Vision Research 157 (2019) 44–54

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

External and internal facial features modulate processing of vertical but not horizontal spatial relations

Günter Meinhardt[a,*], David Kurbel[a], Bozana Meinhardt-Injac[b], Malte Persike[a]

[a] Department of Psychology, Methods Section, Johannes Gutenberg University Mainz, Germany
[b] Department of Psychology, Section for Developmental and Educational Psychology, Johannes Gutenberg University Mainz, Germany

ARTICLE INFO

Number of Reviews = 1

Keywords:
Inversion effect
Face cue integration
Spatial relations
Horizontal and vertical information
Attentional window

ABSTRACT

Some years ago an asymmetry was reported for the inversion effect for horizontal (H) and vertical (V) relational face manipulations (Goffaux & Rossion, 2007). Subsequent research examined whether a specific disruption of long-range relations underlies the H/V inversion asymmetry (Sekunova & Barton, 2008). Here, we tested how detection of changes in interocular distance (H) and eye height (V) depends on cardinal internal features and external feature surround. Results replicated the H/V inversion asymmetry. Moreover, we found very different face cue dependencies for both change types. Performance and inversion effects did not depend on the presence of other face cues for detecting H changes. In contrast, accuracy for detecting V changes strongly depended on internal and external features, showing cumulative improvement when more cues were added. Inversion effects were generally large, and larger with external feature surround. The cue independence in detecting H relational changes indicates specialized local processing tightly tuned to the eyes region, while the strong cue dependency in detecting V relational changes indicates a global mechanism of cue integration across different face regions. These findings suggest that the H/V asymmetry of the inversion effect rests on an H/V anisotropy of face cue dependency, since only the global V mechanism suffers from disruption of cue integration as the major effect of face inversion.

1. Introduction

Humans are face-experts due to their longstanding viewing history with individual members of this special object class (Diamond & Carey, 1986; Carey, 1992; Gauthier & Bukach, 2007). However, humans acquire expertise for faces in the upright view. We notice even tiny changes in faces when they are presented upright, but are rather insensitive even to severe distortions when they are presented upside-down (Thompson, 1980; Bartlett & Searcy, 1993; Searcy & Bartlett, 1996). Generally, faces appear to be more vulnerable to inversion than other object categories (Yin, 1969; Valentine, 1988; Rakover, 2002). The effect is observed not only for faces presented in isolation, but also for faces as parts of more complex visual scenes (Taubert et al., 2016), This could reflect a special "configural" encoding of upright faces, which is shaped by experience (Carey, 1992; Carey & Diamond, 1994; Gauthier, Curran, Curby, & Collins, 2003; Meinhardt-Injac, Persike, & Meinhardt, 2014).

Some years ago, Goffaux and Rossion (2007) reported a striking asymmetry in the inversion effect for horizontal compared to vertical eye position. For detecting changes in vertical eye position large inversion effects were reported, while changes in interocular distance could be detected with only modestly less accuracy when faces were presented upside-down. The authors did not offer a theoretical framework for understanding why inversion disproportionately disrupts sensitivity to vertical, compared to horizontal relations. However, they speculated that the specific arrangement of cardinal face features along the vertical axis must have a key role for the observed H/V processing anisotropy. Some years later, Dakin and Watt (2009) revealed that faces own a specific Fourier component structure, which they termed horizontal "bar codes". Analysis showed that the horizontal information in faces is particularly important for face recognition. A face image with intact horizontal spatial frequency components but faded vertically ones is still quite well recognizable, while it appears heavily distorted with intact vertical components but faded horizontal ones. Further experiments of Goffaux and Dakin (2010) showed that filtering which retained mostly horizontal information largely preserved typical face-specific effects (i.e., inversion effect, congruency effect), while filtering that retained mostly vertical information largely altered these effects. Moreover, masking faces with horizontal noise strongly hampered face recognition particularly for upright faces, while masking with vertical

* Corresponding author at: Department of Psychology, Methods Section, JGU, Wallstr. 3, 55099 Mainz, Germany.
E-mail address: meinharg@uni-mainz.de (G. Meinhardt).

https://doi.org/10.1016/j.visres.2017.12.006
Received 27 July 2017; Received in revised form 19 December 2017; Accepted 21 December 2017
Available online 22 March 2018
0042-6989/

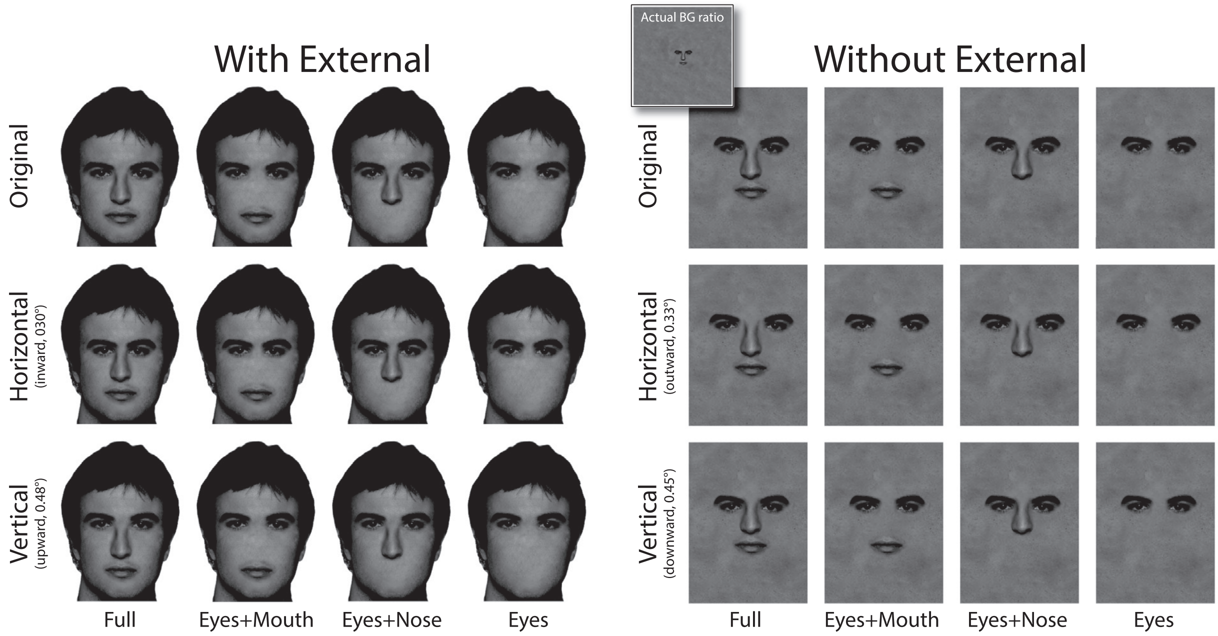

Fig. 1. Examples of face stimuli in the four feature conditions with external feature context (left), and for cardinal internal features only (right). The first row shows stimuli with unaltered eye position, second row horizontal changes (left: smaller eye distance than original, right: larger eye distance), third row vertical changes (left: eyes + eyebrows moved upward, right: moved downward). The pictogram indicates the relative size of cardinal internal features and background texture in the display.

noise had minor effects, and did hardly alter the inversion effect (Goffaux & Dakin, 2010; Pachai, Sekuler, & Bennett, 2013). Presence of horizontal information has also been shown to be crucial for eliciting the face-specific N170 potential (Hashemi, Pachai, Bennett, & Sekuler, 2014; Jacques, Schiltz, & Goffaux, 2014), and is seemingly crucial for emotion recognition (Huynh & Balas, 2014). These results suggest that the H/V processing anisotropy could potentially rely on a differential use of horizontal and vertical spatial frequency components. In particular, the large difference in inversion effects for H relational compared to V relational properties might root in a specific sensitivity to altered horizontal spatial frequency content, because changing eye height introduces changes in exactly these components.

Sekunova and Barton (2008) outlined other potential roots for the disproportionately larger inversion effects for V compared to H relations. This explanation laid emphasis on the contextual face cues that are potentially relevant to anchor judgements about interocular distance and eye height. First, the eyes region attracts attention of the observer both in upright, and in inverted presentation (Barton, Keenan, & Bass, 2001; Williams & Henderson, 2007; Sekuler, Gaspar, Gold, & Bennett, 2004). Potentially relevant cues for referencing interocular distance fall into this region, and are in short distance to the eyes (e.g. the bridge of the nose or the horizontal face outline borders). For judging eye height the authors reasoned that reference to distant face parts is necessary, e.g. the mouth region. Referencing with respect to the mouth would require intact long-range relational coding. Further, the mouth region is not in the main focus of attention when viewing faces (Williams & Henderson, 2007; Xu & Tanaka, 2013). If inversion confines the attentional window to a smaller region focused around the eyes (Barton et al., 2001; Sekunova & Barton, 2008; Rossion, 2009), particularly long-range relations should be affected, while short-range relations should not be harmed to comparable degrees. Sekunova and Barton (2008) tested this conjecture by introducing an artificial short-range cue for eye-height. They shifted just the eyes downward, letting the eyebrow position unchanged, thus enabling the observers to anchor vertical eye position by evaluating changes in eye-eyebrow distance. Inversion effects for this manipulation turned out to be small, and in the same order of magnitude than found for interocular distance. The authors took this as evidence for their claim that the inversion effect scales with cue distance, and is independent of direction, if the relevant cues fall within the same attentional window.

Crookes and Hayward (2012) challenged this claim. They realized small and large interocular distances by moving eyes and eyebrows in and outward, as well as upward and downward, thus producing larger and smaller eyes-to-mouth distances. Results showed that, for same degrees of positional change, inversion effects for V were much larger than for H. In fact, even small positional changes in V produced clearly larger inversion effects than large positional changes in H. Further, these results were practically independent of the direction of change, i.e. whether eyes and eyebrows were moved upward or downward, and inward or outward. The larger inversion effect for V compared to H, however, was retained, even when subjects judged face changes in blocked presentation of change type and orientation, where selective cue usage for H and V changes was encouraged. Hence, the authors found evidence that not the magnitude but the direction of change mattered, which let them conclude that there is an inherent H/V anisotropy that cannot be explained in terms of a scaling of the inversion effect with cue distance.

So far, both studies have left obscure what the face cues are which observers actually use for referencing eye position when judging H and V relational changes. Sekunova and Barton (2008) focused on the potential relevance of the mouth as a long-distance cue. However, differences in vertical eye position may be alternatively be detected by assessing the distance to the nose bridge, changes in forehead height, or the overall positioning within the external feature embedding. Similarly, shifting eyes outward moves the eyes closer to the left and right face outline borders, again potentially relevant and valid short-range cues for interocular distance. When looking at examples of faces modified in interocular distance or eye height (see e.g. Fig. 1 in Crookes & Hayward, 2012) it becomes evident that there are many face cues, both short and long-range, which could potentially guide referencing eye position in judgements of both H and V relational changes.

In order to identify potential roots of the H/V inversion asymmetry we need to explore which facial cues are relevant for judging interocular distance (H), and vertical eye position (V), since, actually, different cues may be used for detecting each type of manipulation. A straightforward way to do this is to measure how performance suffers compared to a full and intact face when a given face part is deleted, and therefore no more available to serve as a reference cue for eye position. It is clear that all face cues available may interact in a highly nonlinear manner in the calculation of eye position. This means that we cannot apply a subtractive logic to infer the exact contribution of each face part. However, at the ordinal level, we can conclude that, if performance drops more for deleting face part B than for face part A, B is a more important component for calculating eye position in the full and intact face than A. Because the external features with face outline, hairs and ears provide important overall shape information, we tested sensitivity to H and V relational changes with several combinations of the cardinal internal features in presence and absence of external features (see Fig. 1). To reveal the relative importance of external features and the cardinal internal features for detecting changes in interocular distance and eye height was the first motivation of the present study. Second, we aimed at testing how the face inversion effect depends on these cues, since the inversion effect has widely been used as a marker of spatial-relational ("configural") face processing (see above). The face inversion effect may also be considered as an indirect marker of "holistic" face processing, since there is significantly less interaction among face parts in inverted presentation (Rossion, 2008, 2009; Meinhardt-Injac, 2013; but see Sekuler et al., 2004). Therefore, we tested the relevance of internal face parts in the presence and absence of external feature context, and in upright and inverted presentation. If cue integration across the whole face is involved, results for the face inversion effect should critically depend on presence and absence of external features, which provide embedding facial context, but are not actively attended when faces are viewed (Williams & Henderson, 2007; Xu & Tanaka, 2013). Thus, we aimed at going a step beyond the approaches of Sekunova and Barton (2008) and Crookes and Hayward (2012) by testing involvement of all cardinal internal face features and external face context in the assessment of interocular distance and vertical eye position.

2. Methods

2.1. Experimental outline

Two experiments were designed to test accuracy for judging interocular distance (H) and vertical eye position (V) when different face cues for the relative positioning of the eyes region are available. In one experiment, different sets of internal features were embedded in their original external features (see Fig. 1 A). In the other one, only the internal features were present, placed on an artificial skin texture-like surface (see Fig. 1 B). In each experiment subjects performed a same/different forced choice task on a sequence of two face images, which differed in interocular distance or in vertical eye position, or not at all. Four feature conditions were realized. Faces either contained all cardinal internal features (Full), or the nose was deleted (Eyes + Mouth), or the mouth was deleted (Eyes + Nose), or nose and mouth were deleted (Eyes). Each subject participated in both experiments, while the order of experiments was counterbalanced across subjects.

2.2. Participants

Thirty-two young adults participated in the study. Mean age was 23.9 years, with a span of 18–26 years, except one 37-years-old student, who also participated. All participants were students of Psychology at the Johannes Gutenberg University Mainz, and all of them reported prior experience with psychological testing. All had normal or corrected-to-normal vision. They were recruited via university information material (in e-mails and flyers) and received compensation (money or participation certificates) for participation.

None of the subjects reported impairments in perception, hearing or cognitive functions. Prior to the study, participants were informed in written form about the general methods, sources of funding, any possible conflicts of interest, and institutional affiliations of the researchers. They were also informed that their data would be analysed anonymously, and that they were free to quit participation at any time without justification. All participants participated voluntarily, and written informed consent was returned from all participants. The experimental procedures were in agreement with the Declaration of Helsinki, and were approved by the local ethics board of the Johannes Gutenberg University Mainz.

2.3. Apparatus

The experiment was administrated with Inquisit 4.0 runtime units. Stimuli were displayed on NEC Spectra View 2040 TFT displays with 1280 × 1024 resolution, using a refresh rate of 60 Hz. The mean luminance of the screen was adjusted to 100 cd/m^2 at a Michelson contrast close to 1, therefore, the background was practically dark (about 1.5 cd/m^2, measured with a calibrated luminance meter). No gamma-correction was used. The ambient illumination was dimmed such that it approximately matched the screen illumination. Subjects viewed binocularly at 70 cm viewing distance. A distance marker but no chin-rest was used. The computer mouse keys were used to signal whether the two face images were same or different. The assignment of response category to mouse key was reversed for half of the subjects. Acoustical trial-by-trial feedback about correctness was provided via light headphones. A brief, "tack" tone signaled correct response, while a "tack-tack" tone signaled an error.

2.4. Stimuli

Photographs of 12 male models (mean age 24.2 years, age span 20–27 years) were used for stimulus construction. These were frontal view shots of a whole face, taken in a professional photo studio under controlled lighting conditions. The original images were manipulated with Adobe Photoshop software to generate the set of stimuli used in the experiment. Photographs were initially converted to 8 bit greyscale pictures. Faces stimuli with intact face context were constructed by first sampling a neutral skin texture from each face. Then, all cardinal internal face features were extracted from the face and the pruned area filled seamlessly with the neutral skin texture. This procedure yielded a set of face parts: blank face with intact external features, left and right eye and eyebrow, nose, and mouth (see Fig. 1). In addition, for each of the face models we generated a large artificial skin texture from their previously sampled neutral skin texture. The artificial texture allowed to present cardinal internal face features devoid of contextual distance cues. The actual absence of these could be verified with the Eyes condition without context in V change type, since vertical eye position cannot be judged in the absence of any relational position cues. This condition should therefore yield chance performance. Stimulus size was about 260 × 365 pixels (width × height), which corresponded to about 6.5° × 9.2° cm visual angle. The dimensions differed slightly across stimulus instances, depending on the individual width × height ratio of the face. Face stimuli with face context were displayed on a light grey background. Face stimuli without face context were displayed on the artificial skin texture, which subtended 1000 × 1000 pixels (width × height). For each face stimulus an individual scrambled mask was constructed by sampling randomly ordered 5 × 5 pixel blocks from the stimulus image. Masks subtended 1000 × 1000 pixels (width × height), or 25° × 25° visual angle.

2.5. Manipulation of interocular distance and vertical eye position

As did Crookes and Hayward (2012) we manipulated interocular distance and vertical eye position in both possible directions to cover all potential relational changes along each axis. Eyes and eyebrows were moved inward and outward (H), as well as upward and downward (V). To find the proper shift values for the experiment we probed various values in a pilot experiment with 5 student aids. The aim of the pilot experiment was to calibrate performance to about 92% correct for both change types and both directions in the easiest condition with fully intact faces, having all features and face context present. A relatively high baseline accuracy value was chosen to leave room for expected strong effects of internal feature deletion and omitting external face context, avoiding problems with potential floor effects. Ceiling effects were not expected to occur, since all experimental manipulations disrupted performance relative to the baseline condition with full and intact faces. The shift values enabling observers to reach 92% accuracy in the pilot study were 13 pixels outward (0.33°), and 12 pixels inward (0.30°) for H, and 19 pixels upward (0.48°), and 18 pixels downward (0.45°) for V. These values correspond to about 6.6% change of interocular distance and to about 8.8% change of eye-mouth distance. These values were used in the main experiments.

2.6. Design and trial composition

The design comprised 2 (Context) × 2 (Change Type) × 4 (Feature) × 2 (Orientation) = 32 conditions. All four factors of the design are repeated measurement (rm) factors. Each condition was measured with 12 "same" and 12 "different" trials ($N = 12$). The 12 "different" trials were realized by using 6 trials for each direction (outward and inward for H, upward and downward for V). "Same" trials for each change type comprised 6 pairs of unaltered faces, and 6 pairs of altered faces with identical manipulations of eye position. In "different" trials an unaltered face was paired with a manipulated face, whereby the temporal order of both alternated randomly. By doing so, we followed the methods of Yang and Schwaninger (2010), who used these type of pairings for "same" and "different" trials to preclude disproportionate learning effects for the original faces. Separate experiments were executed for testing sensitivity to relational changes with external features present and absent. Each experiment comprised 384 experimental trials.

2.7. Procedure

The two experiments were executed with each participant at two successive days, if possible, but with not more than two free days between. Half of the participants started with the experiment with face context, and the other half with the experiment without face context, which was randomly assigned to the participants. Each experiment was subdivided into four experimental blocks, one for each feature condition. Each block contained trials with randomly interleaved presentation of change types (H and V) and orientations (upright and inverted). A block comprised 96 trials, which took about 8 min of experimentation time. An experimental trial had the following event sequence: fixation mark (300 ms) – blank (100 ms) – 1st stimulus (633 ms) – mask (400 ms) – blank (200 ms) – 2nd stimulus (633 ms) – mask (400 ms) – blank frame until response. The positions of each of the two face images were shifted within a radius of 25 pixels (0.63°) around the display center in random direction to preclude pixel matching of the eyes region. The order of the four experimental blocks (feature conditions) was chosen at random for each subject. Before a block was started, the subject was made familiar with the test in 8 probe trials, done with faces that were not used in the main experiment. The subjects were informed that two face images were presented, which showed the same parson, but with potentially alterations in relational face properties. They instructed to compare the two faces of a sequence, and to respond "different" if the face images differed in any respect they perceived. Further, the participants were instructed to respond as accurately and swiftly, but with more weight on accurateness. Before a block was started the experimenter informed the participant about the feature condition, i.e., which face features were present and which omitted. A whole session comprising general instructions, probe trials, the four experimental blocks, each with a brief 2 min pause afterwards, took about one hour in the laboratory.

2.8. Performance measures and data analysis

Performance was measured within the framework of the signal detection paradigm. We defined the hit-rate (Hit) as the proportion of "different" responses in "different" trials, which contained face pairs with different H or V relations. Accordingly, the correct rejection rate (CR) was defined as the proportion of correct "same" judgements. False alarms (FA) and Miss (Miss) rates were defined as the complementary rates to Hit and CR, respectively. The frequencies of correct responses for same and different trials were transformed into the sensitivity measure d', according to $d' = z(\text{Hit}) - z(\text{FA})$. Perfect or zero hit and false alarm rates were corrected before transforming into d', replacing by $p = 1–1/(2N)$, or $p = 1/(2N)$, respectively (see Macmillan & Creelman, 2005, p. 8). Inversion effects were calculated by taking the difference: $\text{IE} = d'(\text{upright}) - d'(\text{inverted})$.

The d' data were analysed with repeated measurements (rm) ANOVA. Because vastly different effects of external feature context, cardinal internal features and orientation on detecting H and V relational manipulation were expected, we first conducted an 2 × 4 × 2 × 2 omnibus ANOVA with external feature Context (without external features, with external features), Feature (Eyes + Nose + Mouth, Eyes + Mouth, Eyes + Nose, Eyes), Change Type (horizontal, vertical) and Orientation (upright, inverted) as repeated measurement factors to verify the existence of first and higher order interactions involving change type. This analysis was followed by separate analyses for each change type to better expose the contrasting results patterns for H and V manipulations. Note that the Eyes condition without external features for the V change type is merely a control condition type, since eye height cannot be judged without any relative position cues (see Fig. 1, right panel). Here, chance performance is expected. We accounted for this by excluding the Eyes condition in the ANOVA for V, and relied on pairwise testing to preserve testing for the Eyes condition with external features present, which is important since external feature context may provide reference cues for eye height. Additionally, effect sizes of pairwise comparisons were calculated using Cohen's d (Cohen, 1988). Due to their high theoretical relevance inversion effects were also analysed with ANOVA and follow-up pairwise contrasts.[1]

3. Results

The omnibus ANOVA (see ANOVA Table A1 in Appendix) showed significant effects of all main factors, and all interactions except the four-way interaction. In particular, the Context × Change Type, Feature × Change Type and Orientation × Change Type interactions were highly significant. Fig. 2 shows the mean d' data as Feature × Orientation (2 × 2) interaction plots in four panels. The data shown in Fig. 2 illustrate the highly differential results obtained for horizontal (see Fig. 2 A) and vertical (see Fig. 2 B) relational manipulations. Further, the data show good agreement of the baseline measurements for all cardinal internal features and full external face context with the targeted values of 92% correct performance in H and V change type (see Methods).[2] To better elucidate the differential effects of Context, Feature and Orientation for horizontal and vertical relational manipulations we present ANOVA results for each change type separately.

[1] Note that the ANOVA results for the IE difference data are given by the first and higher order interactions involving Orientation in the omnibus ANOVA on the original d' data. However, pairwise comparisons of the IEs are feasible only on difference data (see Section 3.3).

[2] In Fig. 2 proportion correct rates (p_c) are additionally shown on the right ordinate axis. The scale values were estimated from d' using nonlinear regression from a 2nd order polynomial, which proved to fit near perfect ($R^2 = 0.997$). See Appendix B.

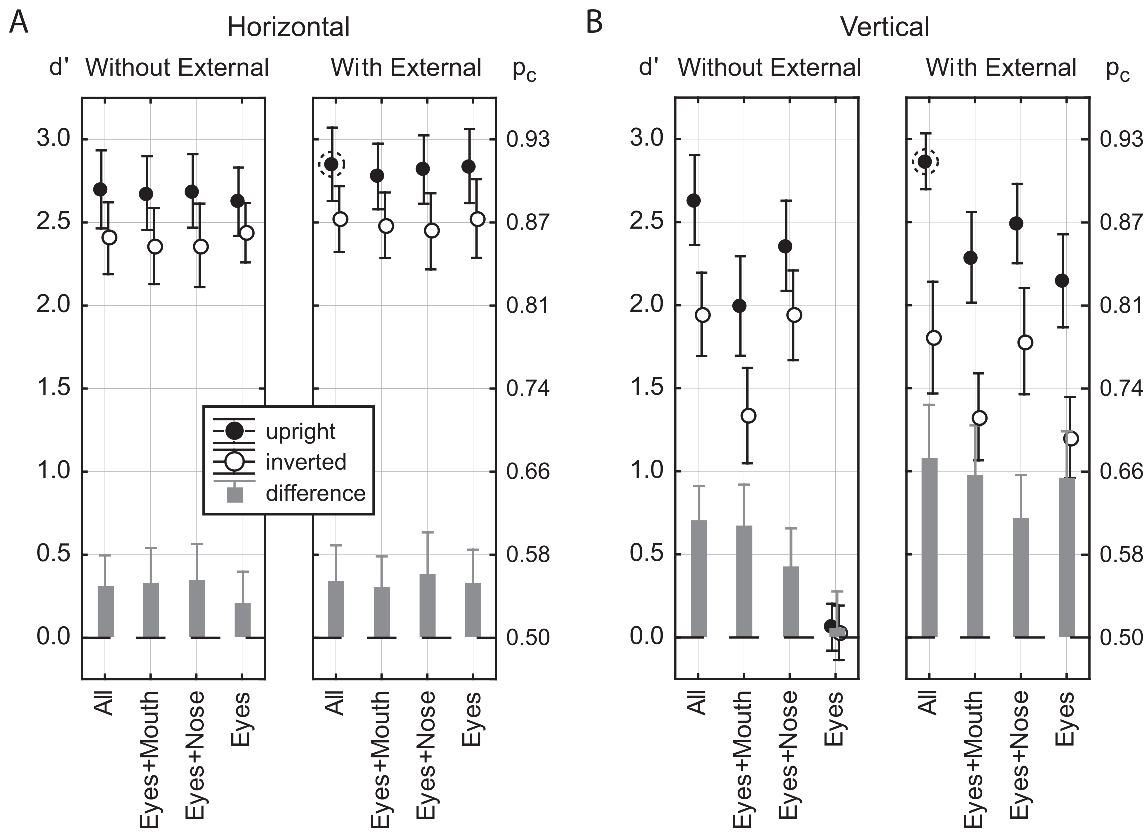

Fig. 2. Mean d' sensitivity for horizontal (left, A) and vertical (right, B) relational image manipulations, measured for spatial arrangements of only the internal features, and for the same arrangements, but embedded in external features. Data for upright presentation are indicated by filled circles, open circles indicate data for inverted presentation. The grey bars indicate inversion effects, calculated as the means of the difference measure IE = d' (upright) − d' (inverted). Error bars indicate the 95% confidence intervals of the means (for inversion effect only the half intervals are shown). The right ordinate shows the proportion correct scale which corresponds to d'. The data for the baseline performance with all cardinal internal features and external face context are marked by dashed circles.

3.1. Sensitivity measure for horizontal relational manipulations

A Context × Feature × Orientation (2 × 4 × 2) ANOVA (see Table 1) revealed a significant main effect of Orientation, indicating higher sensitivity for upright compared to inverted presentation [$\Delta d' = 0.30$, $F(1,31) = 11.90$, $p < .001$, $d = 1.15$]. Further, there was a marginally significant effect of Context [$\Delta d' = 0.13$, $F(1,31) = 3.53$, $p = .070$, $d = 0.33$], which reflected little better performance when external feature context was present. There were no significant or marginally significant interactions, indicating that Orientation and Context determined judgements of H relational manipulations additively, and as the only sources of variation.

In particular, the absence of the Context × Orientation and Feature × Orientation interactions indicated that inversion effects were not modulated by presence or absence of internal features, and also not by presence or absence of the embedding external feature context.

3.2. Sensitivity measure for vertical relational manipulations

The d' data for vertical relational manipulations were analysed with the same ANOVA as used for analyzing horizontal relational manipulations. The analysis for the V change type revealed significance of all main effects, and, additionally, significance of all interactions (see Table A2 in Appendix A). However, these results were confounded with

Table 1
Results table for the rm ANOVA of the d' data obtained for horizontal (H) relational manipulations. The table shows source of variation, Sum of squares (*SS*), degrees of freedom (*df*), variance estimate (η^2), F-ratio (*F*), significance level (*p*), and ratio of explained to total variation within each path of sum of square decomposition (partial eta-square).

Source of variation	*SS*	*df*	η^2	*F*	*p*	partial η^2
CONTEXT	2.02	1	2.02	3.53	.070	.98
Error	17.75	31	0.57			
FEATURE	0.18	3	0.06	0.31	.820	.10
Error	17.89	93	0.19			
ORIENTATION	11.90	1	11.90	42.29	< .001	.01
Error	8.72	31	0.28			
CONTEXT × FEATURE	0.04	3	0.01	0.07	.975	.58
Error	16.72	93	0.18			
CONTEXT × ORIENTATION	0.07	1	0.07	0.26	.615	.00
Error	8.17	31	0.26			
FEATURE × ORIENTATION	0.16	3	0.05	0.36	.780	.01
Error	13.52	93	0.15			
CONTEXT × FEATURE × ORIENTATION	0.10	3	0.03	0.26	.852	.01
Error	11.32	93	0.12			

Table 2
Results table for the rm ANOVA of the *d′* data obtained for vertical (V) relational manipulations. The table shows source of variation, Sum of squares (*SS*), degrees of freedom (*df*), variance estimate (σ^2), F-ratio (*F*), significance level (*p*), and ratio of explained to total variation within each path of sum of square decomposition (partial eta-square).

Source of variation	*SS*	*df*	η^2	*F*	*p*	*partial* η^2
CONTEXT	0.34	1	0.341	0.47	.498	0.01
Error	22.48	31	0.725			
FEATURE	22.37	2	11.187	24.81	< .001	0.44
Error	27.96	62	0.451			
ORIENTATION	53.91	1	53.910	91.56	< .001	0.75
Error	18.25	31	0.589			
CONTEXT × FEATURE	0.39	2	0.193	0.64	.531	0.02
Error	18.72	62	0.302			
CONTEXT × ORIENTATION	2.48	1	2.478	6.41	< .02	0.17
Error	11.98	31	0.386			
FEATURE × ORIENTATION	1.73	2	0.863	4.49	< .02	0.13
Error	11.92	62	0.192			
CONTEXT × FEATURE × ORIENTATION	0.03	2	0.017	0.12	.888	0.00
Error	8.72	62	0.141			

artificial variance, since the Eyes condition in the experiment without context *should* result in chance performance (see Methods). Indeed, chance performance in this condition was observed (see Fig. 2 B). This generated a large amount of variance across the Feature factor and all its interactions. To enable assessment of the experimental conditions free of confounds with this artificial source of variance we calculated ANOVA where the Eyes condition was omitted. Table 2 shows the results. There were significant main effects of Feature and Orientation, but no main effect of Context. Further, the Context × Orientation and the Feature × Orientation interactions were significant. This indicated that the inversion effect was modulated by presence and absence of external features and across internal features (see detailed analysis in Section 3.3). These results strongly contrast with the results for horizontal relational manipulations, where both interactions were absent. The 3rd order interaction of the main factors was not significant.

Exploring the Context × Orientation interaction with pairwise comparisons showed that sensitivity was marginally larger with external features than without for upright [$\Delta d' = 0.22$, $F(1,31) = 4.03$, $p = .053$, $d = 0.35$], but not for inverted presentation [$\Delta d' = 0.10$, $F(1,31) = 0.92$, $p = .345$, $d = 0.17$]. To give a complete picture of all Feature effects including the Eyes condition, we report the results of all pairwise tests at the level of Context × Orientation × Feature. Pairwise contrasts were conducted as F-tests. Significance level and Cohen's *d* are reported (see Table 3). For the given sample size ($N = 32$), small effects in Cohen's taxonomy (Cohen, 1988) did not reach significance, but effects of medium size did, while large effects were significant at $\alpha = 0.001$.

The comparisons reveal that sensitivity with all internal features in the upright orientation was higher than with any feature deleted (see 3rd line of Table 3). This held for both Context conditions. In inverted presentation, however, sensitivity for all internal features was higher compared to Eyes + Mouth and to Eyes, but not compared to Eyes + Nose (see 6th line of Table 3). Again, this held having external features present or absent. Consistently in each context condition and each orientation it was found that sensitivity was significantly lower for Eyes + Mouth compared to Eyes + Nose (see 4th and 7th line of Table 3). With external features, sensitivity for the Eyes condition was lower than for Eyes + Mouth, but not significantly. This result, found in both orientations (see last column of Table 3, 4th and 7th line), indicates that the mouth region did not add a strong cue for judging vertical eye position when there was external feature surround. In contrast, performance with Eyes + Nose was significantly better than with Eyes alone (see last column of Table 3, 5th and 8th line), indicating a significant contribution of the nose. However, it is worth to reiterate that performance in the upright orientation was significantly better with all internal features than with any feature deleted, which implies that adding the mouth had a significant contribution when this completed the face as a whole.

3.3. Inversion effects

The omnibus ANOVA revealed a highly significant Change Type × Orientation interaction (see Table A1 in Appendix A). Analysing difference data, IE = d′(up) − *d′*(inv), showed a much larger inversion effect for V compared to H [$\Delta IE = 0.38$, $F(1,31) = 31.73$, $p < .001$, $d = 0.99$]. Because the separate ANOVA analysis for H showed absence of Context × Orientation and Feature × Orientation interactions (see above), we further analysed inversion effects just for V. These effects were much larger with face context than without [$\Delta IE = 0.32$, $F(1,31) = 6.41$, $p < .02$, $d = 0.45$], and there was modulation by Feature [$F(2,62) = 4.49$, $p < .02$]. We further explored

Table 3
Results of pairwise mean comparisons across internal features for vertical relational manipulations. The Table lists Cohen's *d* measure, marked by the α-level of significance reached in the F-test for the mean comparison. All F-tests had 1 denominator and 31 nominator degrees of freedom. The α- levels are abbreviated as follows: α = 0.001: ***; α = 0.01: **; α = 0.05: *; α = 0.1: +; not significant: n.s.

		Without external features			With external features		
		Eyes + Mouth	Eyes + Nose	Eyes	Eyes + Mouth	Eyes + Nose	Eyes
Upright	All	1.06^{***}	0.43^{***}	3.39^{***}	0.97^{***}	0.85^{***}	1.12^{***}
	Eyes + Mouth		-0.46^{***}	2.75^{***}		-0.31^{+}	$0.27^{n.s.}$
	Eyes + Nose			2.94^{***}			0.58^{***}
Inverted	All	0.74^{***}	$0.01^{n.s.}$	2.45^{***}	0.54^{***}	$0.03^{n.s.}$	0.69^{***}
	Eyes + Mouth		-0.68^{***}	1.41^{***}		-0.50^{***}	$0.17^{n.s.}$
	Eyes + Nose			2.41^{***}			0.75^{***}

Table 4
Results of pairwise comparisons for the inversion effect across internal features for vertical relational manipulations. The Table lists the effect size *d* of the inversion effect difference, marked by the α-level of significance reached in the F-test. All F-tests had 1 denominator and 31 nominator degrees of freedom. Conventions as in Table 3.

		Eyes + Mouth	Eyes + Nose	Eyes
Without Context	All	$0.04^{n.s.}$	0.35^{+}	0.76^{***}
	Eyes + Mouth		0.31^{+}	0.75^{***}
	Eyes + Nose			0.49^{***}
With Context	All	$0.11^{n.s.}$	0.47^{**}	$0.12^{n.s.}$
	Eyes + Mouth		$0.27^{n.s.}$	$0.02^{n.s.}$
	Eyes + Nose			$-0.29^{n.s.}$

the effects of Feature with Eyes condition included, and report results for both context conditions (see Table 4). Without external features, inversion effects for Eyes + Nose tended to be smaller than for all features present and compared to presence of Eyes + Mouth, with an effect size about $d = 0.3$, but these effects reached just marginal significance. With face context, the inversion effect for Eyes + Nose was significantly smaller compared to having all internal features present. There were no further significant differences of inversion effects. Hence, comparing the effects of Feature showed that inversion effects tended to be smallest for Eyes + Nose, while there were similar IEs for Eyes + Mouth and all internal features.

4. Discussion

Using horizontal and vertical relational manipulations of the eyes region, while reducing faces to different sets of internal features with and without external feature surround has revealed very different results for H and V change types. Overall, results showed complete independency of internal features and only a modest, marginally significant dependency on external face context for H, while sensitivity for V was strongly modulated by the presence of cardinal face features. Face cue independence for H and strong modulation by short-and long-range face cues for V was also seen in the face inversion effects. These findings indicate an H/V anisotropy of processing spatial relations, and relate this anisotropy to largely different facial cue dependencies. In the following, we discuss these findings with respect to potentially inherently different processing schemes for H and V relations (Goffaux & Rossion, 2007; Goffaux & Dakin, 2010), the long-range/short-range dichotomy of spatial-configural processing (Sekunova & Barton, 2008; Crookes & Hayward, 2012), and the perceptual field hypothesis of the inversion effect (Barton et al., 2001; Sekunova & Barton, 2008; Rossion, 2009; Tanaka, Kaiser, Hagen, & Pierce, 2014; Meinhardt-Injac, Persike, Imhof, & Meinhardt, 2015). We also briefly address potential implications of our results for the issue whether inversion changes face perception qualitatively, or quantitatively.

4.1. Face cue dependency of H relational changes

We report that processing interocular distance was practically independent of the presence of the remaining internal face features: presence of nose, mouth, or both did not increase accuracy, both in upright, and in inverted presentation. Full external face context yielded only marginally significant improvement. Inversion effects were neither modulated by internal nor by external features. Hence, the IE for isolated eyes & eyebrows was found to be the same than for a whole intact face, and it was the same for different selective combinations of internal features and external feature surround. These findings corroborate earlier findings of Leder, Candrian, Huber, and Bruce (2001), who also found no modulation of the inversion effect by enlarged face context. The results have important implications for processing interocular distance. First, observers apparently did not utilize the nose, which resides in the same horizontal plane as the eyes, as a potentially valid local distance marker. The small effect of external face context indicates that external features were valid spatial reference cues, but only to limited degrees. The non-salient mouth (Barton et al., 2001) is, since it lies in a different and distant horizontal plane, inappropriate to serve as a horizontal relational cue. Results indicate no usage of the mouth as a spatial cue. These findings, and particularly the fact that judging interocular distance with a full intact face was as good as with just eyes and eyebrows placed on an empty face template, or even a nondescript artificial skin texture, indicate that processing interocular distance is not governed by a network of short-range and long-range cues distributed across the face. Inversion effects were independent of internal and external feature presence. The complete face cue independence of the inversion effect for H poses problems for the notion that the inversion effect necessarily reflects disruption of spatial-relational processing. Internal face features, when presented in isolation, still induce inversion effects, especially eyes and eyebrows (Rakover & Teucher, 1997; Tanaka & Sengco, 1997, see there Table 2; Leder et al., 2001). Further, a similar inversion effect (Riesenhuber et al., 2004; Riesenhuber & Wolff, 2009), if not a larger one (Meinhardt-Injac, Persike, & Meinhardt, 2011) was found for featural changes in the eyes region. It is conceivable that interocular distance is measured using a template for typical interocular distance, which is most activated when the eyes region is projected to it in the usual upright orientation. Such a template for horizontal information, built and refined by viewing expertise, may work completely independent of other relational cues in the face.

Viewed in terms of an inherent processing anisotropy of H and V spatial frequency components (Dakin & Watt, 2009), a lack of contextual cue dependency for interocular distance is also expected. Changing horizontal eye position relative to nose and face outline alters vertical spatial frequency components, but leaves the horizontal frequency spectrum largely unaffected. Since the human observer lays much more weight on the latter component in face perception and recognition (Goffaux & Dakin, 2010; Pachai, Sekuler, Bennett, Schyns, & Ramon, 2017), there should be poor sensitivity to cues affecting mostly the V frequency spectrum.

Thus, the inversion effect for interocular distance may indicate more efficient processing of the eyes region in the upright orientation, and no qualitative changes of processing when faces are inverted (Sekuler et al., 2004; Willenbockel et al., 2010). This conclusion is supported by results of Yang and Schwaninger (2010), who reported constant inversion effects over a wide range of changes in interocular distance, going along with steady improvement in upright and inverted orientation when change ratios increased. This let authors conclude that the same operations underlie processing of inverted faces, though executed with less efficiency.[3]

4.2. Face cue dependency of V relational changes

In contrast to H, sensitivity to V relational changes was strongly modulated by presence and absence of internal features. Also external features marginally improved accuracy, but only in the upright orientation. This indicates a large contextual integration window in the upright orientation, whereby contextual cues from different face regions improved referencing of vertical eye position. Performance was best with all cardinal features together, followed by Eyes + Nose, followed by Eyes + Mouth.

[3] Yang and Schwaninger (2010) manipulated interocular distance along with mouth-nose distance. Size of inversion effects, which are in the same order of magnitude than our inversion effects for H, indicate processing of the eyes region but hardly influence oft the non-salient mouth region. When comparing results it is important to note that our face manipulations correspond to what is shown as 12% to 16% in the study of Yang and Schwaninger (see ibid. Fig. 1 and compare to examples shown in Fig. 1 here. Please note similar remarks of Crookes & Hayward, 2012, regarding the scale of changes). We report a modest effect of external feature context, which indicated moderate improvement for H judgements with context present. It is likely that distance to face outline serves as spatial reference when larger values of interocular distance are used. Use of face outline could explain the breakdown oft the inversion effect for critically large interocular distances (Yang & Schwaninger, 2010). Since there is actually only a tiny gap between eye and face outline for large interocular distances, the lacking gap is a valid local cue, which should work equally well in upright and inverted faces.

Having only external face context available, sensitivity to changes in vertical eye position was hardly worse than with additional presence of the mouth, indicating that the mouth added little to referencing eyes height within face outline. However, the nose added significant improvement, while performance was clearly best with all features together. Hence, the nose as a short-range contextual cue added much more improvement than the mouth, which is a distant cue for vertical eye position. If only the best available cue is used, then performance with all cardinal internal features should be as good as with Eyes + Nose. However, adding the mouth to the nose improved performance, and adding face context again added a marginal increment of performance. The cumulative improvement by adding face cues indicate short and long-range cue integration to calculate eye height in the upright orientation.

Results were largely different in inverted presentation. Again, performance was worst with only the mouth present. Having the nose available led to modestly good performance, and there was no further improvement by adding mouth, face context, or both. This indicates that observers mostly used the nose as the best proximal cue for referencing vertical eye position in the face, and no other additional cues entered. Hence, the results for inverted presentation indicate no multiple cue benefit.

4.3. "Holistic" cue integration in processing vertical relations?

In "holistic" concepts of face perception it is claimed that component and spatial-configural information is integrated into a unified face representation (see Maurer, Le Grand, & Mondloch, 2002, for an overview). This concept implies that the effect of combined features is stronger than the sum of the individual feature effects, since abundantly more relations result if one feature adds to the set. For inverted presentation, result showed that mostly the best cue (nose) was used in referencing eye height, in contrast to holistic integration. In the upright orientation, the same order of accuracy was found among internal features with and without external face context, indicating that the relative importance of an internal feature did not change by adding external face context cues. Adding external face context added a constant marginal gain to all internal feature conditions (see Fig. 2). There was no particularly stronger gain for the "all internal features" condition. However, exactly this would be expected from "holistic" integration, since adding external features to all internal features completes the whole face. Hence, as found recently (Gold, Mundy, & Tjan, 2012) there is no particular evidence for holistic integration in the sense of super-additive summation among face components in judging changes in the vertical arrangement of faces.

4.4. The "perceptual field" hypothesis

Various authors have suggested that a major effect of face inversion is a narrowing of the perceptual field to a smaller region around the eyes, while it covers a much wider area across the whole face in upright presentation (Barton et al., 2001; Sekunova & Barton, 2008; Rossion, 2009; Tanaka et al., 2014). This hypothesis comes in different varieties. Sekunova and Barton (2008) claimed that processing spatial-relational information is confined to highly relevant and attended face regions. Rossion (2009) additionally assumes that a change of the processing mode toward featural information comes along with a limitation of the perceptual field. Tanaka and colleagues found that featural and configural changes suffer equally from inversion in non-attended and distal face regions. This let authors conclude that inversion delimits the information flow among attended and non-attended regions, suggesting a purely spatial confinement of the area of face cue integration (see Tanaka et al., 2014, pp. 1011).

The results of this study do not fully support a purely spatial limitation of cue integration as the major effect of inversion. Clearly, performance in inverted presentation for V indicates impairment for distal cues (mouth, outline), which are outside a narrowed perceptual field. When mouth and external feature surround are the only cues for referencing eyes height, performance resides at quite low levels (see Fig. 2). No improvement when distal cues add to the best local cue suggest a small integration window focused on the eyes region for upside-down faces. The cumulative effects of adding distal cues and face context in the upright orientation suggest a wide cue integration window spanned across the whole face. These observations would support the spatial limitation account of inversion (Tanaka et al., 2014). However, albeit marginally smaller, we found a substantial inversion effect also when the nose is the only spatial reference cue, which suggests less efficient cue usage in the eyes region (Sekuler et al., 2004). Hence, also local-configural processing in the most attended face region is concerned by inversion. The inversion effect for the nose cue in V has about the magnitude of all inversion effects obtained in H, whereby the independency of other face cues suggested that the very most effect of inversion is a reduced processing efficiency of the eyes region (s.a.).

4.5. Long-range and short range cue integration and the H/V processing anisotropy

Sekunova and Barton (2008) suggested that a differential dependency on short-range (H) and long-range (V) cue relations underlies the H/V inversion asymmetry. Crookes and Hayward (2012) found that the size of the inversion effect for H did not depend on the magnitude of spatial change. As did Crookes and Hayward (2012), we found that H inversion effects were inherently smaller than V inversion effects, but due to a general lack of facial cue dependency. Hence, we find no support that the H/V inversion asymmetry can be resolved by assuming short-range cue dependencies for H and long-range cue dependencies for V. Instead, the results suggest that the H/V inversion asymmetry rests on an H/V anisotropy of cue dependency: interocular distance is judged independent of other face cues, even of the proximal nose cue, while eye height is referenced with respect to all face cues available. In line with the results of Sekunova and Barton (2008) we find that the inversion effect in V direction scales with inter-cue distance, but only roughly, being marginally stronger for the mouth compared to nose, while all inversion effects are strongly modulated by external feature context. While a long-range/short range dichotomy cannot explain our findings, the spatial frequency anisotropy account of Goffaux and Dakin (2010) seems to be widely compatible with the findings. Both moving eyes upward and downward and deleting cardinal features strongly alters the horizontal spatial frequency spectrum. Deleting the nose strongly changes the horizontal structures around the important eyes region. In line with this we found that nose presence was more crucial for correctly assessing eye height than mouth presence. As discussed above, interocular distance is not referenced with respect to horizontal, but relative to vertical frequency components which receive less weight in face perception and recognition. Albeit not explicitly tested, the spatial frequency anisotropy account seems to be promising for explaining the differential schemes of facial cue reliance for interocular distance and eye height reported here.

4.6. Qualitative or quantitative changes by face inversion?

There is an ongoing debate about the effects of face inversion (see Rossion, 2008; Riesenhuber & Wolff, 2009; Gold et al., 2012; Tanaka et al., 2014), which concentrates on the kind of information and the processing routes involved for upright and inverted faces. A starting point of this debate was the "dual mode" hypothesis (Carey & Diamond, 1977), proposing that both spatial-relational and component information is encoded in the upright orientation, while mostly featural information is processed when faces are inverted. This claim received support from the so-called "Thatcher-Illusion" (Thompson, 1980), which demonstrates that the impression of grotesqueness, induced by inverting mouth and eyes, is strong in the upright orientation, but weak when the whole face is inverted (Murray, Young, & Rhodes, 2000).

The results of this study have some impact for this debate. Meanwhile, there is some convergence of views that the conceptual dichotomy of "featural" and "configural" processing lacks support, since both types of image manipulations do not yield separable effects in behavioral markers, particularly not in the size of the inversion effect (Sekuler et al., 2004; Riesenhuber, Jarudi, Gilad, & Sinha, 2004; Yovel & Kanwisher, 2008; McKone & Yovel, 2009; Meinhardt-Injac et al., 2015; Tanaka et al., 2014). Our finding of completely different cue dependencies in processing H and V relational changes poses a further constraint to the "featural-relational" distinction, since it shows that relational changes must be distinguished into H and V. Our discussion of the H inversion effects has shown that these hardly root in a disruption of spatial relations, since the scheme of cue dependency was the same for upright and inverted presentation. If the same information enters in both orientations, inversion does not likely change processing qualitatively.

Things are different for processing V relational changes. There we found evidence that judgements relied on mostly only the best proximal cues in inverted presentation, while multiple cues distributed over the entire face entered when faces were in their natural upright orientation. Multiple cue integration in upright compared to mostly local cue usage in inverted could give rise to consider the underlying processing regimes as being qualitatively different. However, our discussion of the nature of cue summation effects has shown that the additive effects of additional cues do not support a special "holistic" processing mode in upright, but abolished by inversion. Hence, the underlying processing regime may be the same in inverted presentation, but it may rely on the integration of just proximal cues to calculate eye height.

4.7. Conclusion

The present study provides evidence for inherently different regimes that underlie processing of faces manipulated in interocular distance (H) and vertical eye height (V). Processing of interocular distance proved to be practically independent of the presence of internal features and external feature context, while processing of eye height was highly sensitive to the presence of all face cues, showing cumulative improvement when more cues were available. The rather cue independence found for judging interocular distance indicates processing tightly tuned to just the eyes region. The strong cue dependency in processing eye height indicates a global mechanism of cue integration, while the nose as a proximal cue seems to be more relevant than mouth and external face context. Further, a global mechanism for V judgements is suggested by the much larger inversion effects for faces with external feature context, compared to inner face templates. Albeit not explicitly tested, the H/V anisotropy of cue dependency reported here seems to comply with the differential relevance of horizontal and vertical spatial frequency components (Dakin & Watt, 2009; Goffaux & Dakin, 2010), since the more relevant horizontal components precisely capture the (global) information apt to discriminate faces with different V relations. Testing this account in the context of H and V relations is left to future experimentation.

Appendix A: Overall ANOVA results tables for complete analyses

See Tables A1 and A2

Table A1
Results table for the rm ANOVA of the *d′* data obtained for horizontal (H) and vertical (V) relational manipulations. The table shows source of variation, Sum of squares (*SS*), degrees of freedom (*df*), variance estimate (η^2), F-ratio (*F*), significance level (*p*), and ratio of explained to total variation within each path of sum of square decomposition (partial eta-square).

Source of variation	*SS*	*df*	η^2	*F*	*p*	Partial η^2
CONTEXT (1)	21.38	1	21.38	22.46	< .001	0.42
Error	29.51	31	0.95			
FEATURE (2)	80.50	3	26.83	69.01	< .001	0.69
Error	36.16	93	0.39			
CHANGETYPE (3)	176.98	1	176.98	246.17	< .001	0.89
Error	22.29	31	0.72			
ORIENTATION (4)	62.61	1	62.61	91.71	< .001	0.75
Error	21.16	31	0.68			
CONTEXT × FEATURE	31.08	3	10.36	31.15	< .001	0.50
Error	30.93	93	0.33			
CONTEXT × CHANGETYPE	6.83	1	6.83	19.09	< .001	0.38
Error	11.10	31	0.36			
FEATURE × CHANGETYPE	81.23	3	27.08	108.58	< .001	0.78
Error	23.19	93	0.25			
CONTEXT × ORIENTATION	4.23	1	4.23	9.87	< .01	0.24
Error	13.30	31	0.43			
FEATURE × ORIENTATION	1.97	3	0.66	3.56	< .02	0.10
Error	17.14	93	0.18			
CHANGETYPE × ORIENTATION	9.21	1	9.21	31.73	< .001	0.51
Error	9.00	31	0.29			
CONTEXT × FEATURE × CHANGETYPE	28.60	3	9.53	60.20	< .001	0.66
Error	14.72	93	0.16			
CONTEXT × FEATURE × ORIENTATION	1.50	3	0.50	3.27	< .03	0.10
Error	14.22	93	0.15			
CONTEXT × CHANGETYPE × ORIENTATION	2.85	1	2.85	10.94	< .01	0.26
Error	8.08	31	0.26			
FEATURE × CHANGETYPE × ORIENTATION	1.55	3	0.52	3.25	< .03	0.09
Error	14.73	93	0.16			
1 × 2 × 3 × 4	0.70	3	0.23	1.96	.125	0.06
Error	11.12	93	0.12			

Table A2
Results table for the rm ANOVA of the *d′* data obtained for vertical (V) relational manipulations. The table shows source of variation, Sum of squares (*SS*), degrees of freedom (*df*), variance estimate (σ^2), F-ratio (*F*), significance level (*p*), and ratio of explained to total variation within each path of sum of square decomposition (partial eta-square).

Source of variation	*SS*	*df*	η^2	*F*	*p*	Partial η^2
CONTEXT	26.20	1	26.20	35.51	< .001	0.53
Error	22.87	31	0.74			
FEATURE	161.56	3	53.85	120.80	< .001	0.80
Error	41.46	93	0.45			
ORIENTATION	59.93	1	59.93	86.65	< .001	0.74
Error	21.44	31	0.69			
CONTEXT × FEATURE	59.64	3	19.88	63.89	< .001	0.67
Error	28.94	93	0.31			
CONTEXT × ORIENTATION	7.02	1	7.02	16.47	< .001	0.35
Error	13.21	31	0.43			
FEATURE × ORIENTATION	3.36	3	1.12	5.67	< .001	0.15
Error	18.35	93	0.20			
CONTEXT × FEATURE × ORIENTATION	2.11	3	0.70	4.66	< .01	0.13
Error	14.02	93	0.15			

Appendix B: Proportion correct and d′ scale

If the hit rate equals the correct rejection rate, then *d′* and the proportion correct rate, p_c, are related by $d' = 2\,z(p_c)$ (see Macmillan & Creelman, 2005, p. 9). From this it follows that $p_c = \Phi\,\{d'/2\}$, whereby Φ is the Gaussian distribution function (i.e., the normal probability integral). In a same/different forced choice experiment, equality of the errors of both kinds usually does not hold. However, since $\Phi(x)$ is a convex function for $x \geq 0$, the proportion correct rate can be estimated from *d′* with a polynomial that smoothly fits different degrees of convex curvature. We therefore fitted p_c as a function of *d′* by using all cell means data with a second order polynomial. The function is shown in Fig. B1. The fit for the second order polynomial yielded a ratio of explained to total variance of $R^2 = 0.997$, which is near perfect.

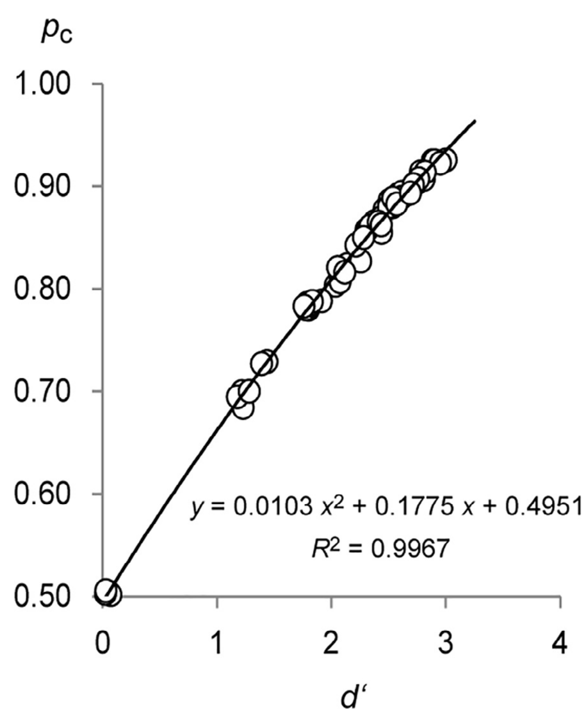

Fig. B1. Result of fitting a second order polynomial for estimating the proportion correct measure, p_c, from *d′*. The caption shows the values of parameter estimates, and the ratio of explained to total variation, R^2.

References

Barton, J. J., Keenan, J. P., & Bass, T. (2001). Discrimination of spatial relations and features in faces: Effects of inversion and viewing duration. *British Journal of Psychology, 92*, 527–549.

Bartlett, J. C., & Searcy, J. (1993). Inversion and Configuration of faces. *Cognitive Psychology, 25*, 281–316.

Carey, S. (1992). Becoming a face expert. *Philosophical Transactions: Biological Sciences, 335*, 95–102.

Carey, S., & Diamond (1977). From piecemeal to configurational representation of faces. *Science, 195*, 312–314.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd edition). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Crookes, K., & Hayward, W. G. (2012). Face inversion disproportionately disrupts sensitivity to vertical over horizontal changes in eye position. *Journal of Experimental Psychology: Human Perception and Performance, 38*, 1428–1437. http://dx.doi.org/10.1037/a0027943.

Dakin, C. D., & Watt, R. J. (2009). Biological "bar codes" in human faces. *Journal of Vision, 9*(4), 1–10. http://dx.doi.org/10.1167/9.4.2.

Diamond, R., & Carey, S. (1986). Why face are and are not special: An effect of expertise. *Journal of Experimental Psychology: General, 115*, 107–117.

Gauthier, I., Curran, T., Curby, K. M., & Collins, D. (2003). Perceptual interference supports a nonmodular account of face processing. *Nature Neuroscience, 6*, 428–432.

Gauthier, I., & Bukach, C. (2007). Should we reject the expertise hypothesis? *Cognition, 103*, 322–330. http://dx.doi.org/10.1016/j.cognition.2006.05.003.

Goffaux, V., & Rossion, B. (2007). Face inversion disproportionately impairs the perception of vertical but not horizontal relations between features. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 995–1002.

Goffaux, V., & Dakin, C. D. (2010). Horizontal information drives the behavioral signatures of face processing. *Frontiers in Psychology, 1*, 143. http://dx.doi.org/10.3389/fpsyg.2010.00143.

Gold, J. M., Mundy, P. J., & Tjan, B. S. (2012). The perception of a face is not more than the sum of the parts. *Psychological Science, 23*, 427–434. http://dx.doi.org/10.1177/0956797611427407.

Hashemi, A., Pachai, M. V., Bennett, P. J., & Sekuler, A. B. (2014). The N170 is driven by the presence of horizontal facial structure. *Journal of Vision, 14*(10), 130. http://dx.doi.org/10.1167/14.10.130.

Huynh, C. M., & Balas, B. (2014). Emotion recognition (sometimes) depends on horizontal orientations. *Attention, Perception & Psychophysics, 76*, 1381–1392. http://dx.doi.org/10.3758/s13414-014-0669-4.

Jacques, C., Schiltz, C., & Goffaux, V. (2014). Face perception is tuned to horizontal orientation in the N170 time window. *Journal of Vision, 14*(2), 1–18. http://dx.doi.org/10.1167/14.2.5.

Leder, H., Candrian, G., Huber, O., & Bruce, V. (2001). Configural features in the context of upright and inverted faces. *Perception, 30*, 73–83.

Macmillan, N. A., & Creelman, C. D. (2005). *Detection theory: A user's guide* (2nd edition). New York: Lawrence Erlbaum Associates.

Maurer, D., Le Grand, R., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in Cognitive Sciences, 6*, 255–260.

McKone, E., & Yovel, G. (2009). Why does picture-plane inversion sometimes dissociate perception of features and spacing in faces, and sometimes not? Toward a new theory of holistic processing. *Psychonomic Bulletin & Review, 16*(5), 778–797.

Meinhardt-Injac, B. (2013). The context congruency effect is face specific. *Acta Psychologica, 142*, 265–272. http://dx.doi.org/10.1016/j.actpsy.2012.12.012.

Meinhardt-Injac, B., Persike, M., & Meinhardt, G. (2011). The time course of face matching for featural and relational image manipulations. *Acta Psychologica, 137*, 48–55.

Meinhardt-Injac, B., Persike, M., & Meinhardt, G. (2014). Development of visual systems for faces and objects: Further evidence for prolonged development of the face system. *PLoS ONE, 9*(6), e99942. http://dx.doi.org/10.1371/journal.pone.0099942.

Meinhardt-Injac, B., Persike, M., Imhof, M., & Meinhardt, G. (2015). The sensitivity to replacement and displacement of the eyes region in early adolescence, young and later adulthood. *Frontiers in Psychology, 6*, 1164. http://dx.doi.org/10.3389/fpsyg.2015.01164.

Murray, J. E., Young, E., & Rhodes, G. (2000). Revisiting the perception of upside-down faces. *Psychological Science, 11*, 492–496.

Pachai, M. V., Sekuler, A. B., & Bennett, P. J. (2013). Sensitivity to information conveyed by horizontal contours is correlated with face identification accuracy. *Frontiers in Psychology, 4*(74), 1–8. http://dx.doi.org/10.3389/fpsyg.2013.00074.

Pachai, M. V., Sekuler, A. B., Bennett, P. J., Schyns, P. G., & Ramon, M. (2017). Personal familiarity enhances sensitivity to horizontal structure during processing of face identity. *Journal of Vision, 17*(6), 1–11. http://dx.doi.org/10.1167/17.6.5.

Rakover, S. S. (2002). Featural vs. configurational information in faces: A conceptual and empirical analysis. *British Journal of Psychology, 93*, 1–30.

Rakover, S., & Teucher, B. (1997). Face inversion effects: Parts and whole relationship. *Perception & Psychophysics, 59*, 752–761. http://dx.doi.org/10.3758/BF03206021.

Riesenhuber, M., Jarudi, I., Gilad, S., & Sinha, P. (2004). Face processing in humans is compatible with a simple shape-based model of vision. *Proceedings in Biological Sciences, 271*, 448–450.

Riesenhuber, M., & Wolff, B. S. (2009). Task effects, performance levels, features, configurations, and holistic face processing: A reply to Rossion. *Acta Psychologica, 132*, 286–292.

Rossion, B. (2008). Picture-plane inversion leads to qualitative changes of face perception. *Acta Psychologica, 128*, 274–289.

Rossion, B. (2009). Distinguishing the cause and consequence of face inversion: The perceptual field hypothesis. *Acta Psychologica, 132*, 300–312. http://dx.doi.org/10.1016/j.actpsy.2009.08.002.

Sekuler, A. B., Gaspar, C. M., Gold, J. M., & Bennett, P. J. (2004). Inversion leads to quantitative, not qualitative, changes in face processing. *Current Biology, 14*, 391–396.

Sekunova, A., & Barton, J. (2008). Long-range and short-range relations in the perception of the vertical position of the eyes in inverted faces. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 1129–1135.

Searcy, J. H., & Bartlett, J. C. (1996). Inversion and processing of components and spatial relational information in faces. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 904–915.

Tanaka, J. W., & Sengco, J. A. (1997). Features and their configuration in face recognition. *Memory and Cognition, 25*, 583–592.

Tanaka, J. W., Kaiser, M. D., Hagen, S., & Pierce, L. J. (2014). Losing face: impaired discrimination of featural and configural information in the mouth region of an inverted face. *Attention, Perception, & Psychophysics, 76*, 1000–1014. http://dx.doi.org/10.3758/s13414-014-0628-0.

Thompson, P. (1980). Margaret Thatcher: A new illusion. *Perception, 9*, 483–484.

Taubert, J., van Golde, C., & Verstraten, F. A. J. (2016). Faces in context: Does face perception depend on the orientation of the Visual Scene? *Perception, 45*, 1184–1192.

Valentine, T. (1988). Upside-down faces: A review of the effect of inversion on face recognition. *British Journal of Psychology, 79*, 471–491.

Willenbockel, V., Fiset, D., Chauvin, A., Blais, C., Arguin, M., Tanaka, J. W., ... Gosselin, F. (2010). Does face inversion change spatial frequency tuning? *Journal of Experimental Psychology: Human Perception & Performance, 36*(1), 122–135.

Williams, C.-C., & Henderson, J. M. (2007). The face inversion effect is not a consequence of aberrant eye movements. *Memory and Cognition, 35*, 1977–1985.

Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology, 81*, 141–145.

Yang, J., & Schwaninger, A. (2010). Face inversion effect emerges under critical configuration discrepancy. *Swiss Journal of Psychology, 69*, 161–167.

Yovel, G., & Kanwisher, N. (2008). The representation of spacing and part-based information are associated for upright faces but dissociated for objects. Evidence from individual differences. *Psychonomic Bulletin & Review, 15*(5), 933–939.

Xu, B., & Tanaka, J. W. (2013). Does face inversion qualitatively change face processing: An eye movement study using a face change detection task. *Journal of Vision, 13*, 22. http://dx.doi.org/10.1167/13.2.22.