Distinct profiles of information-use characterize identity judgments in children and low-expertise adults

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Abstract

Face processing abilities vary across the lifespan: increasing across childhood and adolescence, peaking around 30 years of age, and then declining. Despite extensive investigation, researchers have yet to identify qualitative changes in face processing during development that can account for the observed improvements on laboratory tests. The current study constituted the first detailed characterization of face processing strategies in a large group of typically developing children and adults (N=200) using a novel adaptation of the Bubbles reverse correlation technique (Gosselin & Schyns, 2001). Resultant classification images reveal a compelling age-related shift in strategic information-use during participants' judgments of face identity. This shift suggests a move from an early reliance upon high spatial frequency details around the mouth, eye-brow and jaw-line in young children (~8yrs) to an increasingly more interlinked approach, focused upon the eye region and the center of the face in older children (~11yrs) and adults. Moreover, we reveal that the early vs. late phases of this developmental trajectory correspond with the profiles of information-use observed in weak vs. strong adult face processors. Together, these results provide intriguing new evidence for an important functional role for strategic information-use in the development of face expertise.

Public Significance Statement

Researchers have long puzzled over why some people are better at processing faces than others. For example, we know children find face recognition tasks more difficult than adults, but struggle to pinpoint clear differences in how they do it. Here, we asked if differences in the strategies used to extract information from faces might explain age-related improvements in performance. We mapped the information young children (~8 years), older children (~11 years) and adults rely upon when making decisions about face identity. Results reveal differences which can be broadly described as a shift from an early reliance on feature information to a more integrated approach as children age. Interestingly, similar differences were observed when we compared adults with weak vs. strong face identification abilities. Together, these results indicate that the critical information for face identity judgements changes with age and this might be functionally important for the development of face expertise.

Human face expertise is often characterized as highly specialized, sophisticated and uniformly exceptional. In truth, however, processing abilities vary widely across the population: a notable strength in some individuals (super-recognizers), weakness in others (prosopagnosia, autism spectrum disorder [ASD]) and everything in between. This variability may reflect variability in a multitude of biological, cognitive, and perceptual mechanisms (Calder, Rhodes, Johnson, & Haxby, 2011) and powerfully determine the success of an individual’s social communication and functioning.

Face expertise also varies *within* individuals: across the lifespan. Performance on laboratory measures of face expertise improves across childhood and adolescence, peaks shortly after age 30 and then declines (Germine, Duchaine, & Nakayama, 2011). Perhaps surprisingly, after decades of high-quality research, the key drivers of this developmental change are still considered to be unclear. Several possibilities have been examined, e.g., maturation of: face-selective neural mechanisms (Pelphrey, Lopez, & Morris, 2009); holistic processing (de Heering, Houthuys, & Rossion, 2007); and/or perceptual encoding (multidimensional ‘face space’ representations, Jeffery & Rhodes, 2011). Yet empirical support for these accounts is limited. Current evidence supports qualitatively mature, adult-like neural and cognitive face processing mechanisms from the earliest ages tested (see McKone, Crookes, Jeffery, & Dilks, 2012).

With the current study, we propose to explore an alternative mechanism that has been rarely considered: developmental changes in face-processing strategies: the visual information individuals draw upon for their face judgments. Adults demonstrate highly flexible profiles of information-use when evaluating identity, expression and other face characteristics (Gosselin & Schyns, 2001; Smith, Cottrell, Gosselin & Schyns, 2005). This selective and strategic use of different subsets of ‘diagnostic’ visual information for different face tasks could be critically important for efficiently processing this perceptually homogeneous stimulus category. Consistent with this notion, atypical information-use has been reported in individuals with face processing impairments: children and adults with ASD (Song, Kawabe, Hakoda, & Du, 2012; Spezio, Adolphs, Hurley, & Piven, 2007) and acquired prosopagnosia (Caldara et al., 2005).

We will directly investigate face-processing strategies across developmental time using a novel adaptation of the Bubbles technique to elucidate face-processing strategies during identity judgments in young children (6-8 years), older children (9-12 years) and adults. We also explore functional links between information-use and participants' face expertise by contrasting the processing strategies observed in adults with high and low levels of face recognition ability. If this construct is functionally important for the development of face expertise then differences are predicted across our various participant groups, which differ in age and basic processing ability.

Method

Participants

Participants were 69 adults aged 18 to 43 years (*M*=26.0, *SD*=4.6; 23 males), 64 children aged 6 to 8 years (*M*=7.7, *SD*=0.6**;** 33 males, hereafter referred to as young children) and 67 children aged 9 to 12 years (*M*=10.9, *SD*=0.9; 32 males, hereafter referred to as older children). An additional 1 adult, 25 young children and 20 older children were excluded after observations of fluctuating effort and/or attention during the task (made by an experienced developmental researcher sitting beside each participant while completing the task). Children were recruited from schools in London (UK) and Perth (Australia). Adults were recruited from Birkbeck College and remunerated with £8 or psychology course credit. This study was approved by the Research Ethics Committee at Birkbeck, University of London and the

Department of Education, Western Australia. All adults, children and their parents provided written consent prior to participation.

The Puzzle Bubble Game

All participants completed our 15-20minute game in a quiet room at school or university on a 13-inch MacBook Pro laptop. Adults then completed several other measures, including a brief standardized test of face recognition with strong psychometric properties: Cambridge Face Memory Test[1] (CFMT; Duchaine & Nakayama, 2006). An experimenter sat beside each participant to monitor task engagement and provide encouragement.

Across trials participants were challenged to identify three neutral-expression male faces (standardized greyscale photographs from Schyns & Oliva, 1999) when provided with only limited subsets of visual information through randomly positioned circularly symmetric Gaussian apertures or bubbles (see Gosselin & Schyns, 2001). The sampling density (total number of bubbles, *range* 40-250) was adjusted on each trial using a gradient descent staircase algorithm to target participants' accuracy at 75% correct. All participants started with the same number of bubbles and this individualized calibration of bubble numbers (more when performance was low, fewer when high) ensured that the task was challenging for each age group.

Given the importance of visual information from different spatial frequencies for face perception (Gosselin & Schyns, 2001) each stimulus was sampled not only across locations, but also across different spatial frequency (SF) bands (for full details on the methods and an illustration of the stimulus generation process see Gosselin & Schyns, 2001). Test stimuli were decomposed into five non-overlapping one-octave SF bands (128-64, 64-32, 32-16, 16-8, 8-4 cycles-per-image). Each of these bands was independently sampled with randomly

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[1] Data from one adult participants was lost due to technical difficulties.

positioned bubbles whose size was adjusted at each scale to reveal 3 cycles per aperture and whose number was adjusted to ensure equivalent information sampling across each scale (fewer larger bubbles sampled information from the coarser spatial frequency scales, following Gosselin & Schyns, 2001). The sampled information across each band was then re-combined to produce one experimental stimulus that featured a mixture of high and low SF information in different randomly determined locations. Stimuli appeared centrally on a light gray background at a viewing distance of approximately 70cm so that they subtended 4.6^{o} x 4.6^{o} of visual angle.

The task comprised a training and test phase. During training (18 trials) participants learned to identify the three identities, by their names (Bob, Ted, Dan). Each face appeared intact, then sampled with bubbles to prepare participants for test conditions. Auditory feedback was provided and all participants obtained a minimum 75% accuracy to progress. The test phase comprised 9 blocks of 24 trials (216 total) in which a face appeared centrally for 1000ms, followed by a blank screen until response (verbal for the younger children or labelled button-press). Between-block breaks provided generic encouragement (such as *"keep up the great effort"*) or a game in which participants identified 'bubbled' images of films, TV shows or geographical locations with as little visual information as possible.

Results

Participant performance metrics.

We attempted to equate task difficulty and performance to 75% accuracy by modulating the amount of visual information revealed on each trial. Ultimately, however, equating the initial amount of information sampling and the relatively small number of trials left small differences between groups. A one-way ANOVA confirmed a significant main effect of participant age on categorization accuracy (percent correct), $F(2, 199) = 21.62$, *p*<.001, η_p^2= .18. Adults (*M*=75.5, *SD*=3.7) performed significantly better than young (*M*=67.6, *SD*=9.5) and older children (*M*=72.0, *SD*=6.3) *ts*>3.9, *ps*<.01, who also differed significantly from each other, *t*(129)=3.1, *p*<.01. Parallel results were observed for the median number of bubbles (amount of visual information revealed) that participants needed to achieve these performance levels. Here, the significant main effect of participant age, *F*(2, 199) = 40.06, *p*<.001, η_p^2 = .28, indicated that adults (*M*=80.8, *SD*=5.2) achieved their higher level of performance with fewer bubbles than young (*M*=153.6, *SD*=5.7) and older children (*M*=123.7, *SD*=6.4) *ts* >5.2, *ps* <.01, who also differed, *t*(129)=3.4, *p*<.01. We note that even with this relatively greater number of bubbles children did not quite reach the categorization accuracy target (75%), which signals that they (particularly the younger group) would need even more information to perform at that level.

Bubbles analysis: Information use

We targeted the information that drives correct responses by sorting each trial as a function of whether or not the information presented to the participant resulted in a correct categorization response. The sum of the bubble masks that led to incorrect categorizations was subtracted from the sum of all bubble masks that led to correct categorizations to generate a classification image in which the pixel value at each location represented the association between presenting information at that location and a correct response. We transformed the classification images into z-scores using a non-informative region outside of the face area as a baseline and established those regions statistically associated with correct categorization performance (*p*<.05, z-critical: 3.96, 3.59, 3.18, 2.76 from high to low SF scale respectively[2], see Chauvin, Worsley, Schyns, Arguin, & Gosselin, 2005). Significant regions

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[2] Note that Scale 5 is not included in the analysis because the size of the filter encompasses too great a proportion of the search space for the corrected statistical analysis (see Chauvin et al, 2005).

from each spatial scale were then combined with the face information from an illustrative face identity (a morphed average of all three test identities) to create the effective faces which detail the critical face information used (Figure 1A). Red regions superimposed on this illustrative face indicate the information significantly associated with correct categorization performance at each spatial scale (Figure 2A, see Supplementary Figure 1 for the un-thresholded z-scored classification images).

The classification images highlight a clear developmental shift in face identity processing strategies across age groups. The profile observed in young children indicates that they draw out specific features e.g., around the mouth, eyebrow and jawline at high SF, with limited selective information-use for the coarse shape cues available at lower SF bands. This profile contrasts with that of the older children and adults, where we observed a relatively less piecemeal processing strategy in which the critical information for judgments is more interlinked. They also demonstrated a stronger and increasingly focused reliance upon the eyes and central facial features, compared to the young children. To confirm these differences, we directly compared the classification images for each group with each other by computing the difference of the un-thresholded raw z-scored classification images[3] and highlight only those face regions whose use differs significantly across groups ($p<0.01$, uncorrected, see Figure 1C for overall results on the illustrative face image and Supplementary Figure 2 for the significant differences at each spatial scale).

The refinement of strategic information-use with age and/or face experience could well contribute to face expertise. To directly investigate this possibility, we contrasted profiles of information-use in those adult participants with high and low levels of ability on the Cambridge Face Memory Test (CFMT). Unsurprisingly, CFMT scores in our adult

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[3] Note that for ease of interpretation only positive z-scores, indicating a positive association between information location and performance, were included in the difference comparison.

sample were generally high (M= 78.3% correct, *SD*=14.1). Still, after a median split there was a significant difference in the recognition memory of the lower (n=35, *M*=67.8%, *SD*=11.7, *range* 38.8 – 81.0) and higher performers on the task (n=33, *M*= 89.4%, *SD*=4.8, *range* 81.9 – 100), *F*(1, 67)=39.61, *p*<.001, η_p^2 =.37. Performance metrics indicated that bubbles identity judgments were significantly less accurate among the (CFMT) low performers (*M*=73.9, *SD*=4.6) compared to the high performers (*M*=77.0, *SD*=1.1), *F*(1, 67)=13.40, *p*<.01, η_p^2= .16. These lower performers also needed a significantly greater number of bubbles to achieve this performance level (*M*= 104.0, *SD*=47.4 vs *M*=57.3, *SD*=19.3), *F*(1, 67)=27.72, *p*<.001, η_p^2= .29 (replicating Royer, Blais, Gosselin, Duncan & Fiset, 2015, who found the number of bubbles to correlate with adult CFMT, Cambridge Face Perception Test and Glasgow Face Memory Test). Most crucially, there were clear differences in the diagnostic visual information for identity judgments in the two groups, which mirrored those we observed between young and older children (see Figure 1B, 1D and 2B). That is, compared to the high performers, the lower performers tended to rely on individual (cf. interlinked) features during the identity categorizations and focused less on important high SF eye information.

Discussion

These results provide important new evidence of a shift in face-processing strategies during childhood that could contribute to developmental improvements in processing ability. We reveal that young children are particularly reliant upon specific high SF feature details present around the mouth, eye-brow and jaw-line. By contrast, older children and adults focused more upon information that was centrally located and in interlinked regions around the eyes. Critically, the early vs. later phases of this developmental trajectory correspond with the profiles of information-use we observed in low and high performing adults (respectively).

The striking parallel between the child and adult findings lends weight to the notion that information-use matters for face processing ability. The co-variation of profiles of information-use and performance observed here indirectly in children and directly in adults provides the most direct support to date for a functional association between participants' face processing strategies (targeted reliance upon a specific subset of 'diagnostic' visual information for a given judgment) and expertise. It is unfortunate that face processing ability data is not also available for the current sample of child participants. Investigating the presence vs. absence of these hypothesized functional links will be an important topic for future developmental research.

The notion that there might be developmental changes in featural vs. more integrated processing of face stimuli is not new. Others have asked whether the protracted development of face expertise might be tied to changes in children's configural sensitivity to feature spacing (Mondloch, Le Grand, & Maurer, 2002) or their holistic face coding (e.g., Carey, Diamond, & Woods, 1980). There are certainly reports of young children having difficulties using configural information in face recognition tasks (Mondloch, Maurer & Ahola, 2006; Mondloch & Thomson, 2008; Mondloch, Leis, & Maurer, 2012; Tanaka et al., 2014). Yet the notion of selectively protracted configural-processing development is a contentious one (e.g., Gilchrist and McKone, 2003), moreover the centrality of these processing mechanisms to adult face expertise has recently been directly challenged (Burton, Schweinberger, Jenkins, & Kaufman, 2015). It is intriguing then that these new insights into children's face processing strategies are - at least superficially - consistent with this posited shift toward a more adult-like integrated processing approach with age. Yet direct tests of children and adults' relative use of local vs. global information was never the intended focus of this study and strong claims on this point are beyond the scope of the current data. Our paradigm reveals the extent to which specific facial information is significantly associated with accurate identification judgments at the group level. Furthermore, on an individual trial basis, the test stimuli that participants see necessarily constitute a random subset of the information from the face. Thus each image may feature one or more important features, alone or interlinked with other features, making it difficult to consider global or configural processing in the traditional sense.

Young children (and low performing adults) also demonstrated a diminished focus upon information in the eye region during their identity judgments, compared to older children and adults. The privileged status of the eyes for face experts could reflect a sense of their utility during face perception: as a discriminable feature that may also hold special significance for neural coding mechanisms (Eimer, 1998; Itier, Alain, Sedore, & McIntosh, 2007) or their importance in interpersonal interactions (Emery, 2000; Kleinke, 1986). Either could become increasingly refined with age and face experience.

The critical ‘diagnostic’ information for face identity judgments revealed here represents the intersection of the visual information available to participants and their internal category representation in memory. Our findings cannot speak to whether it is fine-tuning of these internal representations or improvements in attending to and extracting the most informative information that is driving the observed differences in processing strategies in this task. This question, along with the broader *flexibility* of face processing strategies across groups (children vs. adults, low- vs. high-performers) remain important for future studies.

This Bubbles study is one of very few to compare performance across different groups of participants (see Adolphs, Sears, & Piven, 2001; Caldara et al., 2005; Spezio et al., 2007 for single patients compared to a group). In such a scenario, there is necessarily a tradeoff between matching performance accuracy and keeping the amount of information presented on each trial at comparable levels. By beginning the experiment with equivalent information sampling for each group, we chose to focus more on the latter, allowing for small differences in performance accuracy between the groups (8% maximum difference between groups). We take confidence from the fact that all three groups performed well above chance and that the pattern of information use in the low CFMT adult group was similar in nature to that of the younger children, despite higher accuracy and efficiency than either group of children. Given this result, it seems unlikely that the developmental shifts observed simply stemmed from minor performance differences between the groups.

To ensure our study remained accessible to even our youngest participants we employed three novel male identities in the task. For the adult participants, observed profiles of information aligned with those reported in previous studies of face identification using an extended stimulus set (Gosselin & Schyns, 2001), using a large set of famous faces (Butler et al, 2010) and a novel set of personally known face identities (Smith et al, 2016). We are therefore confident that our adult results do generalize well beyond the current stimulus set and to face processing in general. To the extent that we have a relatively small number of trials per participant in this study from which to develop a strategic stimulus-based approach to the task, and that we have no evidence to suggest that children are more strategic than adults (e.g. adapting their strategy to a particular stimulus set) we believe there is considerable grounds to be confident in their results. Future studies that employ a larger stimulus set (perhaps a number of already known faces) with children would be an important extension of this work.

From a methodological standpoint, this study constitutes innovative use of the Bubbles paradigm with children as young as 6 years. To circumvent the practical impossibilities of submitting children to the many hundreds of trials typical of this task (a strain on both their patience and attention) we opted to test larger than standard participant groups (64 younger, 67 older children) to achieve appropriate levels of information sampling. Here participants each completed 216 trials, resulting in ~14000 trials (per group) which is comparable to the 10000 trials (obtained from only 20 participants) reported in the original bubbles face identification study (Gosselin & Schyns, 2001).Crucially, we replicated information-use profiles typically associated with identity judgments with our approach (Gosselin & Schyns, 2001; Butler et al., 2010). Modifying the approach in this way, however, prohibits analysis on the individual participant level and precludes potentially interesting additional analysis e.g. correlating individual feature use with age or ability. Still, it is our sincere hope that having demonstrated the successful extension of the bubbles paradigm to young children, this work launches a broader program of research that uses this novel approach to tackle these, and other outstanding issues in the domain.

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Figure Captions

Figure 1. A. Effective images displaying only those regions significantly correlated with correct categorization performance for younger children (6-8yrs), older children (9-12yrs) and adults, extracted from a sample face image ($p<0.05$ corrected). This information is visualized on an illustrative, morphed face that combines all three test identities (photographs from Schyns & Oliva, 1999), note - this particular image did not appear during the task. B. As A for adults split by median performance on the Cambridge Face Memory Test. C. Information used significantly more by one group of participants than another (e.g. in the first column, information used more by older children (9-12yrs) than younger children (6-8yrs)) extracted from the illustrative face image ($p<0.01$, uncorrected). D. As C for the comparison of good vs. poor adult face processing ability.

Figure 2. A. Red regions signify those locations significantly associated with correct performance for each main participant group at each sampled spatial scale ($p<0.05$ corrected). This information is visualized on an illustrative face (three-face morph of the test identities, originally from Schyns & Oliva, 1999). B. As A for the adult participants split by performance on the CFMT.

Supplementary Figure 1.

A. Classification images for each participant group at each of the spatial scales tested (measured as z-scores). Higher values indicate a greater association between the pixel location and correct categorization performance. Specially designed statistical tests establish the threshold for significance. Note that only positive z-scores, corresponding to a positive association between information location and behavioral performance are shown. B. As A for the adult participants split by performance on the CFMT.

Supplementary Figure 2.

A. Regions of significant difference between the groups depicted as red regions on an illustrative, morphed face (photographs from Schyns & Oliva, 1999) each at each spatial scale ($p<0.01$, uncorrected). B. As A for the adult participants split by performance on the CFMT.

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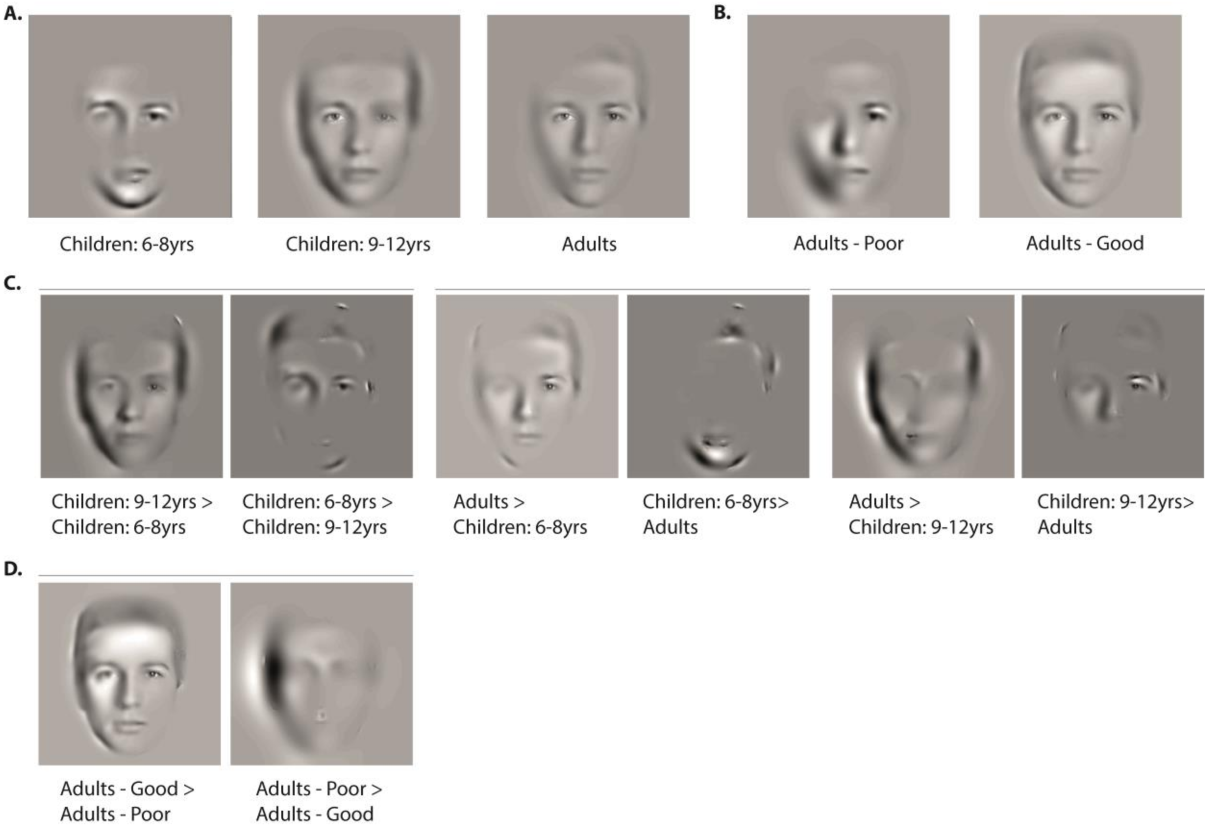


Figure 1.

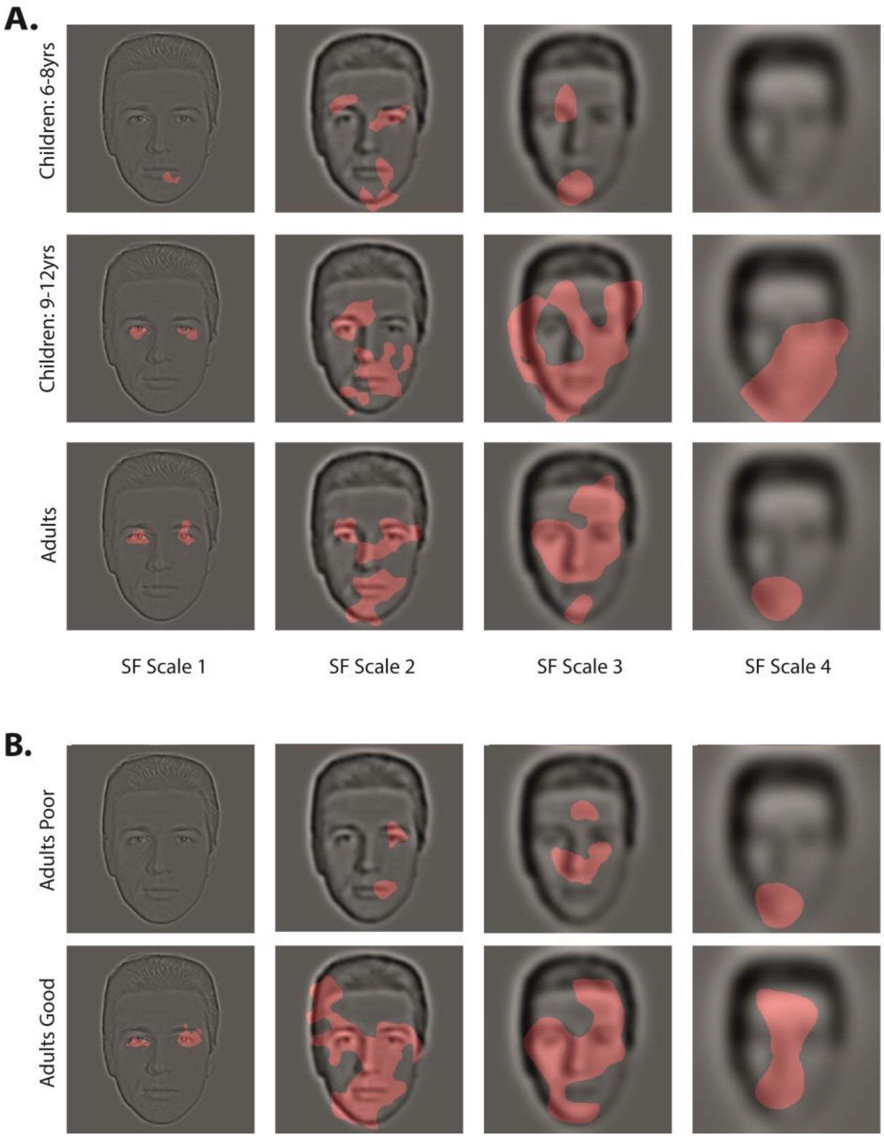
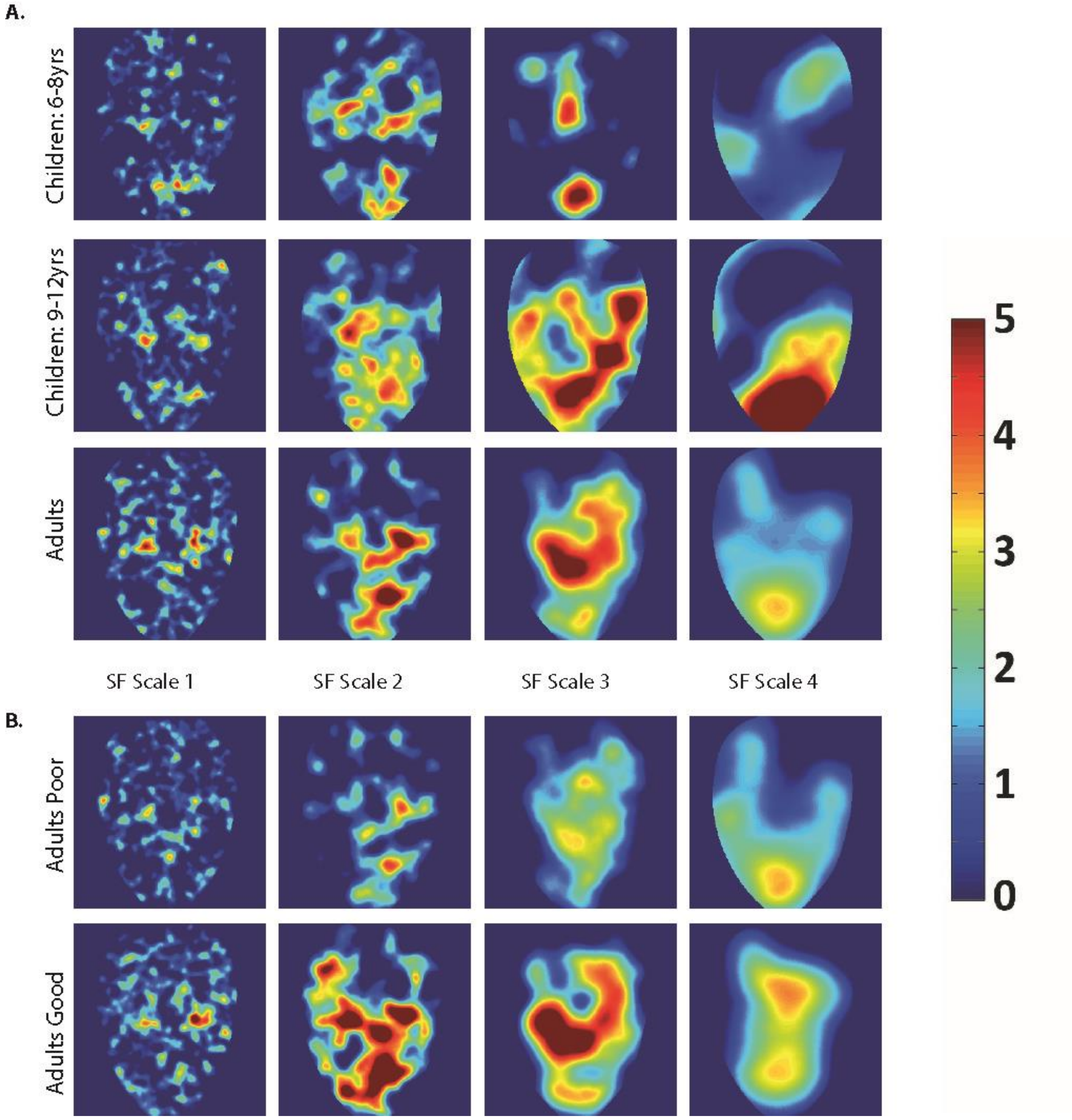

A.
Children: 6-8yrs
Children: 9-12yrs
Adults
SF Scale 1
SF Scale 2
SF Scale 3
SF Scale 4
B.
Adults Poor
Adults Good

Figure 2.


A.
Children: 6-8yrs
Children: 9-12yrs
Adults
SF Scale 1
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SF Scale 3
SF Scale 4
B.
Adults Poor
Adults Good
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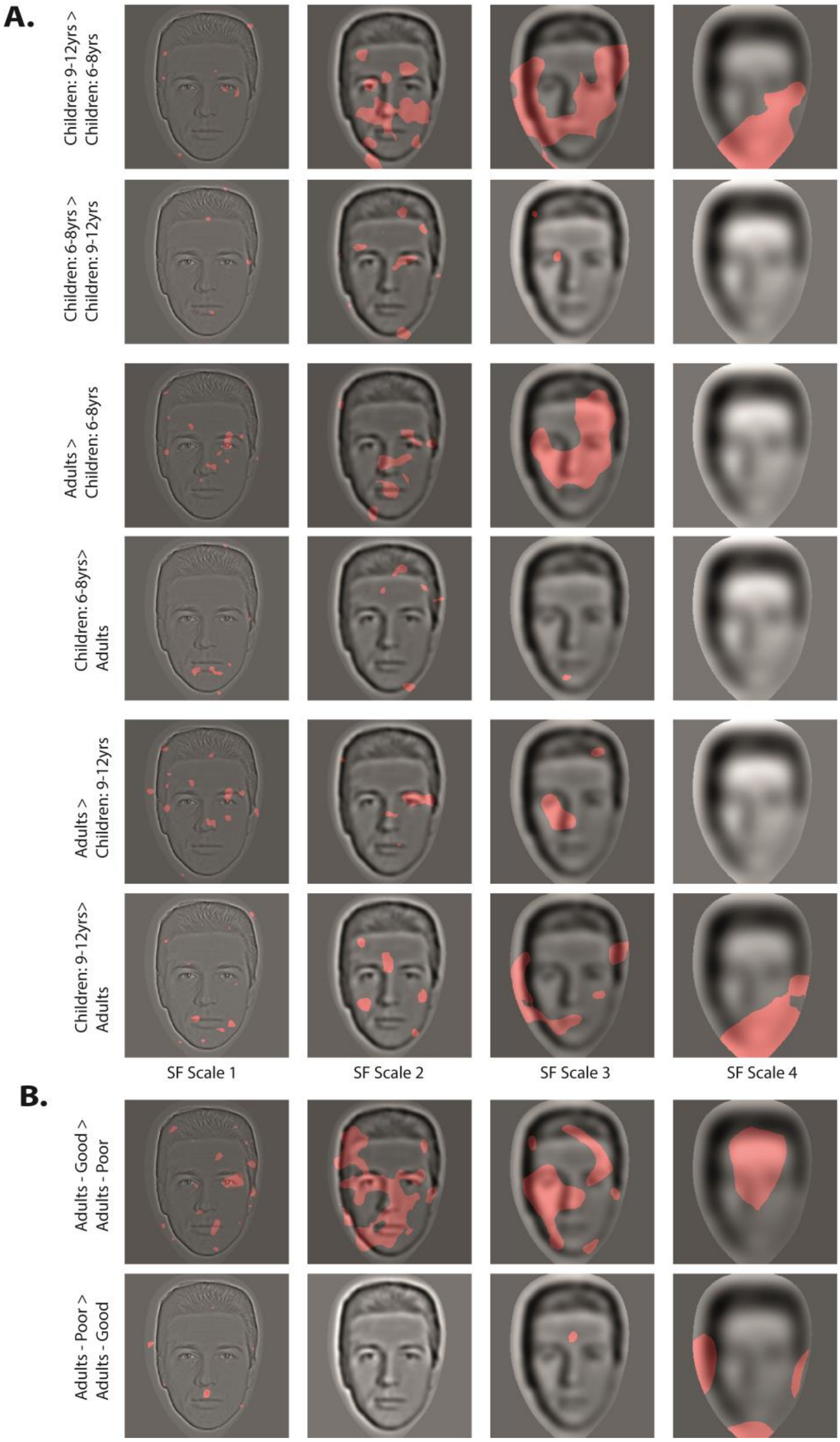
Sup Figure 1


A.
Children: 9-12yrs > Children: 6-8yrs
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Adults > Children: 6-8yrs
Children: 6-8yrs> Adults
Adults > Children: 9-12yrs
Children: 9-12yrs> Adults
SF Scale 1
SF Scale 2
SF Scale 3
SF Scale 4
B.
Adults - Good > Adults - Poor
Adults - Poor > Adults - Good

Sup Figure 2