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Attentional resources in visual tracking through occlusion: The high-beams effect ☆

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Abstract

A considerable amount of research has uncovered heuristics that the visual system employs to keep track of objects through periods of occlusion. Relatively little work, by comparison, has investigated the online resources that support this processing. We explored how attention is distributed when featurally identical objects become occluded during multiple object tracking. During tracking, observers had to detect small probes that appeared sporadically on targets, distracters, occluders, or empty space. Probe detection rates for these categories were taken as indexes of the distribution of attention throughout the display and revealed two novel effects. First, probe detection on an occluder's surface was better when either a target or distractor was currently occluded in that location, compared to when no object was behind that occluder. Thus even occluded (and therefore invisible) objects recruit object-based attention. Second, and more surprising, probe detection for both targets and distractors was always bet-

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ter when they were occluded, compared to when they were visible. This new *attentional high-beams* effect indicates that the ability to track through occlusion, though seemingly effortless, in fact requires the active allocation of special attentional resources.

Keywords: Multiple object tracking; Object-based attention; Object persistence; Inhibition; Occlusion

1. Introduction

During early stages of processing, the visual system dedicates a considerable amount of resources to recovering the three-dimensional structure of the environment that is lost on the retina during optical transmission (Marr, 1982). The resulting representations of surfaces and their occlusion relationships go on to constrain further visual processing and cognition (Nakayama, He, & Shimojo, 1995) – for instance, in visual search (He & Nakayama, 1992) and in the perception of apparent motion (He & Nakayama, 1994). This prioritization of surface representations, and the accompanying body of research exploring how these representations are constructed, can make it appear as though occlusion is a problem that is opened and closed, so to speak, quickly and early in vision. The occlusion relationships that are identified at these early stages seem to form the basis for later cognition, rather than pose a problem for later cognition.

Nearly all of this research has employed static displays, and if occlusion relationships remained stable over time, this perspective might be accurate. In the real world, however, where objects move, and where occlusion relationships are constantly in flux, this view may underestimate the extent to which occlusion presents a challenge to visual cognition. In particular, occlusion complicates the process of maintaining representations of objects as the same persisting individuals through time and motion. Such complications may require the frequent online application of extra resources to resolve, although this processing may not always be phenomenologically apparent. In the present study, we introduce a new phenomenon – *attentional high-beams* – that provides a window into the special resources that are in fact required to maintain persisting object representations through occlusion.

1.1. The problem of object persistence

Determining depth relationships in early vision involves solving a type of inverse mapping problem: three-dimensional relationships exist in the world itself, but are collapsed during optical transmission, and must then be recovered. A similar type of inverse problem characterizes the determination of object *persistence*: objects in the world maintain their identities as the same persisting individuals over time and motion, but these identity relationships are not explicit in the fragmented visual input that our eyes receive, and must be inferred for visual experience to be coherent.

Research with a variety of paradigms and phenomena has uncovered some of the principles that our visual system uses to meet this challenge. Perhaps the most central