Distinct Computational Mechanisms Underlie Holistic Processing of Faces and Non-Face Line Patterns

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Abstract

Holistic processing is the tendency to perceive objects as unified wholes. A hallmark is the composite effect—combining the top half of one object with the bottom half of another creates a novel percept that disappears when misaligned. Although traditionally considered face-specific or expertise-based, recent findings show that even unfamiliar line patterns can be processed holistically, raising the question: Do these processes rely on similar or distinct mechanisms? To find out, we used three convolutional neural networks (CNNs)—one trained on object categorization, one trained on face identification and one untrained—and tested them with faces and line patterns, mirroring human studies. The composite effect for faces emerged only in the face-trained CNN and was disrupted by inversion, suggesting a face-specific mechanism. In contrast, line patterns elicited a composite effect across trained CNNs regardless of inversion, pointing to a domain-general process. Notably, holistic processing for faces peaked at later processing stages than for line patterns. Our results suggest that distinct mechanisms underlie holistic perception for faces and line patterns in CNNs and, we conjecture, also in the human brain.

Keywords: holistic processing, face perception, object perception, deep neural networks

Introduction

Holistic processing—binding features into a unified gestalt—is a hallmark of human face perception (Rossion, 2013; Piepers & Robbins, 2012). Recently, however, holistic processing has recently been observed in unfamiliar line patterns with strong Gestalt properties (Zhao, Bülthoff & Bülthoff, 2016). But do they rely on the same or distinct mechanisms?

Here, we used deep convolutional neural networks (CNNs) to address this question, using the composite effect as a signature measure. The composite effect occurs when identical top halves, paired with different bottom halves, are perceived as different—a phenomenon that disappears when the halves are misaligned. First, using a complete composite task design (Richler, Cheung & Gauthier, 2011), we replicated previous findings with faces and line patterns in human participants. We then examined how task optimization, processing stage and stimulus orientation affect holistic processing in CNNs, thereby probing their underlying computational mechanisms.

Methods and Results

Composite Effect in Humans. To replicate the composite effect in humans, we collected behavioral data (N=29) using stimuli from previous studies: human faces (Rossion, 2013), and line patterns (Zhao et al., 2016) (Fig. 1A). For each stimulus type, we employed a complete composite task design (Richler et al., 2011) where, in which, on each trial, two stimuli are combined in one of four conditions: A) Top and bottom halves of stimulus 1 (*same-congruent*), B) Top half of stimulus 1 with bottom half of stimulus 2 (*same-incongruent*), C) Top half of stimulus 2 with bottom half of stimulus 1 (*different-incongruent*), D) Top with bottom halves of stimulus 2 (*different-congruent*). We assessed holistic processing using two measures: 1) Higher response sensitivity in the congruent compared to incongruent condition. 2) A stronger congruency effect in the aligned compared to the misaligned condition. The composite effect index (CEI) was computed as the congruency effect in the aligned condition minus that in the misaligned condition. Each trial began with a 500 ms black screen, followed by a 200 ms presentation of the

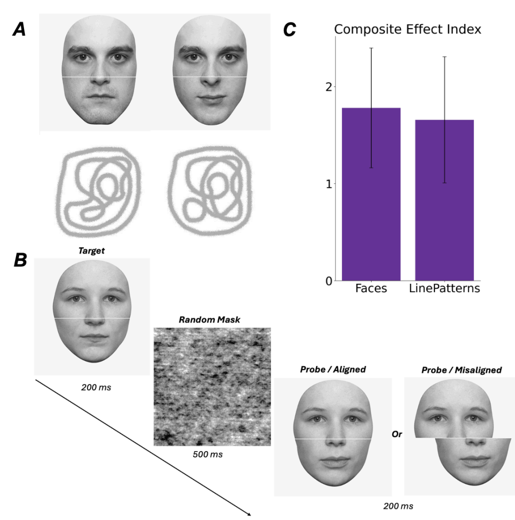

Figure 1: Overview of experimental set-up and results in humans (N=29), A) Sample stimuli, B) Sample trial, C) CEI for faces and line patterns. Error bars: SEM.

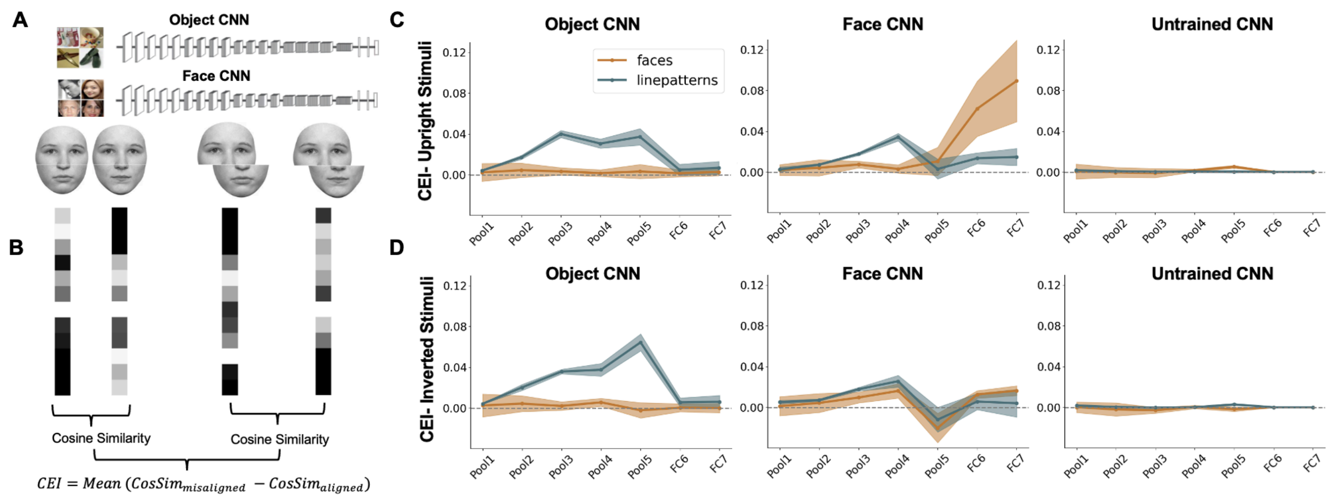

Figure 2: Overview of CEI computation and results in CNNs. A) Task-optimized CNNs, B) Computation of CEI. Layer-wise CEI in Object, Face and Untrained CNNs for upright stimuli (C), and inverted stimuli (D). Shaded areas: 95% CIs.

target stimulus, a 500 ms noise mask, and finally a 200 ms probe stimulus. Participants judged whether the top halves of the target and probe were identical (Fig. 1B).

In line with previous findings, our results showed comparable CEI for both faces and line patterns (Fig. 1C), indicating robust holistic processing in humans. We then investigated holistic processing in CNNs by asking two questions: Do CNNs process these stimuli holistically? And if they do, do the mechanisms for faces and line patterns overlap?

Composite Effect in CNNs. We tested three VGG16-based CNNs (Simonyan, 2014) Using the same stimuli as in our human experiment: one trained on 423 ImageNet object categories (Object CNN), one trained on 1,714 VGGFace2 identities (Face CNN; Fig. 2A) and one untrained (Dobs et al., 2022). We adapted the classic composite task (aligned vs. misaligned conditions) to probe holistic processing, since our CNNs were insensitive to noise and temporal dynamics. For each layer, we extracted activations from target and probe images, computed cosine similarities, and calculated the CEI as difference between aligned misaligned similarity (Fig. 2B). A higher CEI indicates stronger holistic processing, as aligned composites should evoke less similar representations if holistic integration occurs

In the Object CNN, only line patterns elicited a significant composite effect, whereas in the Face CNN both faces and line patterns did (Fig. 2C). The untrained CNN, as expected, showed no composite effect. These findings suggest that holistic processing of faces relies on a domain-specific mechanism, while line patterns are processed via domain-general mechanisms. Furthermore, holistic processing for line patterns emerged in early layers, while for faces it peaked in later layers, consistent with global configural integration (Lim et al., 2023).

We further used inversion, known to disrupt holistic processing of faces, as a control (Fig. 2D). We computed the layer-wise CEI for inverted stimuli and found that inversion disrupted holistic processing for faces but not for line patterns, reinforcing the conclusion that distinct computational mechanisms underlie the holistic processing for these stimulus types.

Conclusion

Our findings reveal a dual mechanism for holistic processing. For faces, holistic processing engages domain-specific computations, emerges in late processing stages, and is sensitive to inversion. In contrast, line patterns rely on domain-general processes, emerge in mid-level processing stages, and remain robust to inversion. These results support the existence of distinct computational mechanisms underlying holistic processing for faces and line patterns (Curby & Moerel, 2019; Curby, Huang & Moerel, 2019) and have important implications for our understanding of both artificial and biological vision systems.

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