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Transportation Research Procedia 2 (2014) 69 – 76

Transportation Research Procedia

www.elsevier.com/locate/procedia

The Conference on Pedestrian and Evacuation Dynamics 2014 (PED2014)

Behavioral dynamics of heading alignment in pedestrian following

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Abstract

The collective behavior of crowds is thought to emerge from local interactions between pedestrians. One widely assumed interaction is heading alignment. We tested four dynamical models of alignment against human data from pairs of pedestrians. A "follower" walked with a "leader" while head trajectories were recorded. In the simplest model, the follower's angular acceleration is proportional to the sine of the heading difference (r=0.71); additional damping or delay parameters did not improve the fit. We conclude that alignment is controlled by nulling the heading difference. The results provide a cognitively-grounded model of alignment that may be generalized to larger crowds.

Peer-review under responsibility of Department of Transport & Planning Faculty of Civil Engineering and Geosciences Delft University of Technology

Keywords: cognitive science; crowd dynamics; experimental data; pedestrian following; visual control

1. Introduction

Crowds of pedestrians are able to walk together with seemingly little effort, yet they often exhibit global patterns of coherent motion. Similar collective behavior across many species is thought to emerge from local interactions between individuals, according to principles of self-organization. Numerous theoretical models have been proposed to account for these swarm dynamics, often predicated on different assumptions (for reviews, see Couzin and Krause (2003); Schellinck and White (2011); Vicsek and Zafeiris (2012)). Common to many of these models is a set of local rules or forces that serve to coordinate the speed and direction (heading) of individual motion. For example, Self-Propelled Particle models (Czirók and Vicsek (2000)) assume that an individual matches the mean motion direction of all neighbors within a given radius while speed is equated, whereas distance-based models seek to maintain a

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Peer-review under responsibility of Department of Transport & Planning Faculty of Civil Engineering and Geosciences Delft University of Technology
doi:10.1016/j.trpro.2014.09.010

constant distance from neighbors (Breder (1954)), and other models are various combinations of the two (Couzin et al. (2002); Reynolds (1987)).

However, relatively few models are based on evidence about the local rules that actually govern pedestrian or animal interactions. A key theoretical finding points out that the same pattern of collective motion can be generated by different rule sets (Vicsek and Zafeiris (2012)). Consequently, formal models may successfully reproduce global patterns yet fail to capture the underlying mechanisms; moreover, this result underscores the difficulty of inferring local rules from observational data on flocks, schools and crowds (Sumpter et al. (2012)). Experiments on local interactions are thus necessary to decipher the perceptual coupling between neighbors, in order to formulate cognitively-grounded models of collective behavior (Moussaïd et al. (2011); Ondrej et al. (2010); Weitz et al. (2012)).

The behavioral dynamics framework (Warren (2006)) offers such an experimental approach to collective behavior. Individual locomotor behaviors and pedestrian interactions are studied in the lab and modeled as simple dynamical systems (Fajen and Warren (2003); Fajen and Warren (2007)), which are then linearly combined to generate more complex behavior (Warren and Fajen (2008)). The perceptual coupling between pedestrians is formulated as a control law that guides the behavior. We are currently developing this approach to account for collective crowd behavior (Bonneaud et al. (2012); Bonneaud and Warren (2012); Rio et al. (2014)).

The goal of the present study is to investigate a critical component of collective motion: how an individual aligns their heading with a neighbor to yield a common motion direction. First, we set up an experimental paradigm in which pairs of pedestrians walked together, either following or side-by-side. The designated leader made a sequence of unpredictable turns while head trajectories were recorded. We then compared four dynamical models of the follower's change in heading as they turned to align with the leader. The result is a simple cognitively-grounded model of heading alignment that may be generalized to multiple neighbors in a crowd.

2. Experiment

In the experiment, we recorded a "follower" walking either behind or beside a designated "leader". On each trial, the leader made two turns over about 20m. We manipulated the turn sequence (LR, RL, LL, RR) and initial interpersonal distance (1, 2, 4m), while the turn magnitude and timing varied at will. The time series of leader and follower head positions were analysed to estimate the coupling strength and time delay, and provide data for subsequent model testing.

2.1. Methods

Participants. 12 undergraduate students recruited from Brown University, 5 female and 7 male, participated in this experiment as part of a longer test session.

Apparatus. The experiment was conducted in a large hall (14.5 x 22.3m) at Brown University. Sixteen infrared motion capture cameras (Qualisys, Deerfield, IL) were placed around a 12 x 20m tracking area and used to record head position at a sampling rate of 60 Hz. Each participant wore a lightweight bicycle helmet with 5 passive reflective markers on protruding stalks in a unique configuration, so each helmet could be identified.

Procedure. The Following and Side-by-Side (SBS) scenarios were presented in separate blocks. In each block, one participant was designated as the "leader" and the other participant as the "follower." The leader was trained and performed two practice trials before the follower entered the hall. The follower was instructed to walk together with the leader and stay with them if they changed direction, while maintaining a constant distance. On each trial, the participants walked to starting marks on the floor that specified the initial interpersonal distance (1, 2, or 4 m). The leader received covert written instructions about the turn sequence: Left-Right (LR), Right-Left (RL), Left-Left (LL), or Right-Right (RR). To initiate the trial, the experimenter gave a verbal "begin" command to both participants, who started walking forward. The leader then made two turns while walking about 20 m across the hall, varying the timing and magnitude of each turn at will. The four turn sequences and three initial distances were presented once in a random order, yielding 12 trials per block.