recent (within 5 years). Consequently, researchers are encouraged to examine individual differences in face detection further, as individual differences in face detection may facilitate face perception and, in turn, face memory (Verhallen et al., 2017). A respectable test of face detection is the Mooney test, a publicly available test (Verhallen et al., 2014; Verhallen & Mollon, 2016). Furthermore, it remains to be determined whether face processing abilities predict individual differences in face pareidolia, an error in the human face detection system where objects or random images are interpreted as faces. Recent research suggests that there is a link between the detection of illusory faces in objects and the higher-level visual cortex (Wardle, Taubert, Teichmann, & Baker, 2020).

A total of 11 studies were found to have investigated the association between face perception and intelligence. Unfortunately, none of the face perception studies included both excellent measures of intelligence and an unrestricted sample. Thus, our estimated meta-analytic correlation, including the psychometric meta-analytic correlation, is likely an appreciable underestimate. Similarly, there was only one study for face memory that employed both excellent measures of intelligence and an unrestricted sample (Herlitz & Yonker, 2002), suggesting more studies are needed with excellent measures of intelligence and reliable/valid measures of face processing, in addition to unrestricted samples, in order to estimate more accurately the magnitude of the effect in the population. More generally, we note that only around half of effect sizes (53%) included in this investigation were based on good or excellent measures of intelligence, according to the guidelines set out by Gignac and Bates (2017). As noted above, the quality of intelligence measurement can be improved by measuring multiple dimensions of intelligence (≥ 4) via multiple subtests.

Finally, intelligence test score internal consistency reliability was reported for only 15% of the included studies (4 out of 26). By comparison, the rate at which internal consistency was reported for the face processing measures was better, but still low (31%; 8 out of 26). Only three studies (12%) reported the internal consistency reliability for both measures. Such low levels of test core reliability reporting are typical (Vacha-Haase, Henson, & Caruso, 2002). We recommend that future studies report and evaluate the reliability of their test scores, as reliability is known to impact effect size estimation (Nunnally & Bernstein, 1994).

5.5. Limitations

Although the current investigation was associated with some strengths, it was also associated with some limitations. For example,

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[7] Peng et al. (2019) focussed on fluid reasoning (*Gf*), a broad ability known to associate highly with general intelligence (Schweizer et al., 2011).

[8] We acknowledge that practitioners would likely consult information additional to face memory span test scores when considering a diagnosis of prosopagnosia.

some correlations between intelligence and face processing had to be estimated using data simulated to reflect reported information in the included studies, rather than author reported correlations. It is possible that such a procedure misestimated some of the correlations. However, it is unlikely that the misestimation was systematically biased in one direction. Consequently, we believe the results are likely mostly an accurate representation, in the context of a meta-analysis. A second limitation was that reliability had to be estimated via the KR-21′ formulation for a large number of studies, as only a minority of articles included internal consistency reliability estimates. Again, we do not believe the procedures used in this investigation biased the results systematically in any one particular direction; however, it should, nonetheless, be noted as a limitation.

Additionally, although we disattenuated the correlations for imperfect reliability in the test scores, we did not correct for range restriction. On that basis, we believe the meta-analytic correlations reported in this investigation are underestimates. Consider, for example, that in Hedley et al. (2014) intelligence and face memory study, the VIQ and PIQ scores were associated with standard deviations of ≈ 12, i.e., 20% less variability than that found in the general population. Additionally, in a face perception study, Rigby et al. (2018) reported a FSIQ standard deviation of 8.7, i.e., 42% less variability than that found in the general population. Unfortunately, there was insufficient information, or insufficient normative data, to facilitate a complete psychometric meta-analysis (Hunter & Schmidt, 2004). Thus, we feel confident that the face processing abilities investigated in this meta-analysis likely correlate with general intellectual functioning in the area of 0.40 to 0.50 in the general population.

Although our investigation helped estimate relatively precisely the association between face memory and intelligence, our results cannot speak to the possibility that the shared variance between face memory and intelligence is mediated by independent (non-shared) genetic effects, as reported by the heritability study by Shakeshaft and Plomin (2015). However, shared genetic effects is not a specified requirement for inclusion into the CHC model of intelligence (McGrew, 2009), nor is it a requirement for the conventional assessment of a learning disability (Wilmshurst, 2012). Thus, the issue of shared versus unique genetic effects is not directly relevant to our investigation. Nonetheless, we note that although Shakeshaft and Plomin (2015) results are suggestive, their measurement of intelligence included only two subtests, neither of which measured two important Stratum II dimensions of intelligence: short-term memory (*Gsm*) and processing speed (*Gs*). Correspondingly, they reported a correlation of only 0.16 between their total intelligence scores and their measure of face memory (the CFMT). A compelling genetic specificity investigation, in this context, would be to model a general intelligence latent variable defined by a minimum of nine diverse subtests and a face memory latent variable defined by three subtests.

Finally, we acknowledge that the current investigation could not precisely situate any of the face processing abilities within the CHC model, as too few studies have administered a comprehensive battery of cognitive ability tests and face processing tests. With such data, a factor analysis could be conducted, and face processing ability could be more clearly situated within the CHC model. Nonetheless, we believe the theoretical and empirical results reported in this investigation suggest compellingly that face processing ability will likely prove to be a narrow, Stratum I cognitive ability.

6. Conclusion

On theoretical and empirical grounds, the face processing abilities investigated here may eventually be included within the CHC model of cognitive abilities. Additionally, the intelligence and face memory positive association may help inform a more psychometrically grounded approach to the assessment of prosopagnosia, and possibly the conceptualisation of prosopagnosia as a learning disability. Finally, like other Stratum I cognitive abilities (e.g., Reading Comprehension), researchers should not consider face processing abilities as isomorphic with general intelligence. Instead, there is a sufficient amount of unique true score variance to merit individual differences research focally interested in face processing.

Data availability

All data and scripts are available on the OSF (linked in manuscript).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.intell.2022.101718.

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