Large inversion effects are not specific to faces and do not vary with object expertise

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Abstract

Visual object recognition is impaired when stimuli are shown upside-down. This phenomenon is known as the *inversion effect*, and a substantial body of evidence suggests it is much larger for faces than non-face objects. The large inversion effect for faces has been widely used as key evidence that face processing is special, and hundreds of studies have used it as a tool to investigate face-specific processes. Here we show that large inversion effects are not specific to faces. We developed two car tasks that tap basic object recognition and within-class recognition. Both car tasks generated large inversion effects (~25% on a three-choice format), which were identical to those produced by parallel face tasks. Additional analyses showed that the large car inversion effects did not vary with expertise. Our findings demonstrate that non-face object recognition can depend on processes that are highly orientation-specific, challenging a critical behavioral marker of face-specific processes.

1. Introduction

Inversion effects – the reduced ability to visually recognize objects shown upside-down – are observed for most objects that have a canonical orientation, but the effects are much larger for faces than for other objects. This finding led Yin (1969) to argue that face processing relies on special mechanisms, and his initial results have been widely replicated during the past 50 years. In a meta-analysis of 77 studies exploring perceptual hallmarks of face-specificity (the inversion, composite, part-whole and contrast negation effects), Bruyer (2011) found that the inversion effect was, by far, the most investigated (appearing in 63% of all studies), the largest, and the most reliable. The effect size differences between faces and objects are most evident in studies comparing them directly. In their review, Robbins and McKone (2007) noted that inversion effects for faces are usually between 15-25% compared to 0-8% for objects.

Large inversion effects for faces are theoretically important for two reasons. First, they have been used as an experimental method to characterize face processing in hundreds of studies across psychology and neuroscience. These studies span the cognitive (Rhodes, Brake, & Atkinson, 1993; Yin, 1969), developmental (Carey & Diamond, 1977; Fagan, 1972), comparative (Kendrick, Atkins, Hinton, Heavens, & Keverne, 1996; Parr, Dove, & Hopkins, 1998), neuroscience (Freiwald, Tsao, & Livingstone, 2009; Yovel & Kanwisher, 2005), and clinical (Farah, Wilson, Drain, & Tanaka, 1995; Hobson, Ouston, & Lee, 1988) literatures. Second, large inversion effects for faces have been used as key evidence for the face-specific hypothesis (Robbins & McKone, 2007) and the expertise hypothesis (Diamond & Carey, 1986; Gauthier, Skudlarski, Gore, & Anderson, 2000). The face-specific hypothesis asserts that larger inversion effects for faces than for objects indicate that upright face processing involves special mechanisms that are not used in object processing. The expertise hypothesis claims that face processing seems special only because we have much more experience with upright faces than we do with other objects. According to this view, faces produce large inversion effects because almost everyone is an expert upright face recognizer, but other objects of expertise would engage the same mechanisms and thus produce similar effects (Diamond & Carey, 1986; Gauthier et al., 2000). The face-specific hypothesis and the expertise hypothesis differ in how they account for the emergence of mechanisms involved in face processing, but they agree that inversion effects for most objects should be smaller than inversion effects for faces or for objects with which we have expertise.

Here we show that large, face-like inversion effects can be obtained for non-face objects and that these effects are not linked to expertise. Using cars as model stimuli, we developed two car tasks that reliably produce inversion effects as large as the largest effects reported with faces. One task taps basic object recognition (discriminating cars from non-cars), the other taps within-class recognition (discriminating one particular car from other cars).

2. Method

2.1. Participants.

According to a recent meta-analysis (Bruyer, 2011), the difference between the average inversion effect sizes reported for faces and objects was 0.5. A power analysis revealed that a sample of 54 participants was required to achieve 95% power to detect this difference (significance threshold .05; two-tailed repeated-measures t-test).

We tested two groups of participants over the web and in the laboratory. Our original web sample consisted of 71 participants from Amazon Mechanical Turk, of which we excluded eight based on abnormally fast response times suggesting lack of engagement with the task. Our final web sample consisted of 63 participants (36 male) with mean age of 36.1 years (SD = 10.1). Our lab sample consisted of 57 undergraduate students (11 male) from Victoria University of Wellington. Their mean age was 18.8 years (SD = 1.6).

2.2. Procedure.

Participants completed the following four tests in random order.

Basic-level recognition of faces (Verhallen et al., 2014). This task is a modified version of the classic Mooney task (Mooney, 1957). Each trial presented three images: a target image – one of the original Mooney faces –and two distractor images, created by rearranging parts of Mooney faces in systematic ways (see Verhallen et al., 2014, for details). The three images were shown side by side for 400ms. Participants had to indicate as quickly as possible the image containing the Mooney face by pressing a key. Participants completed one block with upright images and another with upside-down images. Block order was randomized. Each block started with three practice trials and continued with 39 test trials. A demo version of the experiment can be found at: testable.org/t/493353c.

Basic-level recognition of cars. We developed an identical basic-level recognition task with cars instead of faces. Forty images of SUVs were taken from the Fine-Grained Categorization Car Dataset (Krause, Deng, Stark, & Fei-Fei, 2013) and were carefully edited as in Verhallen et al. (2014) to create a Mooney car target and two Mooney distractors for each car target. All task parameters were identical to the face task. Pilot testing ensured performance with upright cars was comparable to performance with upright faces. A demo version can be found here: testable.org/t/4b14caa.

Within-class recognition of faces (Rezlescu, Pitcher, & Duchaine, 2012). In this task, participants are asked to match one of three test faces (side view) to a target face (frontal view). All stimuli are grayscale male faces with a standard black cap to cover the hair. Participants first saw the target face for 400ms, followed immediately by the three simultaneously presented test faces for 2000ms. Participants had unlimited time to respond. There were 40 upright trials and 40 inverted trials that were randomized. A demo version can be found here: testable.org/t/43a13cc.

Within-class recognition of cars. We developed a similar within-level recognition task with cars instead of faces. The car stimuli consisted of 20 BMW car models, downloaded from the BMW official website (www.bmw.com). All cars were black. The target car was presented at a 20 degrees angle, while the test cars were presented at 50 degrees angles. The design and presentation times were identical to the face task. Pilot testing ensured performance with upright cars was matched to performance with upright faces. A demo version can be found here: testable.org/t/4536cd0.

Example images from all tasks are presented in Figure 1.

3. Results

3.1. Inversion effects for basic-level recognition

Web sample. For faces, average performance in the upright condition was 80.0% (SD = 8.8%) and in the inverted condition 51.9% (SD = 10.9%). The inversion effect for faces was 28.1% (SD = 12.9%; Cohen's d = 2.84). For cars, average performance was 75.1% (SD = 11.7%) in the upright condition and 46.7% (SD = 9.7%) in the inverted condition. The inversion effect for cars was 28.4% (SD = 11.7%; Cohen's d = 2.64). There was no difference between the inversion effects for faces and cars [$t(62) = 0.115$; $p = .909$].

Lab sample. Average performance with upright faces was 75.9% (SD = 8.1%) and with inverted faces 49.9% (SD = 11.8%). The face inversion effect was 26.0% (SD = 10.6%; Cohen's d = 2.57). For cars, average performance was 76.1% (SD = 11.1%) in the upright condition and 48.9% (SD = 10.7%) in the inverted condition. The car inversion effect was 27.2% (SD = 12.6%; Cohen's d = 2.50). Again, there was no difference between the face inversion effect and the car inversion effect [t(56) = 0.58; p = .565].

Web vs. lab samples. The size of the face inversion effect in the web sample was not different from that in the lab sample [t(118) = 0.99; p = .325]. Similarly, the size of the car inversion effect across the two samples was also similar [t(118) = 0.55; p = .587]. When data from both samples were collapsed, the face inversion effect (M = 27.1%, SD = 11.9%) was not significantly different from the car inversion effect (M = 27.8%, SD = 12.1%) [t(119) = 0.47; p = .639].

3.2. Inversion effects for within-class recognition

Web sample. For faces, average performance was 78.7% (SD = 11.6%) in the upright condition and 53.6% (SD = 13.5%) in the inverted condition. The face inversion effect was 25.0% (SD = 12.7%; Cohen's d = 2.00). For cars, average performance was 76.5% (SD = 10.1%) in the upright condition and 53.2% (SD = 11.1%) in the inverted condition. The car inversion effect was 23.3% (SD = 9.3%; Cohen's d = 2.20). There was no difference between the face inversion effect and the car inversion effect [t(62) = 0.869; p = .388].

Lab sample. For faces, average performance was 84.2% (SD = 9.2%) in the upright condition and 59.1% (SD = 11.7%) in the inverted condition. The face inversion effect was 25.1% (SD = 10.0%; Cohen's d = 2.39). For cars, average performance was 75.4% (SD = 11.4%) in the upright condition and 49.4% (SD = 10.9%) in the inverted condition. The car inversion effect was 26.0% (SD = 9.5%; Cohen's d = 2.33). The face inversion effect and the car inversion effect were not significantly different [t(56) = 0.467; p = .643].

Web vs. lab samples. The size of the face inversion effect in the web sample was not different from that in the lab sample [t(118) = 0.02; p = .982]. Similarly, the size of the car inversion effect across the two samples was also similar [t(118) = 1.57; p = .119]. When data from both samples were collapsed, the face inversion effect (M = 25.1%, SD = 11.5%) was not significantly different from the car inversion effect (M = 24.5%, SD = 9.5%) [t(119) = 0.37; p = .711].

All face and car inversion results are summarized in Figure 2.

3.3. The role of car expertise

Car experts are expected to perform better than non-experts at discriminating very similar car exemplars. Therefore, our measure of car expertise was performance with upright cars in the within-class recognition task. Because the results for the web and lab samples were very similar, we pooled data from both samples (n = 120) and we checked whether our results are driven by car expertise in two ways.

First, we excluded participants who scored above the median on the within-class upright car recognition (i.e. we excluded participants more likely to be considered car experts) and re-computed all inversion effects (remaining sample: n = 65). The inversion effects for faces and cars remained comparable. For basic-level recognition, the face inversion effect (M = 27.8%, SD = 11.1%) was not significantly different from the car inversion effect (M = 27.1%, SD = 11.9%) [t(64) = 0.31; p = .756]. Similarly, for within-class recognition, the face inversion effect (M = 25.1%, SD = 12.5%) was not significantly different from the car inversion effect (M = 22.1%, SD = 8.9%) [t(64) = 1.56; p = .124].

The second method used to check if inversion effects were due to expertise was to examine if the two correlated. If larger inversion effects were due to increased expertise, one would expect to find a correlation between expertise (i.e. upright performance in the within-class recognition task) and the inversion effect as measured by an independent task (i.e. the basic recognition task). This was not the case – Pearson's correlation r = .13 was not significant (p = .161, 95% CI = [-.05 .30]). For comparison, we also did not find a correlation between face expertise (i.e. upright performance in the within-class recognition task) and the face inversion effect in the basic-level recognition task (r = .07, p = .940, 95% CI = [-.17 .19]).

4. Discussion

4.1. Large inversion effects are not specific to faces

Our study shows that non-face objects like cars can produce inversion effects as large as those produced by faces. The face-like inversion effects for cars were obtained with two tasks measuring different aspects of visual recognition. The first task used two-tone Mooney stimuli and showed that *basic-level recognition* of upright cars is substantially better than recognition of upside-down cars. The second test used natural stimuli (real car models downloaded from an automaker website) and showed that successful car *individuation* is heavily dependent on the upright orientation. In both tasks, upright performance and inversion effects were virtually identical for cars and faces. This is compelling evidence that the disproportionately large inversion effects previously reported with faces (e.g. Husk, Bennett, & Sekuler, 2007; Robbins & McKone, 2007; Yin, 1969) are not specific to faces.

Comparable inversion effects for faces and non-faces have been reported before, but their implications were limited because their baseline face inversion effects were relatively small, suggesting that the tasks did not fully tap mechanisms involved in processing upright faces. This is visible in Figure 3 (and the associated Table S1 in Supplemental Materials) that compares our inversion effects with results from previous studies. When cars were used, reported inversion effects were small (8% in Xu, Liu, & Kanwisher, 2005; d' of .84 and .57 for car experts and non-experts, respectively, in Gauthier et al., 2000; Cowan's K of .435 and .053 for experts and non-experts, respectively, in Curby, Glazek, & Gauthier, 2009), consistent with the idea that non-faces produce much smaller inversion effects than faces. There was only one study (Diamond & Carey, 1986) that reported large, face-like inversion effects – 20% for faces and 22% for dogs on a two-choice task – but the dog results were obtained only with dog experts. Participants who were not expert dog judges showed a much smaller inversion effect (5%). Moreover, these expertise-driven inversion effects failed to replicate in later studies (Bruyer & Crispeels, 1992; Rossion & Curran, 2010), even when experimental conditions were almost identical (Robbins & McKone, 2007).

A few studies claimed that human bodies demonstrated face-like inversion effects (Reed, Stone, Bozova, & Tanaka, 2003; Reed, Stone, Grubb, & McGoldrick, 2006; Susilo, Yovel, Barton, & Duchaine, 2013; Yovel, Pelc, & Lubetzky, 2010). However, three limitations challenged these claims. First, three studies (Brandman & Yovel, 2012; Susilo et al., 2013; Yovel et al., 2010) showed that the body inversion effect depends on the presence of a (faceless) head attached to the body, suggesting the BIE is due to a *faulty* activation of face-processing mechanisms. Second, and similar to other studies claiming to report face-like inversion effects with non-faces, the inversion effects in these studies were small (5% for bodies and 7% for faces in Reed et al., 2003; 0.3 decrease in d' for bodies and faces in Reed et al., 2006; 13% for bodies and 12% for faces in Brandman & Yovel, 2012; 10% for bodies and 11% for faces in Susilo et al., 2013), suggesting they might have failed to tap orientation-sensitive mechanisms that are unique to faces or objects-of-expertise. Third, the reported BIE is not an individuation effect – in all these studies the experimental task was to match body postures not body identities – so it is debatable whether *object recognition* mechanisms are driving the effect. In contrast, we report robust and massive inversion effects for both faces (25-28%) and cars (23-28%). Moreover, our car inversion effects cannot be explained by an incidental activation of face processing mechanisms. We were careful to exclude any possibility that our car stimuli resemble face configurations by presenting only side views of cars.

Because we used cars as stimuli, our results may be interpreted to support the idea that large inversion effects depend on expertise - if one believes we are all car experts. While this hypothesis can be decisively evaluated only by testing a population with limited exposure to cars, we believe it is highly unlikely. Excluding participants with scores above the median in matching upright cars (a good measure of expertise) had negligible impact on our results. Furthermore, we found no correlation between car expertise and the size of the inversion effect. While expertise may increase inversion effects because of better performance of experts with upright stimuli, our data strongly suggest expertise is not necessary for obtaining large inversion effects.

4.2. Possible mechanisms for inversion effects

To date, most researchers suggested that large inversion effects are linked to mechanisms involved in holistic processing (Rossion, 2008; Yin, 1969), although there are differences between definitions of holistic processing and whether holistic processing is seen as specific to upright faces or, more generally, to all objects of expertise. For example, Diamond & Carey (1986) defined holistic processing as the second-order relational information between parts within an object (e.g. the position of the mouth relative to the nose in a face) and argued that recognition of all objects of expertise with prototypical spatial configurations is dependent on holistic processing. Rhodes, Brennan, & Carey (1987) proposed that the second-order relational information is not computed within a specific object, but between that specific object and an *upright* class norm. This account has a straightforward explanation for the much better recognition of upright objects compared to inverted objects (which presumably do not have a norm). Note that these hypotheses assume that either all exemplars within an object class are processed holistically, or all exemplars are processed on a part-like manner.

In contrast, our results raise the possibility that object classes do not have a permanent “on” switch for holistic processing, but rather holistic processing can be switched on and off within the same class of objects depending on exemplar similarity and task requirements. Rhodes, Brake, & Atkinson (1993) alluded to a two-stage recognition process. In the first stage, objects are encoded in a part-based manner, with their representation including information on spatial relations between parts (i.e., first-order relational information) which facilitates recognition of a stimulus as belonging to a particular class (e.g. a car). This part-based representation is usually sufficient for recognition of everyday objects, because: i) most objects do not require recognition at an individual level; ii) when exemplar recognition is necessary (e.g. my car versus your car), the differences between parts of different object are usually conspicuous. However, when exemplar recognition is necessary and differences in individual parts are uninformative (may be too subtle or provide inconsistent results), computations over larger sets of features are performed – what is often generically referred to as holistic processing (the second stage in the recognition process proposed by Rhodes et al., 1993[1]).

We propose that objects are processed holistically when the following conditions are met: i) exemplar individuation is needed; ii) object belongs to a complex but highly homogeneous set, i.e. one object has multiple parts that can vary in unpredictable ways (within limits), but variations in individual parts are not sufficient to allow recognition; note that, for a given task, exemplar sets from within the same object class can be more or less homogeneous (e.g. a set of black BMW sedans is highly homogeneous; a set of different car brands less so); iii) object has a canonical orientation. The canonical orientation can enhance recognition by encoding exemplars in relation to a canonical norm and/or tuning recognition mechanisms to that orientation. It is possible norms and holistic processing are also present for non-canonical orientations, however only recognition mechanisms fine-tuned to the canonical orientation will create large inversion effects.

Most of the results in the literature can be explained within this framework. First, faces are special because they are the only visual stimuli that regularly fulfill all conditions for holistic processing: faces trigger an automatic individuation response in viewers (to facilitate social interaction), they are complex, almost any set of faces is highly homogeneous due to nature, and they have a canonical orientation. In contrast, objects are first identified at the basic level (Grill-Spector & Kanwisher, 2005; Jolicoeur, Gluck, & Kosslyn, 1984) and most often this recognition suffices for further processing. However, exemplar individuation is sometimes necessary. Note that an individuation task is not enough to trigger holistic processing; the objects need also to belong to a highly homogeneous set. We believe previous studies examining holistic processing in within-class object recognition neglected this aspect. In this context, we note that, methodologically, obtaining large inversion effects with faces is relatively straightforward, while with cars it requires careful selection of the stimuli.

While basic level recognition typically relies on part-based processing, there is a special situation in which it requires holistic processing: when objects are occluded to the

[1] Rhodes et al. (1993) argued holistic processing needs a "norm" exemplar of an object class (e.g. an average upright face) and implied inversion effects can be explained by the fact that upright faces have such a norm while inverted faces do not. We are agnostic with respect to the existence of norms and we do not believe holistic processing depends on norms. The global computation performed by holistic processing can very well involve relative differences between exemplars without reference to a norm.

extent that individual part information becomes insufficient to support recognition. That is the case with Mooney stimuli and the reason for the inversion effects in our detection tasks. This is consistent with evidence that individuals who lost their ability to recognize faces also have problems recognizing occluded objects (Levine & Calvanio, 1989; Rezlescu et al., 2012; Takahashi, Kawamura, Hirayama, Shiota, & Isono, 1995). For example, we are not aware of any case of acquired prosopagnosia with normal performance in Gestalt completion tasks (involving object recognition from stimuli like those first suggested by Street, 1931).

4.3. Conclusion and implications for the face-specific hypothesis

We have presented conclusive evidence that large inversion effects are not specific to faces. We suggest that, rather than being face-specific, inversion effects are the result of a special type of processing engaged in recognition of exemplars from complex but highly homogeneous sets of objects with a canonical orientation. However, the implications of our findings go beyond this hypothesis (which may turn out to be true or not) – they are a potential challenge to a large share of the evidence supporting face-specificity.

Most psychology and neuroscience investigations are based on comparisons between results on a condition of interest and results on a control condition. Therefore, the findings reported in these studies are only as good as their control condition. If the control condition fails to eliminate aspects not relevant for the condition of interest, the interpretation of results is severely limited. This applies equally to behavioral, neural, and neuropsychological investigations. In the case of face perception literature, our findings raise the question whether previous studies failed to control for *non-face-specific* mechanisms that are engaged in the visual recognition of particular stimuli (not exclusively faces) in their canonical orientation. Previous landmark findings reported to support face specificity (e.g. face-selective brain areas and electrophysiological markers, neuropsychological deficits restricted to face processing) require re-examination with control tasks producing face-like inversion effects.

Figure 1. Example trials from the two tasks. In the basic-level recognition task, participants were asked to select the image that presented a face/car. In the within-class recognition task, participants had to select the image that showed a different view of a previously presented target exemplar (at the top). The correct responses are highlighted.

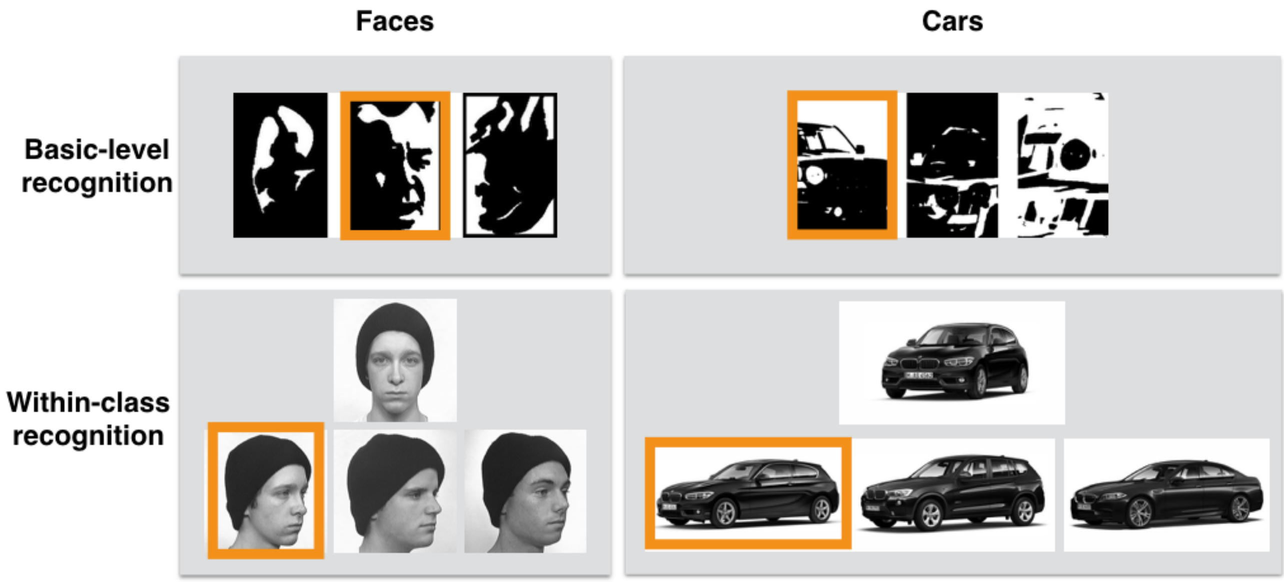


Figure 2. Performance from web and lab participants in the two tasks. Scores obtained with faces and cars were comparable in all conditions, leading to almost identical inversion effects (inversion effect = upright score – inverted score).

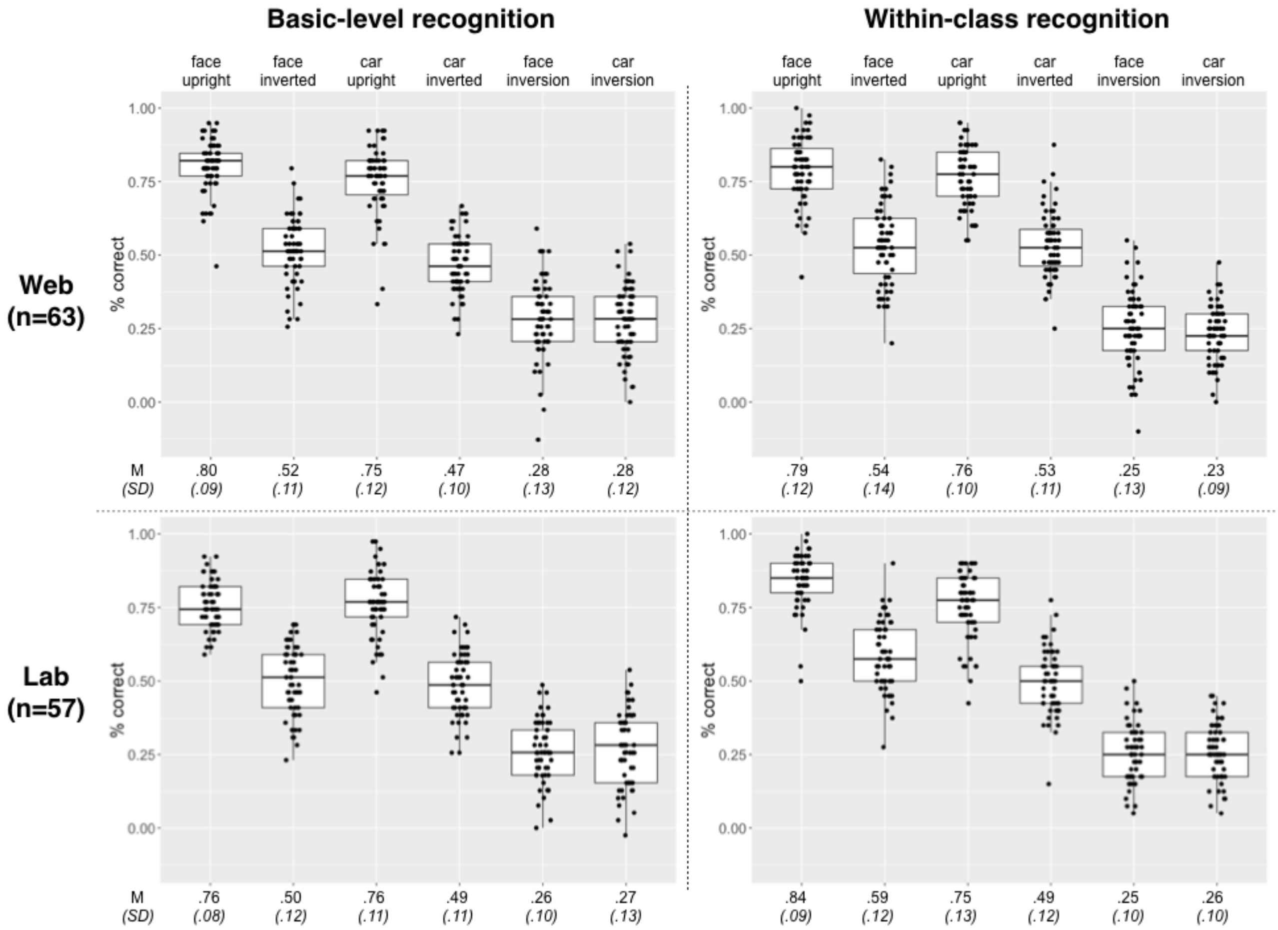
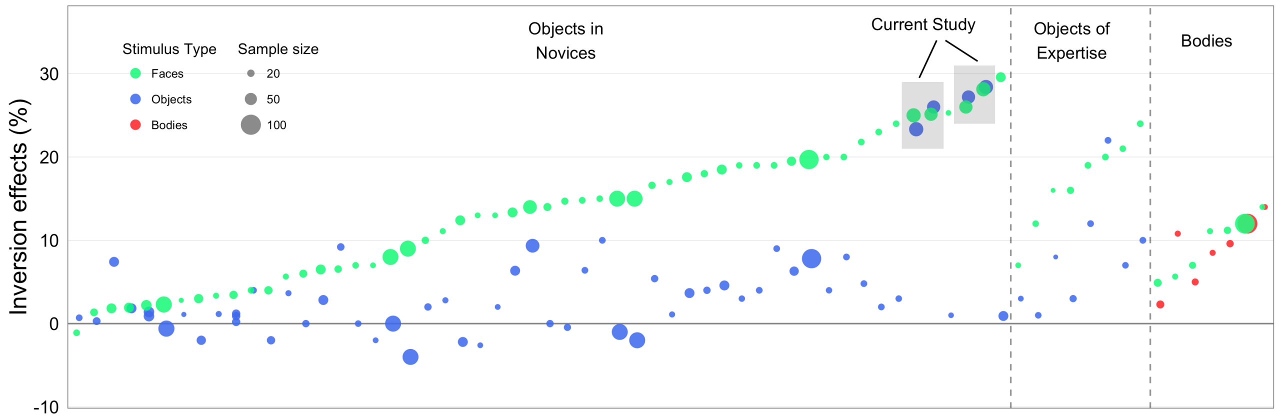


Figure 3. Reported inversion effects for faces, objects and bodies (please see Table S1 for supporting data and references). Studies are sorted on the X axis according to the size of the reported face inversion effects. Panel A shows raw data, while Panel B shows scaled effects. Scaled inversion effect = (raw inversion effect) / (1-chance). Current study (shaded) reports large and equivalent inversion effects for faces and cars, in contrast to previous studies showing substantial differences between inversion effects for faces and non-faces.

A.



B.

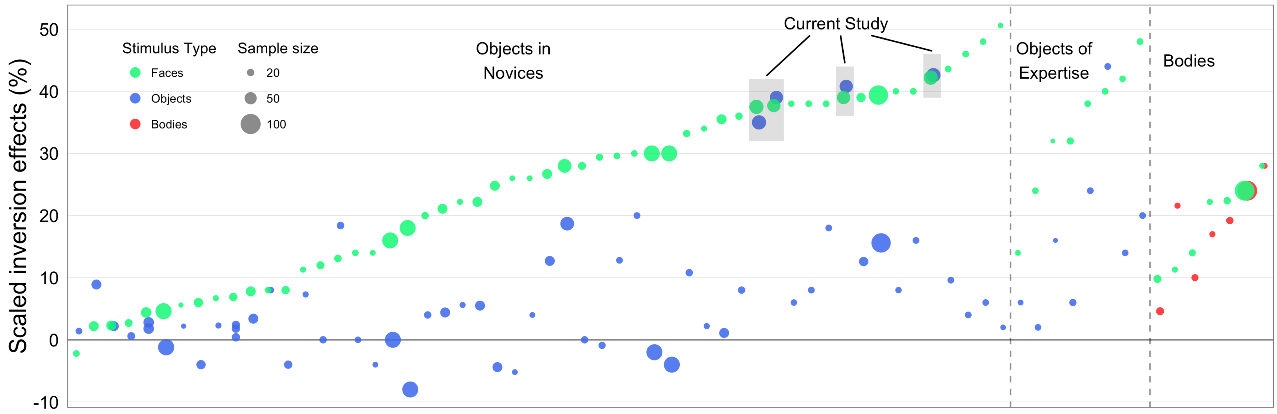


Table S1. Studies comparing inversion effects for faces with inversion effects for objects and bodies (data are presented visually in Figure 3). Within each group (objects in novices, objects of expertise, bodies), studies are sorted according to the scaled inversion effects found for faces, from smallest to largest. Scaled inversion effect = (inversion effect) / (1-chance).

Objects in Novices

Reference	Expt	Cond	n	Chance (%)	Inversion Effect (% acc) Face	Inversion Effect (% acc) Object	Scaled Inversion (% acc) Face	Scaled Inversion (% acc) Object	Object type
Lahaie2006	1	1	16	50.0	-1.1	0.7	-2.2	1.4	Greebles
Leder2006	1	1	36	16.7	1.8	7.4	2.2	8.9	House
Leder2006	1	2	36	16.7	1.9	1.8	2.3	2.2	House
Yin1969	3	1	23	50.0	1.3	0.3	2.7	0.6	Costumes
Yarmey1971	1	1	80	50.0	2.2	1.4	4.4	2.8	Dogs
						0.9		1.8	Buildings
deGelder2009	1	1	75	50.0	2.3	-0.6	4.6	-1.2	Shoes
Haxby1999	1	1	6	50.0	2.8	1.1	5.6	2.2	House
deGelder2015	1	1	32	50.0	3.0	-2.0	6.0	-4.0	Shoes
Yin1970	1	1	12	50.0	3.3	1.2	6.7	2.3	House
Yin1969	1	1	26	50.0	3.5	1.2	6.9	2.4	House
						0.2		0.4	Airplane
						0.9		1.8	Men in motion
Leder2006	1	6	36	16.7	6.5	2.8	7.8	3.4	House
Boutet2006	2	2	15	50.0	4.0	4.0	8.0	8.0	Chair/House
deGelder2015	1	2	26	50.0	4.0	-2.0	8.0	-4.0	Shoes
Urgesi2014	1	1	12	50.0	5.7	3.7	11.3	7.3	Motorcycles
Meinhardt-Injac2014	1	2	44	50.0	6.0	0.0	12.0	0.0	Watch
Picozzi2009	2	1	21	50.0	6.5	9.2	13.1	18.4	Cars
Boutet2006	2	1	15	50.0	7.0	0.0	14.0	0.0	Chair/House
Rossion2002	1	2	10	50.0	7.0	-2.0	14.0	-4.0	Greebles
Yovel2008	1	1	74	50.0	8.0	0.0	16.0	0.0	House
Yovel2004	2	1	74	50.0	9.0	-4.0	18.0	-8.0	House
Robbins2007	3	2	20	50.0	10.0	2.0	20.0	4.0	Dogs
Leder2006	1	5	36	16.7	17.6	3.7	21.1	4.4	House
Bosbach2006	1	1	12	50.0	11.1	2.8	22.2	5.6	House
Leder2006	1	4	36	16.7	18.5	4.6	22.2	5.5	House
Picozzi2009	1	1	36	50.0	12.4	-2.2	24.8	-4.4	Shoes
Picozzi2009	3	1	10	50.0	13.0	-2.6	26.0	-5.2	Cars
Picozzi2009	3	2	10	50.0	13.0	2.0	26.0	4.0	Cars
Carey1977	1	1	36	50.0	13.3	6.3	26.7	12.7	House
Bushmakin2014	2	1	60	25.0	21.0	14.0	28.0	18.7	Novel
Meinhardt-Injac2014	1	1	44	50.0	14.0	0.0	28.0	0.0	Watch
Picozzi2009	2	2	19	50.0	14.7	-0.5	29.4	-0.9	Cars
Valentine1986	3	2	16	50.0	14.8	6.4	29.6	12.8	House
Bruce1991	6	1	62	50.0	15.0	10.0	30.0	20.0	House
Yovel2004	2	2	74	50.0	15.0	-1.0	30.0	-2.0	House
Yovel2008	1	2	74	50.0	15.0	-2.0	30.0	-4.0	House
Valentine1986	2	1	20	50.0	16.6	5.4	33.2	10.8	House
Busigny2010	4	1	12	50.0	17.0	1.1	34.0	2.2	Cars
Leder2006	1	3	36	16.7	29.6	0.9	35.5	1.1	House
Rossion2010	1	2	20	50.0	18.0	4.0	36.0	8.0	Cars
Rezlescu2017	**1**	**Within (MTurk)**	**63**	**33.3**	**25.0**	**23.3**	**37.5**	**35.0**	**Cars**
Rezlescu2017	**1**	**Within (Lab)**	**57**	**33.3**	**25.1**	**26.0**	**37.7**	**39.0**	**Cars**
Boutet2006	1	2	14	50.0	19.0	3.0	38.0	6.0	Chair/House
Bruyer1992	1	2	16	50.0	19.0	4.0	38.0	8.0	Handwriting
Diamond1986	1	1	16	50.0	19.0	9.0	38.0	18.0	Scenes
Rezlescu2017	**1**	**Basic (Lab)**	**57**	**33.3**	**26.0**	**27.2**	**39.0**	**40.8**	**Cars**
Williams2007	1	1	32	50.0	19.5	6.3	39.0	12.6	Radio
Phillips1979	1	1	95	50.0	19.7	7.8	39.4	15.6	Woodcuts
Boutet2006	1	1	14	50.0	20.0	4.0	40.0	8.0	Chair/House

Diamond1986	2	2	16	50.0	20.0	8.0	40.0	16.0	Dogs
Rezlescu2017	**1**	**Basic (MTurk)**	**63**	**33.3**	**28.1**	**28.4**	**42.2**	**42.6**	**Cars**
Valentine1986	3	1	16	50.0	21.8	4.8	43.6	9.6	House
Diamond1986	3	2	16	50.0	23.0	2.0	46.0	4.0	Dogs
Robbins2007	1	2	15	50.0	24.0	3.0	48.0	6.0	Dogs
Busigny2010	3	1	9	50.0	25.3	1.0	50.6	2.0	Cars

Objects of Expertise

					Inversion Effect (% acc)		Scaled Inversion (% acc)		
Reference	**Expt**	**Cond**	**n**	**Chance (%)**	**Face**	**Object**	**Face**	**Object**	**Object type**
Rossion2002	1	1	10	50.0	7.0	3.0	14.0	6.0	Greebles
Robbins2007	3	1	15	50.0	12.0	1.0	24.0	2.0	Dogs
Busey2005	2	1	4	50.0	16.0	8.0	32.0	16.0	Fingerprints
Rossion2010	1	1	19	50.0	16.0	3.0	32.0	6.0	Cars
Diamond1986	2	1	16	50.0	19.0	12.0	38.0	24.0	Dogs
Diamond1986	3	1	16	50.0	20.0	22.0	40.0	44.0	Dogs
Robbins2007	1	1	15	50.0	21.0	7.0	42.0	14.0	Dogs
Bruyer1992	1	1	16	50.0	24.0	10.0	48.0	20.0	Handwriting

Bodies

					Inversion Effect (% acc)		Scaled Inversion (% acc)		
Reference	**Expt**	**Cond**	**n**	**Chance (%)**	**Face**	**Object**	**Face**	**Object**	**Object type**
Reed2006	3	1	24	50.0	4.9	2.3	9.8	4.6	Bodies
Urgesi2014	1	1	12	50.0	5.7	3.7	11.3	21.6	Bodies
Reed2003	2	1	18	50.0	7.0	0.0	14.0	10.0	Bodies
Bosbach2006	1	1	12	50.0	11.1	2.8	22.2	17.0	Bodies
Susilo2013	1	1	20	50.0	11.2	0.0	22.4	19.2	Bodies
Brandman2012	1	1	98	50.0	12.0	0.0	24.0	24.0	Bodies
Yovel2010	1	1	10	50.0	14.0	0.0	28.0	28.0	Bodies

Author contributions

C. Rezlescu and T. Susilo developed the study concept. C. Rezlescu, A. Chapman, and T. Susilo contributed to the study design. Testing and data collection were performed by C. Rezlescu and A. Chapman. C. Rezlescu, A. Chapman, and T. Susilo performed the data analysis and interpretation. C. Rezlescu and A. Chapman drafted the manuscript, and T. Susilo and A. Caramazza provided critical revisions. All authors approved the final version of the manuscript for submission.

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