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Discrepant integration times for upright and inverted faces

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Abstract. Judgments of upright faces tend to be more rapid than judgments of inverted faces. This is consistent with encoding at different rates via discrepant mechanisms, or via a common mechanism that is more sensitive to upright input. However, to the best of our knowledge no previous study of facial coding speed has tried to equate sensitivity across the characteristics under investigation (eg emotional expression, facial gender, or facial orientation). Consequently we cannot tell whether different decision speeds result from mechanisms that accrue information at different rates, or because facial images can differ in the amount of information they make available. To address this, we examined temporal integration times, the times across which information is accrued toward a perceptual decision. We examined facial gender and emotional expressions. We first identified image pairs that could be differentiated on 80% of trials with protracted presentations (1 s). We then presented these images at a range of brief durations to determine how rapidly performance plateaued, which is indicative of integration time. For upright faces gender was associated with a protracted integration relative to expression judgments. This difference was eliminated by inversion, with both gender and expression judgments associated with a common, rapid, integration time. Overall, our data suggest that upright facial gender and expression are encoded via distinct processes and that inversion does not just result in impaired sensitivity. Rather, inversion caused gender judgments, which had been associated with a protracted integration, to become associated with a more rapid process.

1 Introduction

Time-based analyses of perception can offer tantalising insights into the processes underlying various perceptual decisions. For instance, previous research examined the speed at which perceptual decisions can be made about upright and inverted facial images, suggesting that inversion results in slower perceptual decisions (McKone and Yovel 2009; Rossion and Gauthier 2002). This could indicate that perceptual decisions regarding upright and inverted facial images involve distinct mechanisms that accrue information at different rates. Alternatively, it is possible that both judgments reflect a common process which can more readily access information from upright, as opposed to inverted, facial images (see Perrett et al 1998).

Another method of measuring the temporal properties of sensory coding is to assess integration times. These refer to the extent of time across which information is accrued toward reaching a perceptual decision. The integration times are assessed by manipulating exposure durations, rather than by making speeded perceptual decisions. Most integration time studies have focused on simple visual features, such as movement (Albrecht 1995; Braddick 1973; van Doorn and Koenderink 1982), colour (Uchikawa and Yoshizawa 1993), and binocular disparity (Arnold and Wilcock 2007; Tyler 1991; Uttal et al 1975). However, several recent studies have assessed the integration of facial information (de Fockert and Wolfenstein 2009; Haberman and Whitney 2007, 2009; Haberman et al 2009; Sweeny et al 2009). Thus far it has been established that, like other visual features, information concerning facial expressions is integrated across both space (de Fockert and Wolfenstein 2009; Haberman and Whitney 2007, 2009; Sweeny et al 2009) and time (Haberman et al 2009).

It is essential to note that integration times and the speed at which perceptual decisions can be made are related to sensory signal strength. Thus, large binocular disparities can be detected more rapidly than smaller disparities, not because these signals are encoded by distinct processes, but because there is more information available for integration in a large-disparity signal (Arnold and Wilcock 2007; Tyler 1991; Uttal et al 1975). This relationship, between the amount of sensory information available in an image and integration time, makes it difficult to interpret past time-based measures of face perception.

To the best of our knowledge, no previous study has tried to equate sensitivity to the diverse facial characteristics under investigation prior to conducting a time-based analysis. Thus it is impossible to tell whether any time differences were due to discrepant processes working at different rates, or because there was more information available in one or another facial display. For instance, a particular actor with a masculine face might be poor at expressing emotions. A time-based analysis of emotion and gender judgments using this actor might reveal faster decisions for gender, but this might reflect on the actors' ability rather than on the inherent speeds at which gender and emotional expressions can be analysed.

To remove this potential confound, we decided to develop a paradigm wherein we first identify image pairs that can be differentiated on 80% of trials during objective forced-choice discrimination tasks with protracted (1 s) stimulus presentations. This performance level was chosen to avoid ceiling (perfect performance) and floor (chance performance) effects. Our baseline procedure should ensure that, at least for protracted presentations, we present image pairs that provide decision processes with behaviourally matched levels of signal to noise. We can then determine the exposure durations required for the development of these matched levels of performance. If matched levels of performance are achieved after discrepant exposure times, support would be given to the view that these perceptual decisions are based on distinct processes that accrue information at different rates.

We directed our analyses toward two persistent debates. First, we assessed whether upright and inverted faces are encoded by different mechanisms (eg Diamond and Carey 1986; Maurer et al 2002; Rossion 2008; Tanaka and Farah 1993) or by a common process attuned to upright input (eg Sekuler et al 2004; Valentine 1988; for a recent review see McKone and Yovel 2009). The majority of work looking at inversion effects has focused on judgments of facial identity. However, given our desire to equate sensitivity across diverse characteristics, we will assess a facial characteristic more suited for this purpose, facial gender. Gender has been the focus of a subset of inversion studies (eg Baudouin and Humphreys 2006; Campanella et al 2001) and is an important dimension for face recognition (see Baudouin and Tiberghien 2002). Second, we decided to examine whether analyses of emotional expression and facial structure are independent (eg Bruce and Young 1986) or interrelated (eg Calder and Young 2005; Haxby et al 2002; Karnadewi and Lipp 2011).

2 Methods

Six participants, the first author and five students who were naive as to the purpose of the experiment, volunteered and provided informed consent. All had normal or corrected-to-normal visual acuity.

Visual stimuli were generated with a ViSaGe stimulus generator (Cambridge Research Systems) and presented on a gamma-corrected 19-inch Sony Trinitron Multiscan G420 monitor (resolution 1024 × 768 pixels, refresh rate 120 Hz). Stimuli were viewed from a distance of 57 cm, controlled with a chin-rest, while the participant was seated in a dark room.

2.1 *Image construction*

Exemplar images were constructed by averaging multiple facial images with Abrosoft Fanta Morph (Version 4, 2002–2007 Edition). Pictures of 6 males and 6 females adopting eutral, happy, and angry expressions were selected from the NimStim facial database (Tottenham et al 2009). Images were chosen largely on the basis that the relevant actors were not showing teeth when smiling. An exemplar androgynous expressionless face (central image, figure 1) was constructed by averaging the 12 pictures of the 6 male and 6 female actors adopting neutral expressions. Exemplar expressionless female (left image, figure 1) and exemplar expressionless male (right image, figure 1) images were constructed by respectively averaging 6 images of females and 6 images of males adopting neutral expressions. Exemplar androgynous happy (top image, figure 1) and exemplar androgynous angry (bottom image, figure 1) images were constructed by averaging 12 images of 6 males and 6 females, respectively adopting happy and angry expressions. Note that none of the exemplar images depicted an individual actor. Rather, they were an averaged composite image of 12 or 6 facial images.

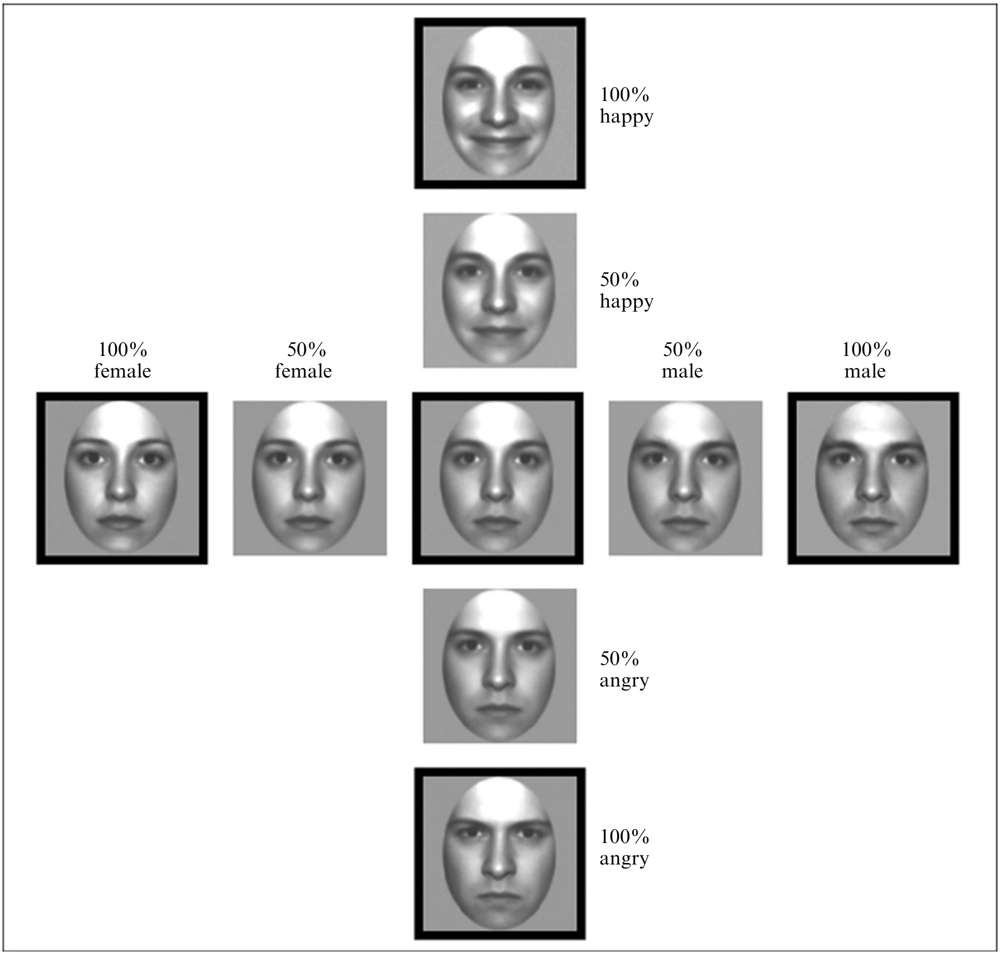

Figure 1. Depiction of some images used in this study. The standard image was an androgynous expressionless face (see central image). Arrays of 100 images, morphing between the standard and other exemplar images, were created. Exemplar facial images included an expressionless female face (100% female image, left), an expressionless male face (100% male, right), an androgynous happy face (100% happy, top), and an androgynous angry face (100% angry, bottom). Images in-between the exemplar images (without borders) depict the midpoints of each array of morphed images.

2.2 *Baseline procedures*

To identify images resulting in equal performance following 1 s exposures, we constructed 4 arrays of images that gradually morphed between the exemplar androgynous expressionless face (central image, figure 1) and the other averaged exemplar images (top, left, right, and bottom images, figure 1). The average luminance of all images (62 cd m^{-2}) was equated by using the Shine toolbox for Matlab (Willenbockel et al 2010). Across separate baseline procedures, adaptive staircase procedures were used to identify images within the morph arrays that could be correctly identified, within a sequential two-alternative forced-choice task, as either more happy, more angry, more male, or more female than the androgynous expressionless face on 80% of trials.

During baseline procedures, on each trial participants were sequentially shown two faces for 1 s each, a standard (androgynous expressionless face, see central image, figure 1) and a comparison face selected from the array of morphed images being sampled during that run of trials. A white-noise mask was presented before and after each face, and there was a 1 s interstimulus interval. The order of presentation, standard – comparison or comparison – standard, was determined at random on a trial-by-trial basis. The participants' task on each trial was to indicate which of the two sequential images looked more angry, more happy, more male, or more female, depending on which of the four facial characteristics was being judged on that particular run of baseline trials. The adaptive staircase procedure converged on a comparison image that could be correctly identified on 80% of trials.

To ensure that we always contrasted images to which participants were equally sensitive, baseline procedures were completed immediately prior to each and every run of experimental trials.

2.3 *Experimental trials*

Details concerning experimental runs of trials were similar to the immediately preceding baseline procedures, with the following exceptions. Only one comparison image was presented during a run of trials, the image successfully identified (as more male, female, angry, or happy than the standard expressionless/androgynous image) on 80% of trials during the immediately preceding baseline procedure. Note that the comparison image could therefore be physically different across participants, and for the same participant in the same experimental condition on the two different runs of experimental trials. The duration for which images were presented (50, 100, 150, 250, 500, 1000, or 2000 ms) was manipulated according to the method of constant stimuli. During a run of trials each presentation duration was sampled 25 times in a random order.

Each participant completed two runs of experimental trials for each of the 4 types of comparison images (androgynous happy, androgynous angry, expressionless male, and expressionless female faces). Given the laborious nature of the experiment, participants always took a break of at least $\frac{1}{2}$h between different runs of trials. More often, different runs of trials were completed on separate days. Consequently, fatigue did not impact on our measurements in different experimental sessions, nor did practice as performance was calibrated by using a test image that had resulted in 80% accuracy during the immediately preceding baseline procedure and we only ever compared data collected during the same runs of trials.

To assess how sensitivity for facial gender and emotional expression was altered by inversion, we repeated the baseline and experimental procedures using inverted facial images. Note that we repeated the baseline procedure before each run of experimental trials. Thus, we were contrasting different faces for which participants had equivalent levels of baseline performance across all experimental conditions.

3 Results

Experimental runs of trials provided distributions of performance as a function of presentation duration. We determined error distributions for judgments of happy, angry, female, and male comparison images. Owing to our experimental design, these varied from a peak of ~0.50 (chance performance for 50 ms presentations) to a plateau of ~0.2 (for presentations of 1 s or longer). Note that an error rate of less than 0.2 for stimulus presentations of 1 s or longer would have shown that participants were performing better during experimental runs of trials than they had in immediately preceding baseline trials. There is no evidence of this in any of our experimental conditions (see figure 2).

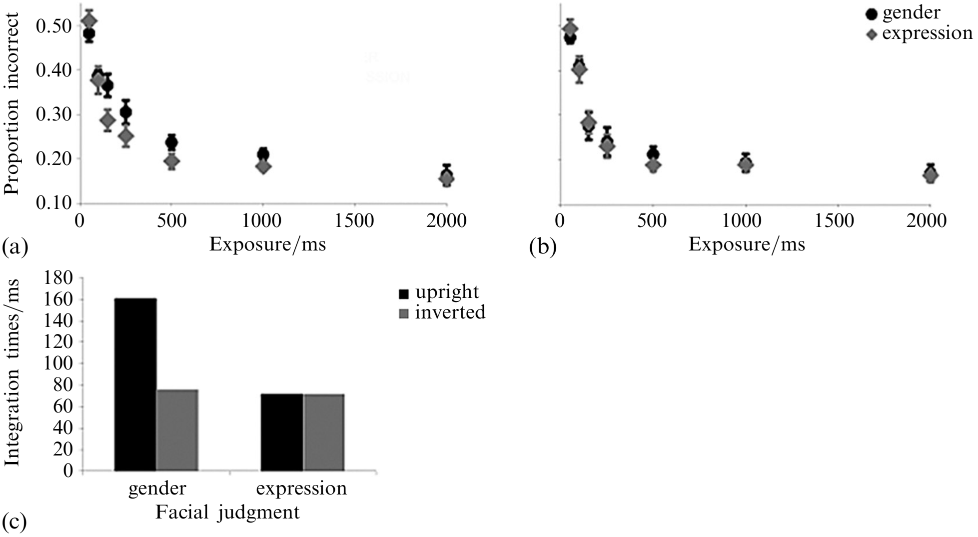

Figure 2. (a) and (b) are $X-Y$ plots depicting error proportions as a function of stimulus exposure times. Data points depict proportional errors averaged across six participants. Error bars depict ±1 standard error between six individuals' error rates. Solid lines depict the best fitting decay function for gender (black) and expression (grey) judgments. Data are shown for judgments concerning upright (a) and inverted (b) facial images. (c) Bar plot depicting integration times for judgments concerning the gender and facial expressions of upright and inverted images.

To assess the development of sensitivity to facial gender and emotional expression, for each participant we averaged error proportions for gender judgments across female and male faces, and for emotion judgments across happy and angry faces. Each participant provided a single error estimate for facial gender and for facial expression at each of the 7 test exposure durations sampled. These estimates were used to form an $X-Y$ plot of error proportions as a function of exposure time for both facial gender and facial expression judgments. Exponential decay functions were fitted to these two distributions (see figure 2). The critical question is how quickly performance plateaued when making judgments about facial gender and expression.

An extra sum-of-squares F test revealed that the best-fitting decay functions for upright faces had different time constants, such that sensitivity for facial expression judgments saturated more rapidly than did sensitivity for facial gender judgments ($F_{1,78} = 7.462$, $p = 0.008$). The half-life of the fitted decay functions can be taken as estimates of temporal integration time. These corresponded with ~72 ms for judgments of facial expression, and with ~161 ms for judgments of facial gender.

We also examined integration times for facial gender and emotional expression judgments when using inverted faces. For these stimuli there was no difference between the time constants of the best-fitting decay functions ($F_{1,78} = 0.017$, $p = 0.90$; see figure 2b).

The average temporal integration time, as indicated by the half-life of the best-fit decay function, for judgments concerning inverted facial expression and gender was $\sim$76 ms. This is reminiscent of the integration time for upright facial expression judgments ($\sim$72 ms), but is dissimilar from the more protracted times for upright facial gender judgments ($\sim$161 ms).

Our baseline measures were designed to ensure that we contrasted image pairs that prompted matched levels of performance in subsequent experimental conditions (by identifying happy, angry, female, and male comparison images that could be differentiated from an androgynous expressionless face on 80% of trials when presented for 1 s). The effects of inversion on baseline measurements are worth noting. We can express each individuals' inverted image baselines (position in morph array, 1 = standard expressionless/androgynous image, 100 = exemplar comparison image) as a proportion of their baselines for upright images. Doing so reveals that inversion did not impact baseline measures of expression judgments (average ratio: 0.96; SE = 0.09). However, inversion had a profound impact on judgments of facial gender, in that a considerably more male/female face was required for the same level of baseline performance (average ratio: 1.9; SE = 0.19).

4 Discussion

For upright faces, we found that gender judgments were associated with a more protracted integration process ($\sim$161 ms) than were judgments concerning emotional expression ($\sim$72 ms). These data are consistent with the conclusion that upright facial gender and expression judgments rely on distinct neural processes that accrue information at different rates. Interestingly, discrepant integration times for judgments of inverted facial gender and expression were not evident. Judgments of inverted facial gender and emotional expression were both subject to a relatively rapid ($\sim$76 ms) integration process. Our data are thus consistent with the conclusion that decisions regarding upright and inverted facial gender rely on distinct processes that accrue information at different rates.

As our approach to a time-based measure of facial coding differs so markedly from those used previously, it is probably worth expanding on why we feel that our data constitute strong evidence for mediation via distinct processes. First, let us consider in broad terms an approach that is more often adopted—speeded classifications. In a typical experiment participants might be shown happy, neutral, and angry faces, and the time taken to classify these images would constitute the dependent variable. If no attempt were made to equate the happy and angry faces in terms of distinctiveness, one or another expression might be classified more rapidly not because its recognition is mediated via a mechanism that works relatively rapidly, but because it is more distinctive. Actors, for instance, might be better at feigning happiness than anger, or vice versa. To avoid this type of dilemma, we adopted a behavioural control by which we first equated performance for all facial judgments (upright and inverted maleness, femaleness, and upright and inverted happiness and anger). Importantly, this was done with unspeeded two-alternative forced-choice judgments concerning images presented for 1 s. As we carefully avoided ceiling effects, we could thus ensure that we were contrasting images that provided the relevant decision process with behaviourally matched levels of signal to noise—otherwise objective sensitivity would have differed across our experimental conditions.

Our baseline procedures allowed us to examine how rapidly different decision processes could accrue behaviourally matched signals. Consequently, the discrepant integration times we measured during experimental runs cannot be attributed to variable decision criteria, as any attempt to make hastier decisions would have resulted in reduced performance. Also, given that our perceptual judgments were unspeeded, there was no motivation to adopt more or less relaxed response criteria. Moreover, the discrepant integration times cannot be attributed to one or another perceptual decision having access to more or less information, because performance was equated. We thus regard our data as providing strong evidence that decisions regarding upright facial gender and upright emotional expression, and about upright and inverted facial gender, were made on the basis of discrepant decision processes that accrue information at different rates.

Our data may seem to contradict previous time-based analyses of the impact of facial inversion. These have shown that inversion frequently results in slower perceptual decisions (see Rossion and Gauthier 2002; but also McKone and Yovel 2009). However, to the best of our knowledge no previous time-based study of facial coding has attempted to equate performance for upright and inverted stimuli. We therefore believe that the slower perceptual decisions for inverted images in previous studies were not due to inverted images being encoded via a relatively sluggish process, but rather because humans are sensitive to an additional source(s) of information when faces are upright (see Goffaux and Dakin 2010).

We would also like to stress that the inconsistency between our own data and previous time-based analyses of facial inversion may be more apparent than factual. We do not believe that our data are inconsistent with previous time-based analyses, as we have measured for how long information is accrued toward a perceptual decision, whereas previous studies have examined perceptual decision speeds—two related, but fundamentally different measures. Perhaps even more important is that we have equated performance for upright and inverted images, whereas previous studies made no attempt to do so.

It may seem surprising to suggest that simply inverting an image could change the information contained therein. However, at least two explanations for this can be found in the literature. First, it has been argued that faces might be encoded as a one-dimensional pattern that varies from top to bottom—that at some level of the visual hierarchy the human face is encoded as a bar-code like representation (see Dakin and Watt 2009; Goffaux and Dakin 2010). Such a bar-code like representation would be disrupted by inversion, potentially explaining why inversion results in a loss of information. Another possibility is that inversion disrupts sensitivity to form cues provided by lighting. People are attuned to lighting that originates from above, and have reduced sensitivity when this relationship is reversed. Inverting a facial image therefore almost invariably has two consequences: the facial form is both seen at and lit from an unfamiliar angle. Interestingly, when this confound is broken, by having images of inverted faces lit from above, the inversion effect is strongly mitigated or entirely eliminated (Hill and Bruce 1996; Johnston et al 1992; Talati et al 2010; see Liu et al 1999 for similar evidence relating to contrast polarity).

We note with interest a similarity between our data and those recently reported by Curby and Gauthier (2009). While we have focused exclusively on the extent of time across which facial information is accrued, this previous study examined the temporal dynamics for individuating objects more generally. Tellingly, an interaction was observed between presentation duration and facial orientation, such that sensitivity to upright faces continued to improve beyond encoding durations at which performance for inverted faces had plateaued (Curby and Gauthier 2009). This is entirely consistent with our findings, suggesting that information concerning upright faces is integrated across greater time spans than is information concerning inverted faces.

One of the most persistent controversies in face-perception research is whether impaired sensitivity for inverted faces is due to upright and inverted faces being encoded by different processes (Diamond and Carey 1986; Maurer et al 2002; Rossion 2008; Tanaka and Farah 1993), or because they are encoded via a common process that is simply less attuned to inverted input (Sekuler et al 2004; Valentine 1988).

Our data suggest that judgments about upright facial gender rely on a more protracted integration process than those concerning inverted facial gender. Note that this was true despite our having compensated for reduced sensitivity for inverted inputs, by using more distinctive inverted comparison images. Thus the evident reliance on different processes, as suggested by discrepant integration times, cannot be attributed to differences in sensitivity.

Our baseline measurements showed that, when discriminating between a standard androgynous expressionless face and a male or female comparison image, more masculine or more feminine comparison images were required after inversion to achieve equivalent levels of performance. Our data thus suggest that the impact of inversion is twofold. It reduces sensitivity (as indicated by the need for more distinctive comparison images to equate performance) and causes decisions to be based on a distinct code characterised by a more rapid integration process. These data are consistent with the notion that inverted faces are encoded via distinct processes relative to upright faces.

Another persistent debate concerns whether analyses of facial gender and emotional expression are independent (Bruce and Young 1986) or interrelated (Calder and Young 2005; Haxby et al 2002). That the analysis of facial gender is not affected by emotional expression is suggested by the apparent precedence of facial gender analyses. For instance, it has been shown that facial gender can bias judgments of expression, but that gender decisions are not impacted by facial expressions (Atkinson et al 2005; Karnadewi and Lipp 2011).

Our data are obviously inconsistent with a strict precedence for facial gender analyses, as in our study these were subject to a more protracted integration process than were expression judgments. However, our data do not preclude the possibility that these analyses might take place in tandem, or that they might interact. Integration times usually scale with signal strength. In this study we adopted a behavioural control, equating performance for facial gender and emotional expression for protracted stimulus presentations. In previous studies the distinctiveness of facial gender might have been greater than that of the emotional expressions, allowing analyses of the former to be completed more rapidly than the latter. This could result in a scenario wherein gender impacts on expression judgments but not vice versa. This, however, would not dictate that the former analysis must precede the latter.

Our integration time estimates for upright emotional expressions (~ 72 ms) are much shorter than those reported in a recent study (~ 818 ms—Haberman et al 2009). However, there are some important differences between studies. For instance, the former study assessed the ability to recognise the average expression across repeated facial presentations, whereas we have assessed the ability to recognise an individual expression from a single presentation. We do not believe, therefore, that the two data sets are in conflict. Rather, we take the discrepancy as evidence that integration times are malleable. It would seem that, if participants are asked to assess expressions over time (Haberman et al 2009), they can utilise a process that is capable of a more protracted integration than is characteristic of the processes underlying the emotional expression judgments in this study.

4.1 *Speculation*

Our data suggest that judgments of upright facial gender are associated with a more protracted integration process than are judgments of emotional expression. We speculate that these longer and shorter integration periods correspond with holistic and featural coding strategies, respectively. Moreover, we believe our data suggest that inversion selectively disrupts holistic coding, forcing both facial gender and emotional expression judgments to rely on featural analyses which have shorter integration times.

4.2 *Caveats*

It could reasonably be argued that our findings concerning emotional facial expressions were driven both by the restricted number and particular expressions we examined, anger and happiness. These could be distinguished from neutral by monitoring a particular facial feature, the mouth. Discriminating between more subtlety, different expressions might tap holistic coding to a greater extent. Similarly, increased uncertainty due to there being multiple candidate emotional states, as opposed to just one, might result in a greater reliance on holistic coding. If true, there are at least two important implications. First, facial expression judgments might not necessarily rely on featural analyses, as suggested by the lack of an inversion effect here and in other studies (Lipp et al 2009; McKelvie 1995). Rather, the degree to which a perceptual decision taps holistic coding might reflect the nature of the decision, selectively tapping featural analyses when these are sufficient, and incrementally recruiting holistic coding at need. Second, attempts at tight experimental control, in this context, might result in somewhat misleading data sets, elucidating strategies adopted when faces with highly constrained perceptual decisions, which are largely irrelevant in daily life. Thus our data might speak more to the interpretation of this and other facial coding experiments, which have focused on differentiating between a restricted range of facial expressions (Lipp et al 2009; McKelvie 1995), rather than to perceptual strategies that are more pertinent in daily life.

While we think it is important to acknowledge that some of our data might speak more to face-perception research than to face perception in daily life, we do not think this renders our data uninteresting. First, it is important to understand what can, and cannot, be inferred on the basis of numerous face-perception studies. Highly constrained studies like ours, for instance, might overstate the importance of local operations when judging facial expression. Second, we think it is interesting that participants might have adopted an unnatural strategy when attempting to judge the gender of inverted faces. This provides yet further evidence that facial inversion results in a loss of ready access to the type of information that is usually used when judging faces.

4.3 *Conclusion*

Possibly the most important feature of our data is that analyses of upright facial gender were shown to rely on processes with protracted integration times relative to judgments of inverted facial gender. This is inconsistent with the notion that these two analyses are mediated by a common process that is more attuned to upright input (Sekuler et al 2004; Valentine 1988). Instead, our data support the view that judgments concerning upright and inverted facial images rely on distinct processes (Diamond and Carey 1986; Maurer et al 2002; Rossion 2008; Tanaka and Farah 1993).

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