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Allocentric time-to-contact and the devastating effect of perspective

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ABSTRACT

With regard to impending object–object collisions, observers may use different sources of information to judge time to contact (t_C). We introduced changes of the observer's vantage point to test among three sets of hypotheses: (1) Observers may use a distance-divided-by-velocity algorithm or, alternatively, elaborated τ-formulae, all of which give exact t_C information; (2) observers may use simple τ-formulae (i.e., formulae of the type: visual angle divided by its own first temporal derivative); (3) observers may capitalize on non-τ variables. Hypotheses (2) and (3) imply specific patterns of errors. We presented animated, impending collisions between a moving object and a stationary pole to naïve observers. The moving object either was a square tile or a small dot of fixed size. Participants viewed these events in a prediction-motion paradigm from different vantage points, covering a full circle around the setting. As accuracy of responses varied sinusoidally with viewing angle, irrespective of the type of object used, we conclude that observers mainly responded to the perspective view of the gap between object and pole, and less to the object's changing visual angle, or τ. Results are discussed with regard to evolutionary demands and issues of generalization.

1. Introduction

A visible egocentric trajectory connects a human observer and an external place in front of her or him, whereas an allocentric trajectory connects two places in the world, detached from the observer's station point. Here, we investigated time-to-contact judgments of impending collision events on visible, allocentric trajectories. Time-to-contact (t_C, also called time-to-collision or time-to-arrival) is the time remaining before a moving object touches another object (Knowles & Carel, 1958; Purdy, 1958; Schiff & Oldak, 1990). In physical terms, and in the absence of accelerations or decelerations, t_C is the ratio of distance and speed. In an imminent, egocentric collision encounter between a moving object and a stationary observer, the approaching object projects at an expanding visual angle (Euclid, Optics, § 5; Gibson, 1958). Lee (1974) derived mathematically that the ratio of this angle and its first temporal derivative approximately gives t_C. That ratio was later called τ (Lee, 1976).[1] Lee's (1974) analysis holds for head-on approaches along straight trajectories but can be generalized to other cases as well, including allocentric trajectories, yielding a family of elaborated τ-formulae (e.g., Bootsma & Craig, 2002: "composite τ"; Lee & Young, 1985; Tresilian, 1990: "time-to-nearest-approach"). Instead of directly using optical information, observers may attempt to reconstruct the kinematics of the collision event and apply the metric concepts of distance and velocity in order to compute t_C (Cavallo & Laurent, 1988).[2] In either of the latter two cases, and irrespective of the type of trajectory, *if* observers succeed in adequately reconstructing the event or succeed in correctly applying the complex τ-formulae, they should come up with reasonable t_C estimates. However, observers may find allocentric trajectories more difficult to judge than egocentric ones, for which performance already is far from perfect (Schiff & Detwiler, 1979). Also, observers may fall back on simplifying heuristics. These include reliance on visual angles, their changes, and rates of changes per se (Hosking & Crassini, 2011; Smith et al., 2001), and misapplication of simple instead of elaborate τ-formulae (Lee et al., 1983). Such behavior necessarily entails characteristic errors in t_C judgments. The work reported in the present paper aimed at deciding among some of

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[1] The exact definition of τ depends on the definition of visual angle (Lee & Young, 1985; cf. Tresilian, 1991; for an accepted terminology for variants of τ). In our present work, we used plane visual angles, referring to the outer, opposing edges of an object (a tile), or the facing parts of two objects (a tile and a pole), which are separated by a gap (cf. Fig. 2).

[2] Horn, Fang, and Masaki (2007) have developed a third method to compute t_C, based on an analysis of image brightness derivatives. It is not known whether such computation could be implemented in living tissue (cf. Borst & Euler, 2011; Jékely, 2009; Vaney, Sivyer, & Taylor, 2012).

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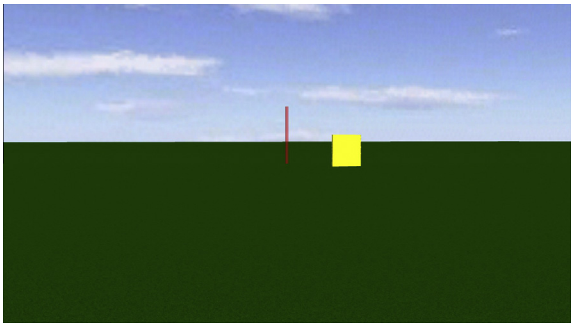

Fig. 1. Sample screenshot of the scenario. A 150 deg recession event from Experiment 1 is shown.

the aforementioned alternatives of using different sources of information for t_C estimation for allocentric object–object collisions.

By means of computer simulation, we presented impending collisions between a moving object and a stationary pole (Fig. 1). Events corresponded to observations from different vantage points, and included linear approaches and recessions, as well as frontoparallel motions of the object (Fig. 2). Schiff and Oldak (1990) have previously conducted a similar experiment. Using single-frame animated tabletop photography, a toy car appeared to move straight towards a central opening in a wooden barrier. Three or six seconds before arrival, the car disappeared and observers had to extrapolate the event – that is, estimate t_C. As seen by observers, the car either approached from behind the barrier's opening, or its trajectory was rotated to be perpendicular, or inclined at an angle of 45 deg, to the observer's cyclopean line of gaze. We elaborated on Schiff and Oldak's design by rotating our observers' virtual vantage point in steps of 30 deg full circle around our simulated setup, so as to include recession events and left–right reversals of trajectories that had not been included in Schiff and Oldak's original study. Although geometrically equivalent, left–right reversals should always be considered in studies of ego movement or object motion because observers' perception and performance is often better when motion vectors coincide with the direction of writing and reading (cf. McManus, 2002). The necessity to consider several oblique trajectories derives from the need to assess performance outside the typically used cases of sagittal and frontoparallel motion, for which qualitative heuristics may exist.

In Schiff and Oldak's (1990) experiment, t_C judgments were much too early for observer-centered approaches, generally still ahead of time for oblique trajectories, and fairly accurate or even too late for transverse ones (at least for the shorter extrapolation time used). Although the authors considered an evolutionary explanation as well as the use of different strategies of information processing to account for this pattern of results, with reference to Hills (1980), they eventually favored a simpler explanation in terms of available information and thresholds (W. Schiff, personal communication to K. Landwehr, August 28, 1991): Typically, the change of the visual angle that refers to the gap between object and goal is much more pronounced during lateral motion than is the change of the visual angle that refers to the object during head-on approach.

Bootsma and Oudejans (1993), who studied object–object collisions by letting two outline squares move towards a common finish line, detailed the optical information alluded to by Schiff and Oldak (1990) in terms of τ-variables.[3] In their experiments,

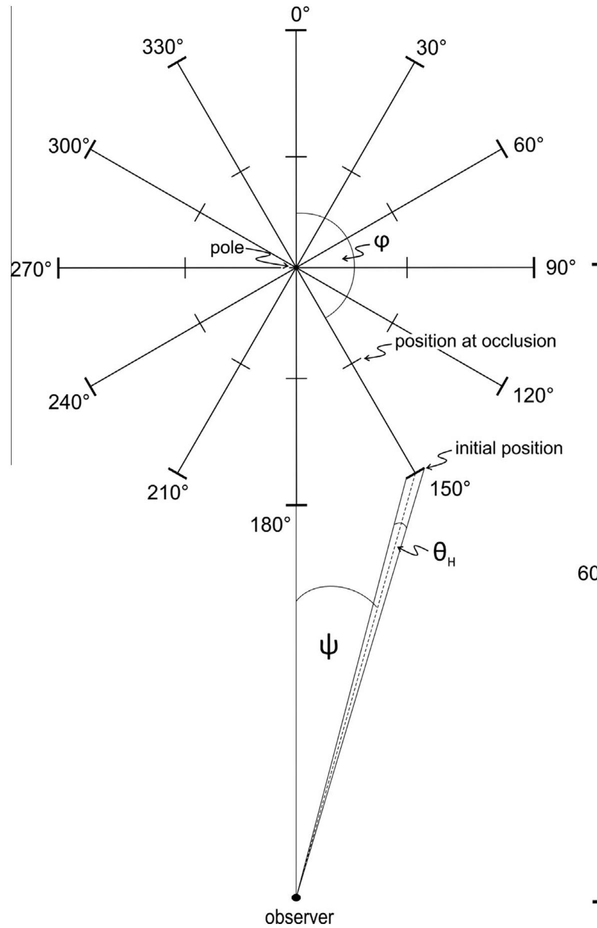

Fig. 2. Bird's-eye view of simulated scenery. The drawing is to scale for d = 22.5 m (cf. Table 1). ψ = visual angle of the gap between center of moving object and stationary pole. θ_h = horizontal visual angle of the tile. θ_v, the vertical visual angle of the tile, cannot be shown in this ground-floor plan. φ = angle between observers' cyclopean line of gaze and the object's trajectory (here, an angle of 150 deg is marked). The scenery can also be interpreted to consist of a single trajectory with the observer moving around the setting along a circular path.

using a two alternative forced choice (2AFC) paradigm, Bootsma and Oudejans (1993) found poorer performance on recession trials, as well as on trials that mixed different trajectories, as compared to frontoparallel motion. Observed distributions of errors suggested that observers put different weights on the two classes of visual angles, preferring the one that displayed the maximum nonlinear change – which, for purely geometrical reasons, is the gap angle during recession (p. 1051). Although Bootsma and Oudejans incorporated three cardinal types of trajectories in their design (approach, recession, and frontoparallel passage), only five different orientations were used, four of which were intentionally confounded with the objects' travel speed to yield identical contact points with the finish line. Also, Bootsma and Oudejans' scenario was much sparser than Schiff and Oldak's (1990), and the use of two objects instead of one posed a quite different task (relative versus absolute prediction; cf. Lugtigheid & Welchman, 2011; Tresilian, 1995, for comparative evaluations; Hancock & Manser, 1997; for an alternative occlusion paradigm). We therefore decided to extend the presently described previous work on object–object collisions within a unitary realistic setting and experimental paradigm.

A more specific aim of our present work was to answer Bootsma and Oudejans' (1993) question to which degree, if at all, observers base t_C judgments for object–object collisions on

[3] Bootsma and Oudejans (1993) and later, Bootsma and Craig (2002), defined "generalized τ", or "composite τ", in a way that puts two τ-variables, one referring to a moving object and one referring to the gap between object and goal, into a single formula (cf. Calabro, Beardsley, & Vaina, 2011, for an empirical test). We did not follow Bootsma et al.'s derivations because we were interested in separating the effects of gap- and object-related information.