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Large inversion effects for common objects and objects that require little if any holistic processing

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It is widely assumed that faces are processed holistically whereas objects are not because only face recognition efficiency is greatly affected when stimuli are presented upside-down. This phenomenon – the face inversion effect – has been taken as support for both theories of domain-specificity and expertise, and as an index of holistic/configural processing. The present study, which comprised 122 Danish psychology students, demonstrates that large inversion effects can be found for objects too, even when they do not belong to categories of expertise or are structurally similar. Furthermore, inversion effects were also found in conditions that require little if any holistic processing. While these findings do not refute that face processing may be domain-specific, a product of expertise, or that inversion effects can reflect holistic/configural processing, they do suggest that inversion effects by themselves provide little specific evidence in favor of any these assumptions.

Keywords Face recognition, Holistic processing, Inversion effect, Object recognition, Structural similarity

In 1969 Yin reported that recognition of faces was disproportionately more impaired than recognition of objects when stimuli were presented upside-down (inverted); a finding that has been replicated numerous times since[2]. This phenomenon, which is referred to as the face inversion effect, is considered important for several reasons: It is used as a measure of expertise[3]; as a specific measure of holistic/configural processing[4,5]; as a way to control for low-level properties of face images[6]; and as constituting some of the core evidence supporting the notion that faces are processed in a domain-specific manner[7,8]. The effect has also been investigated in several (sub)disciplines including developmental psychology, cognitive psychology, neuropsychology, experimental psychology, comparative psychology, and neuroscience.

A dominant explanation for the face inversion effect is that upright faces are processed in a qualitatively different way than inverted faces and also qualitatively differently from both upright and inverted objects. More specifically it is assumed that local features (parts) in upright faces are processed in parallel and integrated into a unified whole (holistic processing), whereas inverted faces and both upright and inverted objects are processed based on serial analysis of local features e.g[7,9]. Newer findings have cast doubt on this explanation because inversion effects can be just as large for objects as for faces[10,11].

An influential theory that tries to explain why inversion effects may also arise for *certain non*-face categories is the expertise account[4,12]. On this account, inversion is assumed to be detrimental to recognition of stimuli also from non-face categories provided that their members: (i) are structurally similar (sharing similar parts in the same configuration), (ii) are to be differentiated at a subordinate/exemplar level, and (iii) belong to categories that people are experts in individuating. The object inversion effects found by Gerlach, et al.[10] and Rezlescu, et al.[11], however, did not fulfil these criteria because they were found in tasks that did not require identification at the subordinate/exemplar level[10], and with objects that did not belong to the realm of expertise[10,11]. Thus, it seems that inversion effects for objects are not as restricted as previously assumed.

From the extensive literature on the face inversion effect, it is clear that inversion impairs the processing of both isolated features[13], configurations of features[14], and the global face contour[15]. Whether the same applies to inversion effects for objects is not known because these effects thus far have been considered exceptional. The present study aims to fill part of this gap by examining two central questions.

The first question is whether global object contour – the object's outer bounding line – plays a significant role in driving object inversion effects. This possibility is likely because global shape contour is the first type of information that is available to the object recognition system laying the ground for both prediction-making and for the build-up of elaborate shape representations[16].

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The second question is whether inversion effects are more pronounced for structurally similar (SS) objects than for structurally distinct (SD) objects. This would be expected if the expertise account's criterion regarding the role of similarity in inversion effects also holds for objects.

The role of global shape contour was investigated here by presenting objects as silhouettes because silhouetting degrades parts – and especially internal parts – while keeping the global shape contour intact. If global shape contour is an important factor driving the inversion effect for objects, the inversion effect should be present also for silhouettes.

Support for the assumption that recognition of silhouettes is primarily based on outline shape rather than features/feature configurations comes from studies of patients with integrative agnosia. As reflected by the name of this disorder, patients with integrative agnosia have difficulties integrating parts into holistic representations[17]. Despite this they may recognize silhouettes just as well as neurotypical individuals see e.g[18]. This suggest that recognition of silhouettes is primarily based on global shape information. Evidence for the dominant role of outline shape in recognition of silhouettes also come from studies with neurotypicals showing that recognition of silhouettes is less affected than recognition of line-drawings by short stimulus exposure[19] which favor global shape processing relative to processing of parts[20].

In the present experiment, the role of structural similarity was examined by contrasting recognition of natural objects and artefacts. Of these domains, natural objects typically belong to categories characterized by high structural similarity and artefacts to categories with low(er) structural similarity[21,22]. If inversion affects recognition of SS objects but not SD objects (to the same degree), as would be assumed based on the expertise account, recognition of natural objects (SS objects) should be associated with larger inversion effects than artefacts (SD objects), yielding an interaction between Orientation and Category (SD vs. SS objects).

Hence, the present experiment tested two predictions: (i) inversion effects will be found for recognition of silhouettes, and (ii) inversion effects will be larger for SS objects than for SD objects.

Materials and methods

Participants

122 first-year psychology students, naïve to the specific hypotheses tested, took part in the study as part of their course in cognitive psychology. Participants were free to opt-out if they wished, and participation in the experiments was taken as consent. Hence, the sample size was determined by the number of students who took the course and were present at the test dates where the experiment was conducted. None of these participants were excluded from the data analyses.

Design

To test the hypothesis that recognition of silhouettes will lead to inversion effects, participants performed two object decision tasks where they had to decide whether stimuli depicted real objects or nonobjects, one with regular line-drawings of objects (baseline task) and one where the same stimuli were silhouetted (see Fig. 1). Half of the stimuli were presented in their canonical orientation and half were inverted. To ensure that potential effects of inversion were not limited to a specific set of objects, orientation was counterbalanced so that the stimuli (both real objects and nonobjects) were presented equally often in upright view as in inverted view across participants. In each task, the participants were instructed to press the '1'-key if the picture represented a real object and the '2'-key if it represented a nonobject. Participants were encouraged to respond as fast and as accurately as possible, and they were informed that some of the objects would be presented in normal orientation

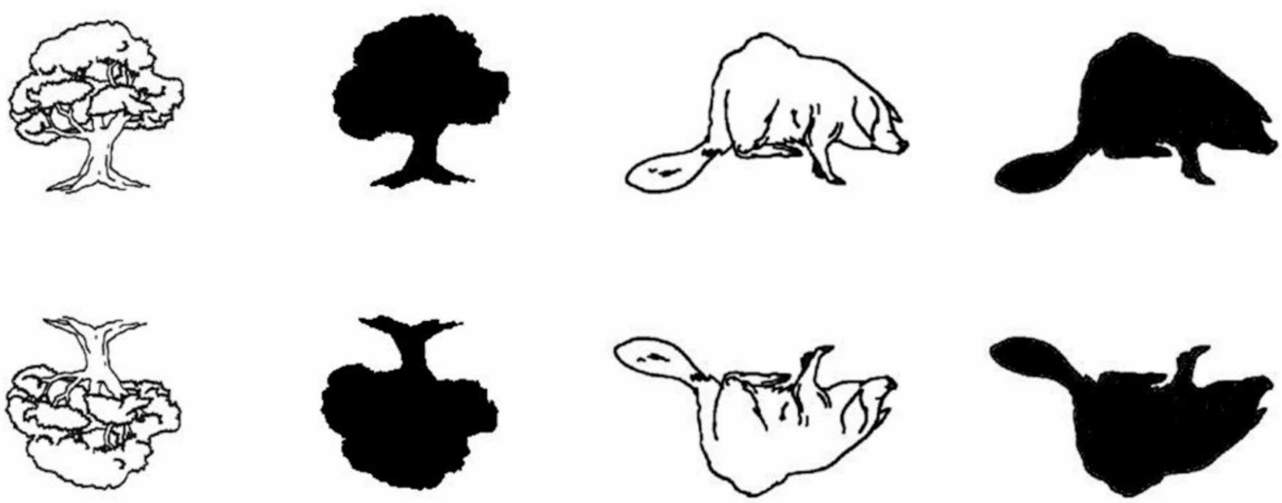

Fig. 1. Examples of the objects presented in the object decision tasks. Upper panel: To the left an example of a real object (tree) presented as a line-drawings and as a silhouette. To the right an example of a nonobject (half a beaver and half a pig) presented as a line-drawing and as a silhouette. Lower panel: The same stimuli presented upside down.

and some of them in inverted orientation. Prior to each task the participants performed a practice version of the upcoming task comprising a total of 16 trials. Stimuli used in these practice versions were not used in the actual experimental conditions. Half of the participants began with line-drawings and half with silhouettes.

Stimuli

128 pictures were presented in each task: 64 real objects and 64 nonobjects. The line-drawings of real objects were taken from the set of Snodgrass and Vanderwart[23] and consisted of 32 SS objects (natural objects) and 32 SD objects (artefacts) which were highly mono-oriented. Based on the norms provided by Snodgrass and Vanderwart the two sets of real objects were matched with respect to familiarity and visual complexity. It was also verified that the two categories differed in structural similarity. Structural similarity is not a unitary construct, however, and it has been operationalized differently by different authors. Hence two different measures of structural similarity, taken from two independent studies, were used to assess this aspect of the stimuli: (i) The degree of contour overlap (CO) among objects[21], and (ii) the degree of within-item structural diversity (WSD) among objects[22]. The measure of CO was generated by: (i) Normalizing all the pictures of objects in the Snodgrass and Vanderwart (1980) corpus for orientation and size, (ii) overlaying each picture on a grid with pictures of every other object from the same category (the categories being animals, birds, body parts, buildings, clothes, crustacea, fruit, furniture, implements, insects, vegetables, and vehicles), and (iii) calculating the average overlap between the pictures on their bounding contour – that is, on their outline shape without consideration of internal details – as a function of the amount of contour in each target picture[21]. The measure of WSD was derived by presenting individuals with the name of an object (e.g., dog, fork) and asking them to rate the extent to which instances with that name had similar structural representations (on a scale from 1 to 5; 1 = very dissimilar; 5 = very similar). Hence, elephants score higher on this measure than chairs because chairs come in a variety of shapes whereas elephants do not. The WSD measure can be considered a high-level measure of structural similarity because it is based on memories of objects rather than on the physical properties of objects (drawings) such as the CO measure.

According to the CO measure, natural objects were more structurally similar than artefacts ($t_{57} = 6.17$, $p < .001$, $M_{dif} = 5.7$ [95% CI: 3.86–7.56], $d = 1.61$ [95% CI: 1.01–2.19]), and artefacts also scored significantly higher on the WSD measure than natural objects ($t_{62} = 2.63$, $p = .011$, $M_{dif} = 0.42$ [95% CI: 0.1 – 0.74], $d = 0.66$ [95% CI: 0.15–1.16]). Hence, natural objects were found to differ less than artefacts on both measures, suggesting that they were more structurally similar than artefacts. The CO measure was available for 29 (91%) of the SD objects and for 30 (94%) of the SS objects. The WSD measure was available for all stimuli.

The 64 chimeric drawings of nonobjects were selected mainly from the set made by Lloyd-Jones and Humphreys[24]. These nonobjects are line-drawings of closed figures constructed by exchanging single parts belonging to objects from the same category. The silhouette versions of the regular line-drawings were made by replacing the color of each pixel within the interiors of the line-drawings with the color black. The order of pictures was randomized in each task. The present object decision tasks can be considered difficult because the nonobjects are composed of parts from real objects. Compared with object decision tasks using completely novel nonobjects this forces participants to process the stimuli in an elaborated manner because a decision cannot be made based on just a single feature[19] or some superficial characteristic[25]. Importantly, this not only affects processing of nonobjects but also processing of the real objects[10]. Consequently, processing of real objects in difficult object decision tasks give rise to extensive activation in the ventral object processing pathway[26].

Procedure

All stimuli were presented centrally on a white background on a PC-monitor and subtended 3–5 degrees of visual angle. The stimuli were displayed until the participants made a response. The interval between response and presentation of the next object was 1 s. RTs were recorded by means of the keyboard/touchpad.

Statistical analyses

Because the nonobjects in the object decision tasks serve no other purpose than to ensure detailed shape processing of the real objects, all analyses of latency and accuracy data described below are based on responses to real objects only.

Latency data (reaction times (RT)) were trimmed for each participant by removing RTs on correct trials that deviated 2.5 SDs from the mean of that participant. This was done separately for each sub-condition in each task, e.g., inverted artefacts presented as line-drawings, etc. On average, trimming resulted in the removal of 3.3% trials for each of the eight sub-conditions (range: 2.3–4.4%), which is within the recommended limits suggested by Ratcliff[27]. Then the mean trimmed RT was computed for each of the eight sub-conditions for each participant.

Even though the participants were encouraged to "respond as fast and as accurately as possible" they may still differ in how they weigh speed and accuracy giving rise to potential speed-accuracy trade-offs. To handle this potential problem, and to use a single measure that gauge effects across both latency and accuracy, the ANOVA presented below was based on balanced integration scores (BIS)[28]. BIS scores are calculated by standardizing the mean RTs and mean proportion correct (PC) answers across participants and subtracting the standardized RT value (Z_{RT}) from the standardized PC value (Z_{PC}) for each participant. Standardization is performed across all participants and conditions in the experiment[28,29].

Results

A three-way within-participants ANOVA with the factors Stimulus Type (line-drawings vs. silhouettes), Category (SD vs. SS objects), and Orientation (upright vs. inverted stimuli) revealed a main effect of Stimulus Type ($F1(1,121) = 34.62$, $p < .001$, $\eta_p^2 = 0.22$), with more efficient processing of line-drawings than silhouettes, a main effect of Category ($F1(1,121) = 310.7$, $p < .001$, $\eta_p^2 = 0.72$), with more efficient processing of SS compared with

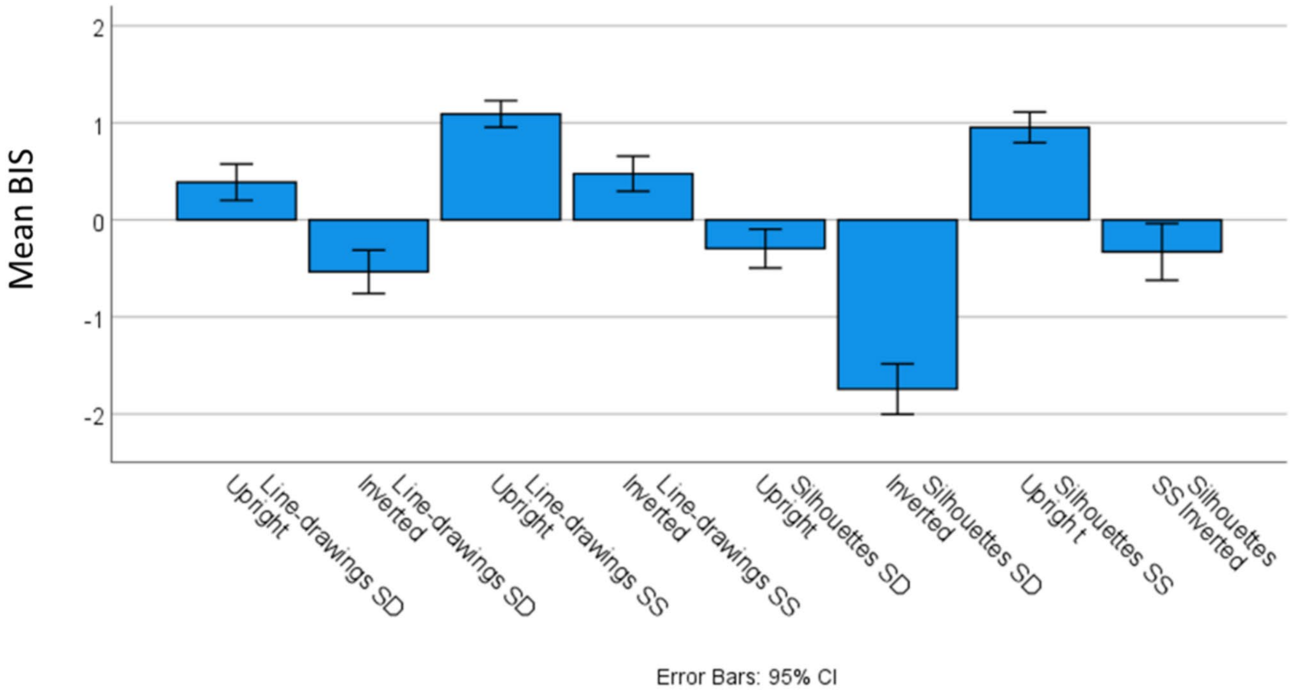

Fig. 2. The mean BIS (balanced integration score) for each of the eight conditions. Error bars represent the 95% confidence interval. SD = Structurally distinct. SS = Structurally similar.

	Line-drawings		**Silhouettes**	
	RT	**% Correct**	**RT**	**% Correct**
SD Upright	895 [849, 941]	96.4 [95.8, 97]	862 [823, 900]	92 [91.2, 92.8]
SD Inverted	1026 [970, 1082]	93.9 [93.1, 94.8]	1010 [950, 1069]	87 [86, 88]
SS Upright	828 [792, 864]	98.9 [98.6, 99.3]	834 [795, 873]	98.3 [97.9, 98.7]
SS Inverted	925 [883, 968]	97.5 [96.8, 98.2]	993 [930, 1056]	94.4 [93.5, 95.3]

Table 1. The mean correct RTs (ms.) and mean percentage correct responses for each of the eight conditions. 95% confidence intervals are given in []. SD = Structurally distinct. SS = Structurally similar.

SD stimuli, a main effect of Orientation ($F1(1,121) = 385.28$, $p < .001$, $\eta_p^2 = 0.76$), with more efficient processing of upright than inverted stimuli, an interaction between Stimulus Type and Orientation ($F1(1,121) = 40.91$, $p < .001$, $\eta_p^2 = 0.25$), an interaction between Stimulus Type and Category ($F1(1,121) = 29.67$, $p < .001$, $\eta_p^2 = 0.2$), and an interaction between Category and Orientation ($F1(1,121) = 6.09$, $p = .015$, $\eta_p^2 = 0.05$). The three-way interaction between Stimulus Type, Category and Orientation was not significant ($F1(1,121) = 0.64$, $p = .43$) (An ANOVA based on the raw (non-trimmed) data yielded the same results: see the Appendix in the supplementary materials). For information regarding the mean BIS and 95% CI for each condition see Fig. 2. For the mean RTs and mean percentage correct for each condition, on which the BISs are computed, see Table 1.

The interaction between Stimulus Type and Orientation was examined by analysis of the simple main effects with data averaged across SD and SS stimuli. This analysis revealed that the effect of Stimulus Type was significant for both upright ($t_{121} = 3.89$, $p < .001$, $M_{dif} = 0.41$ [95% CI: 0.2 – 0.62], $d = 0.35$ [95% CI: 0.17 – 0.53]) and inverted stimuli ($t_{121} = 6.76$, $p < .001$, $M_{dif} = 1.01$ [95% CI: 0.71–1.3], $d = 0.61$ [95% CI: 0.42 – 0.8]). In addition, the effect of Orientation was also significant for both line-drawings ($t_{121} = 11.76$, $p < .001$, $M_{dif} = 0.77$ [95% CI: 0.64 – 0.9], $d = 1.06$ [95% CI: 0.84–1.29]) and for silhouettes ($t_{121} = 17.67$, $p < .001$, $M_{dif} = 1.36$ [95% CI: 1.21–1.51], $d = 1.6$ [95% CI: 1.33–1.87]). Hence, and as can be seen in Fig. 3a, the interaction reflected that the effect of Orientation was larger for silhouettes than for line-drawings.

The interaction between Stimulus Type and Category was examined by analysis of the simple main effects with data averaged across upright and inverted stimuli. This analysis revealed that the effect of Stimulus Type was significant for both SD ($t_{121} = 6.97$, $p < .001$, $M_{dif} = 0.95$ [95% CI: 0.68–1.21], $d = 0.63$ [95% CI: 0.44 – 0.82]) and SS objects ($t_{121} = 3.93$, $p < .001$, $M_{dif} = 0.47$ [95% CI: 0.23 – 0.71], $d = 0.36$ [95% CI: 0.17 – 0.54]). In addition, the effect of Category was also significant for both line-drawings ($t_{121} = 12.86$, $p < .001$, $M_{dif} = 0.86$ [95% CI: 0.72 – 0.99], $d = 1.16$ [95% CI: 0.93–1.39]) and for silhouettes ($t_{121} = 15.86$, $p < .001$, $M_{dif} = 1.33$ [95% CI: 1.16–1.5],

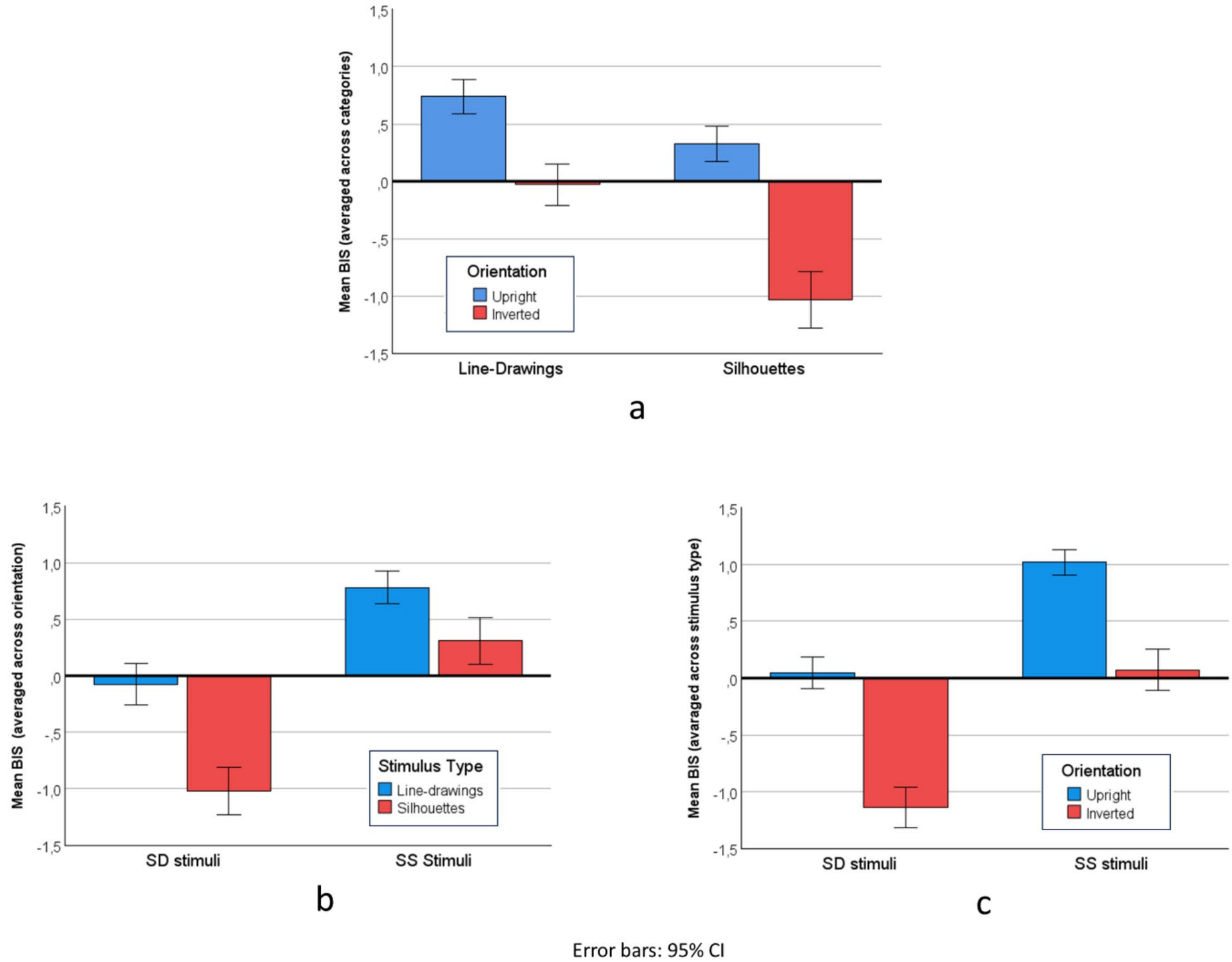

Fig. 3. (a) The mean BIS (balanced integration score) for each of the four conditions averaged over category (structurally dissimilar (SD) and structurally similar (SS) stimuli). (b) The mean BIS for each of the four conditions averaged over orientation (upright and inverted stimuli). (c) The mean BIS for each of the four conditions averaged over Stimulus Type (line-drawings and silhouettes). Error bars represent the 95% confidence interval.

$d = 1.44$ [95% CI: 1.18–1.69]). Hence, and as can be seen in Fig. 3b, the interaction reflected that the effect of Stimulus Type was larger for SD than for SS objects.

The interaction between Category and Orientation was examined by analysis of the simple main effects with data averaged across line-drawings and silhouettes. This analysis revealed that the effect of Category was significant for both upright ($t_{121} = 16.17$, $p < .001$, $M_{dif} = 0.98$ [95% CI: 0.86–1.01], $d = 1.46$ [95% CI: 1.21–1.72]) and inverted objects ($t_{121} = 13.03$, $p < .001$, $M_{dif} = 1.21$ [95% CI: 1.03–1.4], $d = 1.18$ [95% CI: 0.95–1.41]). In addition, the effect of Orientation was also significant for both SD ($t_{121} = 15.6$, $p < .001$, $M_{dif} = 1.19$ [95% CI: 1.03–1.34], $d = 1.41$ [95% CI: 1.16–1.66]) and SS objects ($t_{121} = 13.81$, $p < .001$, $M_{dif} = 0.95$ [95% CI: 0.81–1.08], $d = 1.25$ [95% CI: 1.01–1.49]). As can be seen in Fig. 3c, the interaction reflected that the effect of Orientation was larger for SD than for SS objects.

Discussion

The effect of Orientation was significant for SD objects presented as both line-drawings ($d = 0.84$) and silhouettes ($d = 1.3$) and also for SS objects presented as both line-drawings ($d = 0.79$) and silhouettes ($d = 1.04$). These results clearly confirm that sizeable inversion effects can also be found for objects[10,11].

The main effect of Stimulus Type, with less efficient processing of silhouettes than line-drawings, demonstrate that silhouetting was effective in degrading the amount of information available to support the recognition process causing recognition to become less efficient. Given that silhouetting does not affect the global shape contour but degrades information regarding parts, this shows that parts are important in the recognition of both upright and inverted objects.

The effects of Orientation and Stimulus Type also interacted reflecting that the inversion effects for both SD and SS objects were amplified by silhouetting. This confirms the prediction that inversion effects also apply to silhouettes – and can even be larger for silhouettes than for line-drawings – and thus provides support for the assumption that global shape contour is an important factor in driving the object inversion effect. It does, because the role played by parts in the recognition process is less for silhouettes than for line-drawings. Or put differently: Had the inversion effect been caused by differences between upright and inverted stimuli only in how parts were processed, the inversion effect should have diminished and not – as found here – increased when parts were degraded.

In addition to the main effects of Orientation and Stimulus Type, a main effect of Category was also found, with less efficient processing of SD compared with SS objects. This main effect was qualified by an interaction between Category and Stimulus Type with the difference between SD and SS objects being amplified by silhouetting. Given that silhouetting degrades information regarding parts, causing the recognition process to rely more on global shape contour than on parts, this particular finding is in keeping with previous experiments that have shown that global shape contour is more diagnostic of the identity of SS than of SD objects[20,30–32], and also that identification of SD objects relies more on parts than identification of SS objects[33].

Finally, the main effect of Category was also qualified by an interaction between Category and Orientation. However, contrary to the prediction based on the expertise account of inversion effects, the inversion effect was larger for SD than for SS objects. One way to account for this interaction is to assume that inversion, in addition to impairing processing of global shape contour, also impairs processing of parts. Hence, the effects of Orientation and Stimulus Type are similar in that they both impair processing of parts thus exacerbating the recognition disadvantage for SD objects relative to SS objects. For this very reason, the condition with inverted SD silhouettes is also associated with the worst performance of all eight conditions (see Fig. 2). It is worth noting, though, that the effects of Orientation and Stimulus Type seem to affect recognition of SD and SS objects in an additive fashion because the interaction between Orientation and Stimulus Type is not modulated by Category (there was no significant three-way interaction between Orientation, Stimulus Type, and Category).

The present findings are obtained with stimuli representative of common objects from a broad range of categories. Accordingly, one can argue that the stimuli represent objects people are quite familiar with. However, they do not belong to categories of expertise in the sense that the term "expertise" is used in the expertise account of inversion effects[4,12]. Here, expertise is typically used in the narrower sense to signify individuals who have acquired a lot of domain-specific knowledge that allows them to make swift within-category discriminations, as ornithologists can do with birds, cynologists with dogs or most people with faces. Consequently, inversion effects need not reflect expertise in that sense. There is, however, another sense in which one can argue that expertise might underly the inversion effect after all. As an example, compared with ornithologists most of us have little experience with individuating different types of birds. However, we are all experts in classifying whether a stimulus represents a familiar kind of object or not (e.g., a bird), which is the type of identification process that the object decision task – which was used here – requires. Considered this way, inversion effects do not necessarily reflect extensive experience with individuation of objects belonging to a particular class but rather experience with the type of identification process required. These aspects may, of course, coincide as they do for ornithologists when birds are to be classified at a subordinate level: The point is that they need not coincide. In other words, domain-specific expertise is not required for inversion effects to occur but expertise with the identification process is[10].

Conclusion

The present findings demonstrate that large inversion effects can be found for objects and even for objects that do not belong to categories of expertise. They also show that inversion effects can be large for structurally distinct objects. In fact, the inversion effects in the present study were larger for structurally distinct than for structurally similar objects. This is a novel finding that runs counter to what one would assume based on the influential expertise account of inversion effects[4,12].

The fact that large inversion effects can be found in conditions that do not fulfil any of the criteria specified by the expertise account suggests that inversion affects visual object recognition in a much more general way than previously assumed. Should the processing difference between upright and inverted stimuli reflect that inversion impairs holistic processing[5,7] – a topic that is heavily debated[34,35] – it must follow that objects are also processed holistically.

Given that the present study did not compare inversion effects for objects and faces directly, it cannot be concluded that inversion affects the two domains for the same reason. It might be that inversion effects – as originally suggested by Yin[1] – are disproportionally larger for faces than for objects, which could suggest a difference. Newer studies that directly contrasted face and object processing in contexts where the demands placed on face and object processing were on par[10], or where performance with faces and objects were equated in the upright (baseline) condition[11], however, have found comparable inversion effects for faces and objects. The findings from the present study adds further evidence in favor of similarities between inversion effects for faces and objects by showing that inversion affects processing of both parts and global shape contour in objects, just as it does in faces[13,15].

The finding that the global shape contour of objects can be a strong mediator of inversion effects is a particularly interesting and novel aspect of the present study. This suggests that inversion effects can arise even with stimuli that are not normally considered to require holistic or configural processing, as testified by individuals with integrative agnosia who struggle to recognize line-drawings of objects they can nevertheless recognize as silhouettes[18].

As noted in the introduction, the face inversion effect has been used as an index of expertise, as an index of holistic/configural processing, and as providing core evidence to support the notion that faces are processed in a domain-specific manner. The present findings do not refute any of these interpretations, but clearly show that these interpretations need further qualification, as inversion effects may also: (i) reflect the importance of global shape contour rather than – or in addition to – holistic/configural processing, (ii) be large for objects, and (iii) affect objects even outside the realm of expertise.

Data availability
Materials, data (including primary), and analysis scripts are publicly available here: https://osf.io/zxnrs/.

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Declarations

Competing interests
The authors declare no competing interests.

Ethics approval
The participants took part in the study as part of a course offered by the University of Southern Denmark, and the Author confirm that all methods were performed in accordance with its relevant guidelines and regulations. The experiments conducted do not require further formal ethical approval/registration according to Danish Law and the institutional requirements (https://researchethics.dk/information-for-researchers/overview-of-mandatory-reporting).

Consent to participate/for publication
Prior to participation the students were informed that data collected in the experiments might be used in an anonymous form in future publications. Participants were free to opt-out if they wished, and participation in the experiments was taken as consent.

Additional information
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