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Birthweight predicts individual differences in adult face recognition ability

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It has long been known that premature birth and/or low birthweight can lead to general difficulties in cognitive and emotional functioning throughout childhood. However, the influence of these factors on more specific processes has seldom been addressed, despite their potential to account for wide individual differences in performance that often appear innate. Here, we examined the influence of gestation and birthweight on adults' face perception and face memory skills. Performance on both sub-processes was predicted by birthweight and birthweight-for-gestation, but not gestation alone. Evidence was also found for the domain-specificity of these effects: No perinatal measure correlated with performance on object perception or memory tasks, but they were related to the size of the face inversion effect on the perceptual test. This evidence indicates a novel, very early influence on individual differences in face recognition ability, which persists into adulthood, influences face-processing strategy itself, and may be domain-specific.

Much evidence suggests that premature birth or low birthweight can lead to generalized difficulties in cognitive and emotional functioning (see Molloy et al., 2013). Yet, little work has considered whether perinatal factors may account for individual differences in more specific abilities, which are often interpreted in terms of heritability. For instance, in the face recognition literature, the ability to recognize facial identity appears to vary from very early childhood (Adams, Hills, Bennetts, & Bate, 2019; Dalrymple et al., 2014; Murray, Hills, Bennetts, & Bate, 2018) and is only mildly associated with other visuo-cognitive (e.g., Richler, Cheung, & Gauthier, 2011; Wang, Li, Fang, Tian, & Liu, 2012) and emotional (e.g., Bate, Parris, Haslam, & Kay, 2010; Hills, Marquardt, Young, & Goodenough, 2017; Hills, Werno, & Lewis, 2011; Lander & Poyarekar, 2015; Megreya & Bindemann, 2013) functions. Together with evidence of familial consistencies in face (but not always object) recognition ability (Bennetts, Mole, & Bate, 2017; Bennetts, Murray, Boyce, & Bate, 2017; Dalrymple, Garrido, & Duchaine, 2014; Shakeshaft & Plomin, 2015; Wilmer et al., 2010), this body of work suggests that face recognition skills are largely innate.

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Yet, it is possible that very early perinatal influences affect the development of face recognition ability in some individuals. The most influential work to date that supports this hypothesis suggests that early visual experience with faces is imperative: Geldart, Mondloch, Maurer, de Schonen, and Brent (2002) studied 17 individuals aged between 10 and 38 years who had been treated for bilateral congenital cataracts. These participants had been deprived of patterned visual input for at least the first 7 weeks of life and displayed impaired recognition of facial identity (but not other aspects of facial processing, such as expression recognition) when tested in later childhood or adulthood. Further, Le Grand, Mondloch, Maurer, and Brent (2004) found that these individuals showed no evidence of configural or holistic processing (the strategy that is thought to be unique for face processing, integrating both the features themselves and the spacing between them: Maurer, Le Grand, & Mondloch, 2002), implicating impairment to face-specific mechanisms (see also de Heering & Maurer, 2014).

While very few individuals experience congenital cataracts, it is conceivable that limitations to early visual experience may also occur in infants who require assistance post-partum, such as those born prematurely and/or with a low birthweight. A small amount of work has explored this possibility, reporting that extremely preterm infants (those born prior to 28 weeks of gestation) can experience face recognition difficulties alongside other neurodevelopmental conditions (e.g., Dutton & Jacobson, 2001; Lampi et al., 2012; Serenius et al., 2013). More specifically, Frie, Padilla, Aden, Lagercrantz, and Bartocci (2016) used near-infrared spectroscopy to demonstrate atypicalities in the maturation of cortical face recognition areas in premature infants (again born before 28 gestational weeks) who were tested at the corrected age of 6–10 months. There is also evidence that these abnormalities persist into later childhood: Perez-Roche et al. (2017) found that 5- to 15-year-old children born with a low-for-gestation birthweight (<10th percentile) performed at a lower level on immediate and delayed face recognition tasks compared to those born with an appropriate birthweight for their gestational age.

While these findings suggest that length of gestation and/or birthweight may be important predictors of later face recognition ability, the domain-specificity of these effects remains unknown. Yet, this is an important theoretical issue: The proposed modularity of the face recognition system has long been debated, monopolising the field for over 50 years (e.g., Kanwisher, 2010; McKone & Robbins, 2011; for a recent overview, see Geskin & Behrmann, 2018). While the bulk of work has considered evidence from the typical and lesioned adult brain (e.g., Busigny, Graf, Mayer, & Rossion, 2010; Rezlescu, Pitcher, & Duchaine, 2012), it is much less clear how (and indeed if) these processes segregate during typical and atypical development (Bate, Bennetts, Gregory, et al., 2019; Bate, Bennetts, Tree, Adams, & Murray, 2019; Bate, Bennetts, Tree, et al., 2019; Bennetts, Murray, et al., 2017; Dalrymple, Elison, & Duchaine, 2017; Weigelt et al., 2014). Furthermore, there is some evidence that face memory and face perception may undergo different developmental trajectories (Weigelt et al., 2014; although see Bennetts, Murray, et al., 2017), suggesting that developmental influences on the two processes should be examined separately.

Yet, despite some indications of early segregation of face and object mechanisms (Dalrymple et al., 2017; Otsuka, 2014), the domain-specificity of perinatal influences and their effects on multiple aspects of face processing have not been examined. Importantly, if very early influences are found to exert a specific influence on at least some components of later face-processing performance, this finding may indicate early modularity within the human brain. That is, as indicated by the infantile cataract literature, face-specific processing mechanisms may be established soon after birth, and very early abnormalities may prohibit the development of critical processing strategies that are required for optimal face recognition ability (i.e., configural or holistic mechanisms). In contrast, more general (i.e., object) processing mechanisms that do not rely on these strategies may eventually ‘catch-up’ during maturation. This hypothesis may explain why some perinatal studies have detected more generalized difficulties in visual cognition during childhood and adolescence (e.g., Geldof, van Wassenaer-Leemhuis, Dik, Kok, & Oosterlaan, 2015; Molloy et al., 2013), whereas disproportionate impairments for face versus object (house) recognition were recently observed in adults born at a very low birthweight (Mathewson et al., 2019). While the literature surrounding this issue remains sparse and has neither considered the typical population nor systematically investigated different aspects of face processing, previous work raises the possibility of persistent domain-specific difficulties in face recognition that result from perinatal influences.

The current study aimed to address this issue by examining the relationship between birthweight/gestation and later face recognition ability in typical young adult participants. Following suggestions that different aspects of face processing follow independent developmental trajectories (Weigelt et al., 2014), we included measures of both face perception and face memory. To address the issue of domain-specificity, we included matched object versions of each paradigm. The perception paradigm also included upright and inverted trials, allowing us to examine perinatal influences on underpinning processing strategy (i.e., configural processing; see below for elaboration). Importantly, all the tasks adopted for this investigation are dominant measures of the relevant processes, with appropriate psychometric properties for the assessment of individual differences within the typical population.

Method

Participants

A power analysis indicated that 100 participants was sufficient to detect a f2 of 0.07 (i.e., a small–medium relationship) with 80% power, or a f2 of 0.10 (still small–medium) with 90% power in a multiple regression containing two predictors (calculations carried out in G*Power 3.1). Thus, advertising stopped once 100 participants had completed the study, resulting in a final total of 103 Caucasian adult participants, aged 18–33 years (80 female; $M_{\text{age}} = 21.8$ years, $SD = 2.5$). Exclusion criteria were any history of neurological, intellectual, developmental, or psychiatric disorder. Participants were awarded course credits or a small financial incentive in exchange for their time. Ethical approval was granted by the institutional Ethics Committee.

Materials

Memory tests

The extended form of the Cambridge Face Memory Test (CFMT+: Russell, Duchaine, & Nakayama, 2009) was used to measure face memory. This test is calibrated to detect vast individual differences in face memory within the typical population (Bate, Bennetts, Tree, et al., 2019; Bate et al., 2018; Bate, Frowd, et al., 2019; Fysh, 2018; Royer et al., 2018), presenting cropped greyscale male images for recognition. In an initial encoding phase, participants view each of six target faces three times, for three seconds per exposure. They are then required to select each target from three triads of faces, each containing the target and two distractors. After a 20-s review of the target faces, participants view 30 further triads, again displaying one target and two distractors, under novel lighting and viewpoint conditions. After a further 20-s review of the targets, participants view 24 further triads with added visual noise, and 30 more difficult triads where expression or viewpoint manipulations are more extreme. The entire test is scored out of 102. Importantly, the CFMT + is an extended version of the standard CFMT (Duchaine & Nakayama, 2006) that is known to have excellent psychometric properties (Bowles et al., 2009; Cho et al., 2015).

To measure object memory, we used the Cambridge Car Memory Test (CCMT: Dennett et al., 2012). Although an extended form of this test is not available, we nevertheless selected the CCMT as, other than its length (it does not contain the addition 30 more difficult items that are presented at the end of the CFMT+), it is identical in design to the CFMT+. In place of faces, all stimuli are greyscale cars with no branding or licence plate cues to identity. In addition, the CCMT shares the psychometric properties of its facial equivalent (Dennett et al., 2012).

Perception tests

Face perception was assessed using the Cambridge Face Perception Test (Duchaine, Germine, & Nakayama, 2007), arguably the most dominant test of face perception that is currently available, and that is frequently used in individual differences research (e.g., Rezlescu, Susilo, Wilmer, & Carramazza, 2017; Tardif et al., 2019). This test presents 16 trials: eight upright and eight inverted. Each trial presents a greyscale target face at the top of the screen, and six greyscale test faces beneath. The test faces have been morphed in terms of their similarity to the target face. Participants have 60 s per trial to sort the test faces in order of their similarity to the target. Performance is measured by the number of errors, with a perfect score of 0 on each trial. Error scores are computed per trial by summing the deviations from the correct arrangement for each face (e.g., if a face is two positions from its correct arrangement, two errors are recorded) and are summed separately for upright and inverted trials. This permits calculation of a face inversion effect (i.e., the different in performance between the upright and the inverted condition). Large costs of inversion are often interpreted as evidence for the involvement of configural (Yin, 1969) or holistic (Yovel & Duchaine, 2006; Yovel & Kanwisher, 2004) processing strategies in face recognition. Inclusion of this measure in the current study therefore enables us to go beyond basic accuracy scores to infer whether perinatal measures influence the actual processing strategies that are thought to underpin face recognition.

Object perception was assessed using the Cambridge Car Perception Test (Yang, Penton, Leman Köybaşi, & Banissy, 2017) – a test that is identical in format to the CFPT but presents greyscale cars for sorting. All branding and licence plate information have been removed from the stimuli. The task is scored in the same manner as the CFPT and has previously been used to tap individual differences in object processing within the typical population (Yang et al., 2017).

Empathy

Because difficulties in socio-emotional functioning have (1) been documented in individuals with low birthweight or gestation (Hille et al., 2001; Reijneveld et al., 2006), and (2) linked to face recognition skills in the typical population (Bate et al., 2010; Lander & Poyarekar, 2015; Megreya & Bindemann, 2013), we used the Empathy Quotient (EQ: Baron-Cohen & Wheelwright, 2004) to control for this influence. The EQ is designed to measure how quickly one might pick up on others' feelings and/or how strongly one is affected by these feelings. The questionnaire has 40 items, and participants respond on a 4-point scale ranging from 'strongly agree' to 'strongly disagree'. Each item receives between zero and two points, and the maximum total score is 80. The EQ has a test–retest reliability of .97 and has been shown to relate to other measures of socio-emotional functioning (Baron-Cohen & Wheelwright, 2004).

Procedure

Participants were recruited via advertisements that were distributed around the University and on social media, and were asked to initially contact the experimenter by email. They were then advised that the study required accurate perinatal information, and they should only proceed if they could reliably access these data (e.g., via conversation with a parent or in their own copies of their birth records).

Demographic and perinatal information were initially collected, followed by completion of the EQ. The two memory tests were always completed first (the order of the face and car versions were counterbalanced between participants), followed by the two perception tests (where the order of the face and car versions was also counterbalanced). All participants completed the tests online via a bespoke testing platform on our laboratory's website. Previous work has observed no differences between online versus laboratory performance on the standard version of the CFMT (Germine et al., 2012; Rezlescu, Susilo, Wilmer, & Caramazza, 2017), and our testing platform optimizes stimulus presentation to ensure consistency in the size that images are presented. All participants completed the tests on a laptop or desktop computer.

Statistical analyses

Birthweight and gestation data were converted to kg and number of complete weeks, respectively, allowing us to examine the independent importance of these two measures in predicting adult face versus object recognition ability. However, in clinical practice these measures are thought to only offer a broad indicator of pre- and post-natal health (Norris et al., 2018), and a more useful and frequently used predictor is found in centile charts that offer smoothed birthweight curves across gestational age. Thus, we also calculated a birthweight-for-gestation centile score that represents the full perinatal experience (i.e., combining birthweight, gestation and gender, based on the norming data offered by Norris et al., 2018),[1] allowing differentiation between individuals who share the same birthweight but differ in their gestational age, or vice versa. In this calculation, the term'centile' is short for'percentile'. Thus, if an infant's birthweight falls on the 50th centile, then 50% of infants born in the population at the same gestational age have a lower birthweight, and 50% have a higher birthweight. If an infant's birthweight is calculated to be on the 7th centile, then 7% of babies born at that gestational age will have a lower birthweight, and 93% will have a higher birthweight.

Scores on the two memory tests were converted to percentage correct. Performance on the upright and inverted sections of the two perception tasks were calculated independently, and converted to percentage correct using the formula [100 × (1-(total

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[1] *An online calculator created by these authors was used to generate centile scores: https://timms.le.ac.uk/birth-weight-centiles/. The norming data used by this calculator are taken from 1,269,403 singleton births that occurred in England and Wales in 2013–2014 (irrespective of ethnicity).*

deviation score/maximum score))] as per Rezlescu et al. (2012). An inversion effect was also calculated for the two versions by subtracting the overall accuracy score in the inverted condition from that in the upright condition.[2]

Initial analyses explored the relationship between the three perinatal measures (birthweight, length of gestation, and birthweight-for-gestation centile scores) and the face-processing measures (i.e., the CFMT + and upright section of the CFPT). We then explored the domain-specificity of these effects (via comparison to the relevant object task), and, for the perceptual tasks, whether underpinning face-specific processing strategies are also affected (by examination of inversion effects).

Results

Birthweight, gestation, and face recognition ability

Participant birthweight ranged from 1.00 to 4.86 kg ($M = 3.20$ kg, $SD = 0.72$), and gestational age varied from 25 to 42 weeks ($M = 38.74$ weeks, $SD = 2.89$). Birthweight-for-gestation centiles ranged from 0.10 to 99.90 ($M = 49.71$, $SD = 30.68$). To examine the relationship between these factors and face recognition ability, the three perinatal measures were initially correlated with performance on the two face-processing tests (the CFMT + and the upright trials of the CFPT, see Table 1). Both face recognition measures correlated with birthweight and centile scores, but not gestation alone (see Figure 1). Subsequent analyses therefore only focused on the two measures involving birthweight.

Multiple linear regressions were then performed to investigate the independent effects of centile scores, birthweight and EQ scores on CFMT + and CFPT (upright) performance. Initial inspection of the data indicated that the assumptions of multiple regression were met and the least squares method of regression could be performed. While some outliers were identified, Cook's distance suggested that they did not influence the regression and they were retained in all analyses. However, because centile scores and birthweight were inevitably highly correlated ($r = .54$, $p = .001$), they could not be entered into the same regression. Thus, we proceeded to perform a separate regression for each measure on each of the CFMT + and CFPT data sets, all additionally containing

Table 1. Correlations between perinatal measures and performance on the face and object memory and perception tasks

	CFMT+	CCMT	CFPT (upright)	CFPT (inverted)	CCPT (upright)	CCPT (inverted)
Birthweight	.27**	.08	.25**	−.14	.12	.08
Gestation	.14	.12	.05	−.02	.14	.07
Centile	.24**	−.01	.33**	−.14	−.02	.02
EQ	.16	.08	.21	.05	.12	.14

**$p < .001$; *$p < .02$. Sequential Bonferroni correction applied.

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[2] *The inversion effect was also examined using an inversion index which corrects for differences in baseline performance: (upright – inverted)/(upright + inverted) (see Avidan, Tanzer, & Behrmann, 2011). The pattern of results was the same as simple subtraction; for simplicity, we report subtraction throughout the results.*

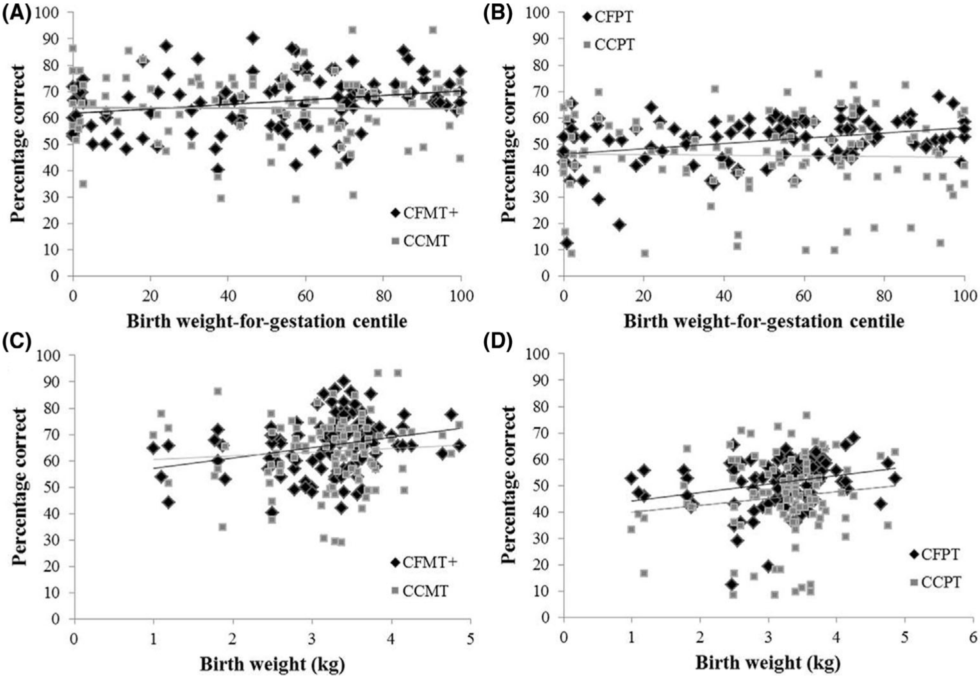

Figure 1. Associations between perinatal measures and face recognition performance. The relationship between birthweight-for-gestation (centile) and face versus object processing is displayed for memory in panel A, and upright perception in panel B. The same relationships are displayed for birthweight on the memory measures in panel C, and the upright perception measures in panel D.

EQ as a predictor. The latter was not significantly correlated with either the centile ($r = .14, p = .161$) or birthweight ($r = .05, p = .596$) measure.

For the CFMT+, the model containing centile score and EQ explained 5.6% of the variance and was a significant predictor of face memory scores, $F(2,102) = 4.034$, $p = .021$. However, only centile score ($\beta = .23$, $p = .021$), and not EQ ($\beta = .12$, $p = .207$), was a significant predictor of face memory (see Figure 1 and Table 2). When the centile measure was exchanged for birthweight, the model remained significant and accounted for 7.4% of the variance, $F(2,102) = 5.086, p = .008$. Again, only birthweight ($\beta = .26, p = .007$), and not EQ ($\beta = .14, p = .142$) significantly predicted face memory performance (see Figure 1 and Table 2).

The same two regressions were performed on CFPT scores. When centile and EQ were entered, the resulting model explained 11.8% of the variance and was a significant predictor of face perception scores, $F(2,102) = 7.835$, $p = .001$. Again, only centile ($\beta = .31$, $p = .002$) and not EQ score ($\beta = .17$, $p = .077$) significantly predicted face perception ability (see Figure 1 and Table 2). When birthweight was entered instead of centiles, the model explained 8.2% of the variance and remained significant, $F(2,102) = 5.582$, $p = .005$. However, for this model, both birthweight ($\beta = .24$, $p = .014$) and EQ ($\beta = .20$, $p = .040$) were independent predictors of face perception performance (see Table 2).

To explore whether face memory is independently affected by perinatal influences (as opposed to being underpinned by the effects on face perception), partial correlations

Table 2. Results from multiple linear regressions investigating the independent effects of birthweight-for-gestation (centile), birthweight and Empathy Quotient (EQ) scores on face memory (CFMT+) and face perception (CFPT: upright) performance

			95% confidence interval for *b*		
	b	Standard error *b*	Lower bound	Upper bound	*β*
Memory					
Centile					
Constant	57.30	3.94	49.49	65.12	
Centile	0.08	0.03	0.01	0.14	.23*
EQ	0.11	0.08	−0.06	0.27	.12
Birthweight					
Constant	48.21	5.69	36.93	59.49	
Birthweight	3.84	1.40	1.06	6.61	.26*
EQ	0.12	0.08	−0.04	0.28	.14
Perception					
Centile					
Constant	41.18	3.32	34.59	47.77	
Centile	0.09	0.03	0.04	0.15	.31*
EQ	0.13	0.07	−0.01	0.27	.17
Birthweight					
Constant	35.00	4.94	25.21	44.80	
Birthweight	3.04	1.22	0.63	5.44	.24*
EQ	0.15	0.07	0.01	0.29	.20*

$^{*}p < .05$; $^{**}p < .01$.

were performed between CFMT + scores and birthweight and centile, controlling for CFPT performance. A significant correlation was observed for birthweight ($r = .202$, $p = .042$), but not centile ($r = .147$, $p = .139$). However, the significance of the birthweight correlation would not withstand a correction for multiple correlations.

Domain-specificity

As displayed in Table 1, no perinatal measure correlated with performance on the two object tests (CCMT and CCPT; see Figure 1), nor the inverted trials of the CFPT. When a multiple linear regression was performed to examine whether centile could be predicted by face memory performance (i.e., CFMT + scores) while controlling for object memory skills (i.e., CCMT scores), the resulting model explained 4.4% of the variance and was significant, $F(2,102) = 3.344, p = .039$. Critically, only face ($\beta = .26, p = .011$), and not object ($\beta = -.06$, $p = .578$) memory, was a significant predictor. When centile was exchanged for birthweight, a similar model emerged, significantly explaining 5.5% of the variance, $F(2,102) = 3.961, p = .022$. Again, only face ($\beta = .26, p = .008$), and not object ($\beta = .03, p = .753$) memory, was a significant predictor (see Table 3).

The equivalent models for perception also supported domain-specificity. For centile, only face ($\beta = .33, p = .001$) and not object ($\beta = -.05, p = .569$) perception contributed to the model, significantly explaining 9.3% of the variance, $F(2,102) = 6.224$, $p = .003$ (see Table 3). Likewise, for birthweight, only face ($\beta = .24$, $p = .016$) and not object

Table 3. Results from multiple linear regressions examining whether birthweight-for-gestation (centile) or birthweight can be predicted by face memory or perception performance (i.e., CFMT + or CFPT upright scores) while controlling for object memory or perception (i.e., CCMT or CCPT upright scores) skills

	b	Standard error *b*	95% confidence interval for *b* Lower bound	Upper bound	*β*
Memory					
Centile					
Constant	9.28	22.19	−34.74	53.29	
Face	0.74	0.29	0.17	1.31	.26*
Car	−0.13	0.24	−0.61	0.34	.06
Birthweight					
Constant	1.91	0.52	0.89	2.93	
Face	0.02	0.01	0.01	0.03	.26*
Car	0.00	0.01	−0.01	0.01	.03
Perception					
Centile					
Constant	−2.65	17.82	−38.02	32.71	
Face	1.12	0.32	0.49	1.75	.33*
Car	−0.11	0.19	−0.48	0.27	−.05
Birthweight					
Constant	2.05	0.43	1.20	2.89	
Face	0.02	0.01	0.00	0.03	.24*
Car	0.00	0.01	−0.01	0.01	.10

**p* < .05; ***p* < .01.

Table 4. Correlations between perinatal measures, the Empathy Quotient (EQ) and the face and car inversion effects (IEs)

	Face IE	Car IE
Birthweight	.29*	.10
Gestation	.05	.14
Centile	.36*	−.07
EQ	.15	−.01

Notes. Sequential Bonferroni correction applied.
**p* < .001; ***p* < .003.

($\beta = .10, p = .330$) perception contributed to the model, significantly explaining 7.0% of the variance, $F(2,102) = 3.782, p = .026$ (see Table 3).

To additionally explore the domain-specificity of the face recognition findings, we examined the inversion effects (i.e., the difference between performances in the upright versus inverted conditions) in the face and car perception tests (i.e., the CFPT and CCPT). A typical pattern of findings was revealed: a significant interaction in a 2 (stimulus: faces, cars) x 2 (orientation: upright, inverted) repeated-measures ANOVA confirmed a larger inversion effect in faces ($M = 12.88\%$, $SD = 10.86$) compared to cars ($M = -0.53\%$, $SD = 8.27$), $F(1,102) = 130.263$, $p = .001$, $\eta\rho^2 = .561$. This interaction superseded a

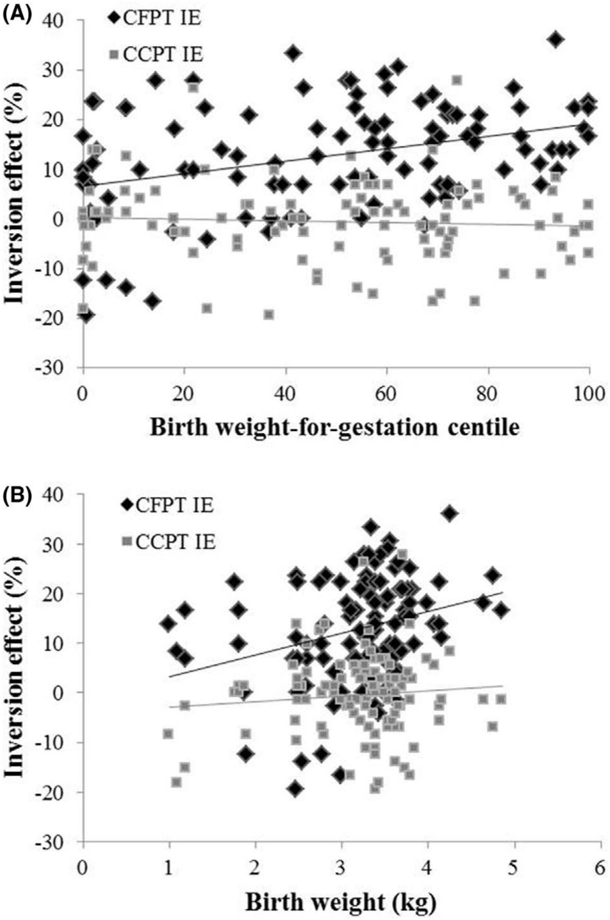

Figure 2. Correlation between (A) birthweight-for-gestation (centile) and (B) birthweight and the inversion effects on the face and object perception tasks.

main effect of orientation but not stimulus: $F(1{,}102) = 68.096, p = .001, \eta\rho^2 = .400$ and $F(1{,}102) = 0.619, p = .433$, respectively.

Subsequently, the three perinatal measures were correlated with the CFPT and CCPT inversion effects (see Table 4). Significant correlations were observed between the face inversion effect and the birthweight and centile measures (see Figure 2), but no perinatal measure correlated with the car inversion effect. Neither inversion effect was related to EQ scores (see Table 4). A Fisher r-to-z transformation confirmed that the correlation between centile and the face inversion effect was significantly larger than the correlation between centile and the object inversion effect, $z = 3.16, p = .002$. However, the same effect did not hold when centile was exchanged with birthweight, $z = 1.40, p = .162$.

Summary of findings

Birthweight and centile, but not gestation alone, were found to be significant predictors of both face memory and face perception skills. There was no consistent pattern of findings to suggest that either birthweight or centile was the strongest overall predictor, and, in any case, the amount of overall variance explained by each measure was relatively small. Thus, correcting birthweight for gestational age had little additional benefit in the context of this study, indicating that birthweight per se is perhaps the critical measure.

Partial correlations suggested that the effects of birthweight on face memory were primarily driven by those that also affected face perception. Further, examination of the inversion effect on the perception tasks indicated an influence on face-specific processing strategies (e.g., configural or holistic mechanisms). Comparisons to the object tasks strongly indicated that all effects were domain-specific, and there was weak evidence for an independent influence of socio-emotional functioning (i.e., EQ score).

Discussion

This study sought to investigate the relationship between birthweight/gestation and face recognition skills in adulthood. While no significant effects were found for objects, domain-specific influences of birthweight and birthweight-for-gestational age (centile) were observed for face perception and face memory. In addition, the same perinatal measures correlated with the inversion effect on the face but not the object perception task, implicating involvement of face-specific processing strategies.

It is of note that only two of the three perinatal measures were associated with adult face-processing ability: birthweight and the combined birthweight-for-gestation centile score that accounts for birthweight, gestation, and gender. Thus, the critical factor influencing face recognition ability is not prematurity but likely birthweight per se, with little to gain by correcting this measure for gestational age. This is consistent with the findings of Perez-Roche et al. (2017), who observed lower face memory skills in children who were born with clinically low birthweights, and Mathewson et al. (2019) in their examination of face matching skills in adults born at a very low weight. Here, we present the same trend within the typical adult population (where only 17 of 103 participants had a birthweight-for-gestation centile score that is lower than 10), using dominant psychometric-standard tasks of face recognition ability. However, only a small amount of variance was explained in all analyses, suggesting that other factors have larger influences on adult face recognition skills. Existing work strongly implicates a role for genetics (e.g., Shakeshaft & Plomin, 2015; Wilmer et al., 2010), and personality and socio-emotional measures (e.g., Bate et al., 2010; Lander & Poyarekar, 2015; Megreya & Bindemann, 2013). Notably, some evidence suggested an influence of empathy in the current study, independently of the perinatal measures.

A novel finding presented here is that birthweight influences face perception as well as face memory. Existing work suggests that while face memory undergoes a protracted developmental trajectory, perhaps not maturing until the age of 30 (Germine, Duchaine, & Nakayama, 2011; Susilo, Germine, & Duchaine, 2013; Weigelt et al., 2014), face perception skills peak during early-to-mid childhood (Bate, Adams, & Bennetts, 2020; Weigelt et al., 2014; see Crookes & McKone, 2009, for discussion). While it could be argued that some form of 'catch-up' might have yet to occur in our young adult participants while face memory continues to mature, it is of note that they have not compensated for, or grown out of, their face perception difficulties. This finding suggests that the influence of birthweight on face recognition skills is likely lifelong, rather than developmental delay.

It is unknown whether the association between face perception and birthweight extends to other, non-identity-based face perception tasks (e.g., expression processing, lip-reading). Cognitive models of face processing suggest that identity and non-identity aspects of faces are processed separately (e.g., Bruce & Young, 1986), and studies on patients treated for congenital cataracts support the contention that different aspects of face processing can be differentially impaired by early visual deprivation (Geldart et al., 2002). However, some studies suggest that similar holistic perceptual processes underpin both identity and expression processing (e.g., Calder, Young, Keane, & Dean, 2000; Palermo et al., 2011) – as such, it is possible that the relationship between inversion effects (which are thought to reflect the engagement of holistic processing) and birthweight observed in this study would also be apparent during other face perception tasks. Models of face recognition also suggest that face memory relies on, but can be separated from, face perception abilities – in other words, while perceptual difficulties are likely to affect face memory, face memory difficulties may also appear independently (Corrow, Dalrymple, & Barton, 2016). From the findings reported here, there is only limited evidence that birthweight may influence face memory ability independently of face perception performance. This finding warrants further investigation using alternative measures of face perception.

Importantly, our findings of domain-specific influences on face processing were supported by the lack of a significant relationship between all perinatal measures and the CCMT and CCPT. Further, the relationship between face recognition and perinatal measures remained significant even when object recognition abilities were controlled for, suggesting that it is not simply an artefact of a link between birthweight and general visuo-cognitive processes. Although this finding is suggestive of domain-specificity, we nevertheless acknowledge recent opinions recommending that evidence from multiple object categories are utilized within the same study (e.g., Geskin & Behrmann, 2018). While we attempted to offset this concern by using the most reliable and equitable tests of face and object processing (where the CCMT is currently the only publicly available object equivalent of the CFMT), further research with specific objects that are designed to test claims about the functional organization of the ventral visual cortex (e.g., Gomez, Barnett, & Grill-Spector, 2019) would be necessary to provide conclusive evidence of domain- or process-specificity.

Nonetheless, our claim for domain-specificity is further bolstered by the positive correlation between two of the perinatal measures and the face (but not the object) inversion effect. That is, participants with higher birthweight-for-gestation centile scores and higher birthweight showed larger face inversion effects in adulthood, which may be interpreted as higher levels of face-specific holistic or configural processing (Maurer et al., 2002; Rossion, 2008); the same significant relationship was not observed for car perception. Notably, this aligns with previous studies that found deficits in configural processing for faces (but not other objects) following early visual deprivation (de Heering & Maurer, 2014; Robbins, Nishimura, Mondloch, Lewis, & Maurer, 2010). Similar to the current study, these deficits were detectable well into adolescence and adulthood, supporting the claim that very early visual experience shapes later perceptual processing.

These findings offer preliminary support for domain-specific influences of birthweight/gestation on face recognition ability, and allow us to hypothesize about the precise underpinnings of the effect. While our exclusion criteria prohibited the participation of any individuals with a history of visual problems, it is nevertheless plausible that low birthweight/gestation participants may have experienced less interaction with faces in the critical first few weeks of life (Geldart et al., 2002). Indeed, infants born with low birthweights for their gestational age are likely to experience restrictions in their low-level perception post-partum, with some requiring treatment (e.g., incubation and/or physical separation from the mother) that may restrict their early visual experience with faces. This suggestion is supported by the additional association with face-specific visual processing strategies (as indexed by the face inversion effect). Importantly, our data also allow us to exclude some alternate mechanisms that may account for the relationship between birthweight and face recognition skills. Most notably, our data indicate that the findings reported here do not result from lower levels of social cognition that are outcomes of the perinatal measures: while empathy was also found to be an independent predictor of face perception ability, it did not correlate with any of the perinatal measures. This finding suggests that sub-clinical perinatal influences on social cognition may become less persistent in adulthood.

In sum, this study presents birthweight as a novel factor that accounts for individual differences in adult face-processing ability. Findings indicate that the impact of this perinatal influence may be somewhat face-specific and independent of general levels of social cognition. Instead, the relationship may result from atypicalities in the visuo-cognitive processing strategies that are believed to underpin the recognition of upright faces.

Conflicts of interest

All authors declare no conflict of interest.

Author contributions

Sarah Bate, Ph.D. (Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Writing – original draft; Writing – review & editing) Natalie Mestry (Conceptualization; Data curation; Investigation; Methodology; Project administration; Supervision; Visualization; Writing – original draft) Maddie Atkinson (Data curation; Investigation; Methodology; Project administration; Writing – original draft) Rachel J. Bennetts (Conceptualization; Formal analysis; Methodology; Visualization; Writing – original draft; Writing – review & editing) Peter J. Hills (Conceptualization; Formal analysis; Methodology; Supervision; Visualization; Writing – original draft).

Data availability statement

The data that support the findings of this study are openly available in the Open Science Framework at http://doi.org/10.17605/OSF.IO/BHDEK.

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