1 Reversing luminance polarity: control faces are harder to recognise but easier to see

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Control stimuli are key for understanding the extent to which the perception of faces relies on affective evaluation versus low-level image properties. Luminance polarity (LP) reversal combined with face inversion is becoming an increasingly popular tool for severely disrupting control face recognition. However, recent findings demonstrate visibility-recognition trade-offs, where these control faces are more salient, despite being harder to recognise. The present report brings together findings from image analysis, simple stimuli, and behavioural data for face perception, in order to provide an overview and account for why control faces subjected to LP reversal are associated with biased perceived salience. These findings have important implications for studies of subjective face appearance, and highlight that future research must be aware of behavioural artefacts due to trade-off effects.

Using the face inversion effect to create control faces.

The human visual system is especially good at interpreting information from the faces of others (Eimer & Holmes, 2007; Yovel & Kanwisher, 2004; Farah et al., 1995). It is generally accepted that this is due to the evolution of specialised and dedicated cognitive mechanisms for identifying and categorising faces (see Schmidt & Cohn 2001). Models of face perception often refer to the importance of extracting first-order relational information from a face. This refers to the interdependent spatial relationships between face parts, or features, that constitutes a face's overall configuration, and contrasts with local information where individual features are perceived independently of their relationship to one another (Diamond & Carey, 1986; Farah et al., 1995). The process by which we encode relational facial information is referred to as configural face processing. First-order relational information is broadly consistent across all human faces, in that faces tend to be information top-heavy, with eyes symmetrically located either side of the centre in the top half of the face, and the mouth appearing towards the bottom, below a roughly centrally-located nose. This is the typical configuration of an upright face, and because it is how we commonly experience faces, configural processing relies on the upright orientation of faces as they appear to us in natural viewing. Therefore, under experimental conditions when faces are spatially inverted (rotated by 180°) the spatial relationships between face parts become distorted, and as a consequence facial recognition performance is markedly impaired (see Yovel, 2016). The impaired ability to correctly identify, categorise, or recognise an inverted face is referred to as the face inversion effect (FIE), and demonstrates the importance of upright relational information extraction for "normal" face processing in natural viewing (Farah et al., 1995; Yovel, 2016). The FIE is therefore a valuable tool for exploring the kind of information required for successful facial recognition, by demonstrating the extent that performance on a given task is impaired versus preserved when faces are inverted.

For this reason, face inversion is a popular tool for creating control stimuli in studies of face perception. If performance on a given task remains the same for both upright *and* inverted faces, it is typically concluded that the mechanisms for successful performance operate independently of configural processing. In psychophysical studies, inverted control faces are also key tools for exploring the degree to which aspects of face expression perception are driven by (1) configural processing, including the way in which their affective and emotional content is evaluated, versus (2) simple advantages afforded by their low-level image properties (Gray et al., 2013; Yang, Zald & Blake, 2007; Stein et al., 2014). This dissociation between the roles of affective content versus low-level image properties for task performance is possible because certain low-level image properties are preserved within inverted faces, despite the loss of configural content required for affective evaluation. An effect observed for upright faces that is preserved for inverted faces suggests that the effect is modulated by image properties retained in control faces, rather than affective evaluation of their configural content that is diminished during inversion. An example from expression perception literature comes from studies of perceptual threat biases for fearful face expressions, where biases for detecting consciously suppressed, or simple localisation of fear expressions, are preserved for both upright and inverted versions of fearful faces (Gray et al., 2013; Stein et al., 2014; Yang, Zald & Blake, 2007). Such findings suggest that biases remain operable in the absence of configural information, and thus independently of recognition. However, the effect of inversion on recognition impairment is limited, such that although performance is markedly worse for inverted compared to upright expressions, it still remains *above* chance (Gray et al., 2013). To overcome this, inversion is sometimes used alongside luminance polarity (LP) reversal to reduce facial recognition performance to below chance. Use of the two

manipulations together are a favourable approach for creating control faces compared to inversion alone (Gray et al., 2013; Webb & Hibbard 2020; Webb, Hibbard & O’Gorman, 2020).

The FIE is therefore a natural consequence of disrupted configural face processing, and is repurposed in experimental conditions to manipulate the degree to which observers’ are able to extract configural information from a face, and to explore the role of low-level image properties for face processing. Although recognition disruption after inversion is limited, it is enhanced when used in conjunction with LP reversal.

Luminance polarity reversal: a novel method for creating control face stimuli.

Luminance polarity refers to the luminance of each pixel in the image relative to the mean luminance. The way in which individual pixel luminance intensities are dispersed between the light-dark continuum refers to an image’s skewness distribution; information relating to cues useful for object identification, including surface properties (Vuong et al., 2005; Haun & Peli, 2013). Luminance polarity reversal “switches” individual luminance intensities, where each pixel is subtracted from the image’s maximum intensity value. In other words, the brightest points become the darkest, and vice versa. For an image whose intensity distribution is mostly skewed towards brighter pixels, this distribution becomes skewed towards mostly darker pixels. Facial stimuli cropped to contain internal face features only (omitting hair and clothing detail) tend to have a skewness distribution toward bright pixel intensities, and so when subjected to LP reversal their appearance resembles that of a photographic negative. An example is shown in Figure 1.

Although inversion reduces accuracy and response time to identify control faces, the degree of impairment on performance is limited, and recognition is not entirely abolished (Itier et al., 2006; Itier & Taylor, 2002; Gray et al. 2013). To ensure that performance for control faces is reduced to chance, inversion has been used in conjunction with LP reversal (Galper, 1970; Gray et al., 2013; Itier et al., 2006; Rossion et al., 2012). Faces subjected to both inversion *and* LP reversal have become a novel face control that typically impairs accuracy and response time more so than either manipulation alone (Gray et al., 2013; Rossion et al., 2012). Their individual effects on performance are similar, and findings show that although these effects on performance differ substantially from upright faces, they do not differ between inverted-only or LP reversed-only faces (Gray et al., 2013; Kemp et al., 1990; Itier & Taylor 2004). When used together, the two manipulations achieve dual disruption effects on recognition performance, evidenced by longer detection times, lowest detectability and reduced accuracy, or “hit races” (Gray et al., 2013; Hedger, Adams & Garner, 2015; Roission et al., 2012; Itier & Taylor, 2004). These additive effects are described by Itier and Taylor (2002) as imposing a “perceptual deficiency” (p. 3) at the level of encoding, and indicate the role of sub-processes for encoding configural face information, where inverted faces are thought to impede both relational and “gist” information extraction, while LP reversed faces primarily disrupt surface properties and pigmentation, leaving the “gist” of a face relatively intact (Hole et al., 1999; Itier & Taylor, 2002; Vuong et al., 2005).

A benefit shared by inversion and LP reversal is the preservation of some low-level image features known to influence image salience. On this basis, LP reversed control faces are used by psychophysical studies whose objectives are often to explore configural attributes of face processing, while controlling for low-level confounds that may inadvertently influence image

salience, including contrast and spatial frequency content. Recent evidence, however, challenges this view, and encourages caution for using LP reversal to create control faces.

Figure 1. An actor portraying a disgusted facial expression, extracted from the KDEF database (Lundqvist et al., 1998). On top, a normal face is composed of primarily light pixel intensities, but the reverse becomes true when the same face is subjected to LP reversal (bottom).

Trade-offs for LP reversed faces: harder to identify but easier to see

While it is generally accepted that LP reversal, especially when combined with inversion, attenuates performance on tasks of face recognition and identification, recent evidence shows that it can also *improve* the visibility of a face image (Webb, Hibbard & O’Gorman 2020; Haun and Peli, 2013). Here, preliminary findings highlight the distinction between judgements of stimulus content, such as explicit recognition of faces’ emotion, and judgements of stimulus appearance including overall visibility, regardless of a face’s

emotional content or identity. In a contrast matching task where observers adjusted the physical contrast of a target face in order to perceptually match it to a reference image, control faces subjected to both inversion and LP reversal required *less* physical contrast compared to upright faces in order to be perceptually matched (Webb, Hibbard & O’Gorman, 2020). In other words, such control faces already appear more salient, in terms of their apparent contrast, compared to their upright counterparts. Conceptual extension of the FIE might lead one to expect that these face controls should be disadvantaged in terms of salience. However, perceptual matching relies on different stimulus information compared to that of explicit recognition, and so is unlikely to be disrupted by image manipulations in the same way. Instead, these findings show trade-off effects associated with LP reversal and inversion, where faces benefit from enhanced perceived salience while at the same time are unrecognisable (Webb, Hibbard & O’Gorman, 2020; Gray et al., 2013). This visibility advantage for LP reversed faces is also observed under intraocular suppression conditions. In a breaking continuous flash suppression study (b. CFS), a target face presented to one eye competes against a dynamic noise mask presented to the other eye in a bid to become the conscious percept (Gray et al., 2013). Response times to detect a consciously suppressed face under b. CFS are thought to index stimulus visibility, but also the degree to which it is prioritised during processing. B. CFS data have shown a detection advantage for inverted LP-reversed faces, where response times were faster than for upright and LP retained versions of the same face (Webb & Hibbard, 2020), suggesting that although recognition of such faces is severely disrupted (Gray et al., 2013), their stimulus strength enables them an advantage against suppressing masks.

An explanation for the visibility effects associated with LP-reversal comes from Haun and Peli (2013). In a contrast evaluation task where observers selected one of two images for the highest contrast, judgements of brightness were biased for images containing more darker compared to lighter regions. The authors propose that the subjective salience of an image, measured by its apparent contrast, is significantly influenced by local dark regions contained within it. Indeed, this is consistent with studies of simpler stimuli, including basic patches of fixed luminance values. For example, findings show that the visual system is particularly sensitive to changes in brightness for stimuli with negative (dark) compared to positive (bright) luminance, where discerning changes in luminance are more concentrated for negative than positive stimuli (see Kane & Bertalmio, 2016). Haun and Peli (2013) propose that this dark bias could be explained by the density of dark-sensitive contrast-encoding neurons at primary visual areas, where such physiological factors could influence perceptual biases, or gains, for images containing more darker regions when forming judgements of apparent contrast (see Haun & Peli, 2013). Elements of an image eliciting dark biases may explain why LP reversed faces, containing more negative than bright regions, appear more salient in terms of visibility and detection thresholds (Webb, Hibbard & O’Gorman, 2020; Webb & Hibbard, 2020). Therefore, because apparent contrast correlates with an image’s real-life image contrast (see Haun & Peli, 2013), it is important to understand how image manipulations such as LP-reversal may inadvertently change a face image’s subjective appearance. Although spatial inversion preserves image features known to influence image salience, including luminance and its distribution, contrast and spatial frequency, LP-reversal does not assure the same degree of consistency. Specifically, the objective of LP-reversal is to switch the brightness of pixel values, such that the distribution of light versus dark pixels is changed in the manipulated image, and so its mean luminance is inherently altered. For example, the LP-reversed face in Figure 1 contains more dark than light pixels than its upright-self, and has a *lower* average luminance. By extension of findings from Haun and Peli (2013), this control face is likely to appear more salient in terms of its apparent contrast

compared to its upright-self simply because it contains a higher density of negative pixels in local areas. This account explains findings that LP-reversed faces may require less physical contrast in order to be perceptually matched (Webb, Hibbard & O’Gorman), and break suppression faster compared to their upright counterparts, despite also being inverted (Webb & Hibbard, 2020).

Findings therefore suggest that LP reversal adjusts the physical composition of a face in a way that increases the distribution of dark pixels. A priori, this in turn is likely to inadvertently increase the apparent contrast of LP reversed faces, in a way that enhances their perceived salience. This account is upheld by behavioural evidence from contrast matching and b. CFS studies, showing an advantage for perceiving and quickness to respond to such faces (Webb, Hibbard & O’Gorman, 2020; Webb & Hibbard, 2020), despite known disadvantages for recognising such faces (Gray et al., 2013; Itier & Taylor, 2004). It is important to note, however, that there are few investigations of these effects within the context of basic visibility of faces, as opposed to explicit recognition, and further investigation is required to better understand them. This is also true for studies of LP reversal and b. CFS, as there is a degree of inconsistency between the very few findings that exist on the matter.

Implications for present and future research

There are two key implications of using LP reversal to create control faces. The first relates to visibility confounds that could be inadvertently introduced to facial stimuli by reversing their LP (Webb & Hibbard; Webb, Hibbard & O’Gorman, 2020; Haun & Peli, 2013). In particular, findings thus far suggest that LP reversal improves stimulus salience, and that this is task-dependent. It is important to highlight here that findings on the topic are relatively few, but do show that visibility advantages associated with LP reversal occur primarily for subjective judgements of stimulus appearance (Webb, Hibbard & O’Gorman, 2020; Haun & Peli, 2013), and in another case, by facilitating the detectability of LP reversed faces under b. CFS conditions (Webb & Hibbard, 2020, but not Gray et al., 2013). For tasks unrelated to the subjective appearance of stimuli, concerned instead with face identification (Galper, 1970; Gray et al., 2013; Itier et al., 2006; Rossion et al., 2012), and detection (Gray et al., 2013; Webb & Hibbard, 2019; Liu-Shuang et al., 2015), LP reversal does not facilitate task performance. This suggests a low-level effect of LP reversal that influences the subjective appearance of a face as a physical stimulus, as opposed to its salience in terms of registering its expression, or identity. For studies concerned with the subjective appearance of facial expressions, it is therefore important to be mindful of visibility confounds associated with LP reversed control faces. Additionally, only two studies explore the effect of LP reversal for face detectability under b. CFS, but do show evidence that LP reversal can also enhance faces’ visibility for crude detection tasks (Webb & Hibbard, 2020, but not Gray et al., 2013). Further investigation is required to confirm the extent of these effects (see below). It is therefore important to consider the role of LP reversal on stimulus salience, and in particular the possibility of inadvertently introducing visibility-recognition trade-off effects when employing it to create control facial images. In cases where image statistics are thought to play an important role for performance, inversion alone may be a more appropriate method for creating face controls. Inversion assures a greater degree of consistency between upright faces of controls in terms of luminance and intensity distributions, such that inverted control and upright faces do not differ in their apparent, perceived contrast.

Secondly, evidence so far also shows that the magnitude and direction of trade-off effects vary according to facial expression and spatial frequency content, and so are especially important for psychophysical studies of expression perception. Specifically, LP reversal *only* facilitates faces' visibility when they are composed of intact broadband or low spatial frequency information, and for mid-range and high frequency versions of the same faces this visibility advantage diminishes (Webb, Hibbard & O'Gorman, 2020). This is likely to be due to the loss of contrast at higher spatial frequency ranges, such that LP reversal effects on intensity distributions are lesser by comparison. Moreover, while broadband and low frequency fear expressions show a visibility advantage over other facial expressions, the reverse is true when the same faces are mid-range and high frequency filtered (Webb, Hibbard & O'Gorman, 2020). This is likely due to natural expression-related differences between faces image composition (Menzel et al., 2018; Webb, Hibbard & O'Gorman, 2020). Therefore, even for studies concerned exclusively with intact broadband faces, LP reversal, like inversion, also has unequal effects on performance for different expressions (McKelvie, 1995; Webb, Hibbard & O'Gorman, 2020).

Direction for future research

There two broad avenues for further investigation. The first is to develop the current understanding of LP reversal effects on face visibility as opposed to explicit recognition. The second is to develop a better understanding of the mechanisms that enable visibility-recognition trade-offs for facial stimuli.

Understanding the role of task-dependence is motivated by mixed outcomes of different task types, and methods for presenting face stimuli. For example, whether detection thresholds indicate awareness of gradually-emerging individual face parts (Liu-Shuang et al., 2015), fully-presented face parts at suprathreshold (Itier & Taylor, 2006; Itier & Taylor, 2006), with linearly increasing brightness against dynamic masks (Webb & Hibbard, 2020; Gray et al., 2013), or backward-masks (Webb & Hibbard, 2019), and moreover, whether the observers task is to indicate awareness of a percept regardless of its location (Gray et al., 2013; Hedger et al., 2015), or to provide location-specific responses (Webb & Hibbard, 2020; Webb & Hibbard, 2019). Such tasks reflect a specific rapidness to respond to and locate LP reversed faces, and are less concerned with subjective judgements of appearance. Tasks concerned with the latter are comparatively scarce and require further investigation (Webb, Hibbard & O'Gorman). Face recognition under LP reversal has been studied extensively compared to fewer investigations of detection thresholds, and by extension under-explored effects related to subjective appearance studies. A greater understanding of these task-related effects is important because control faces are employed broadly across disciplines within social and clinical sciences, and so their appropriateness and efficacy outside of psychophysical studies requires validation. Until recently, LP reversal has been used in conjunction with inversion to create a control face that is unique in inducing random performance. However, it is important to acknowledge and better understand the contexts where LP reversal is appropriate, including those where it can be expected to exert experimental artefacts. Currently findings regarding LP reversal and face *visibility*, as opposed to recognition, come from a small range of studies that although are behaviourally and theoretically supported (Haun & Peli, 2013; Kane & Bertalmio, 2016), require further replication.

It is also necessary to develop a more substantial understanding of both (1) stimulus and (2) cognitive mechanisms responsible for visibility-recognition trade-off effects for LP reversed

control faces. In the first instance, such an understanding is key for the psychophysical development of stimuli. The interaction between target stimulus and background luminance, for example, may play an important role in determining the salience of the target (Kane & Bertalmiño, 2016). Understanding this interaction is crucial for all studies that present grayscale images against uniform grey backgrounds, particularly for those interested in perceived salience. In the second instance, the additive -but not undependably different- effects associated with inversion and LP reversal for face recognition emphasise the role of sub-processes for facial recognition that are influenced differently by the two image manipulations. Further exploring manipulation-specific and combined effects on performance will therefore provide greater insight into the cues, both low level and affective, required for optimal face recognition.

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