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Collision avoidance between two walkers: Role-dependent strategies

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ABSTRACT

This paper studies strategies for collision avoidance between two persons walking along crossing trajectories. It has been previously demonstrated that walkers are able to anticipate the risk of future collision and to react accordingly. The avoidance task has been described as a mutual control of the future distance of closest approach, MPD (i.e., Mininum Predicted Distance). In this paper, we studied the role of each walker in the task of controlling MPD. A specific question was: does the walker giving way (2nd at the crossing) and the one passing first set similar and coordinated strategies? To answer this question, we inspected the effect of motion adaptations on the future distance of closest approach. This analysis is relevant in the case of collision avoidance because subtle anticipatory behaviors or large last moment adaptations can finally yield the same result upon the final crossing distance. Results showed that collision avoidance is performed collaboratively and the crossing order impacts both the contribution and the strategies used: the participant giving way contributes more than the one passing first to avoid the collision. Both walkers reorient their path but the participant giving way also adapts his speed. Future work is planned to investigate the influence of crossing angle and TTC on adaptations as well as new types of interactions, such as intercepting or meeting tasks.

1. Introduction

Collision-free walking requires avoiding static and moving obstacles and, more specifically, other walkers. Collision avoidance can be described as a kinematic motion control problem with two main aspects: the visual information taken and the motion adaptations performed by walkers. Previous studies [1,2] focused on the nature of visual information taken by walkers to answer two questions: is there a risk of future collision, and when may collision occur? Cutting et al. [1] showed that by-pass or collision can be predicted up to 10 s before contact based on gaze movement angle. When a future collision is detected, walkers can estimate the time-to-contact (TTC). TTC can be indicated by the optical variable tau [3–5], by the binocular disparity alone [6] or combined with retinal information [7]. TTC estimation gets more accurate as the contact time gets closer [8].

Collision avoidance is also related to the notion of *personal space*, defined as an area around walkers which is maintained free thanks to some collision avoidance *adaptations* [9]. Stepping over [10–12] or circumventing [13–15] of static obstacle(s) was studied. Some work focused on passive moving obstacles, such as a mannequin mounted on a rail [9,16,17]. Various context-dependent strategies were observed. When walking participants meet mannequins following a 45° colliding paths, they adapt their motion both in the antero-posterior and medio-lateral planes [9]. When a participant and a mannequin are walking face-to-face, a 2-step avoidance strategy is observed: first, a change in *heading* and second, an adjustment of *walking speed* [17]. Interestingly, the initiation of adaptations is performed at a constant distance from the obstacle whatever the obstacle velocity [17]. Moreover, obstacle velocity influences the lateral rate of change of the walker's trajectory [16]: the slower the velocity, the lower the lateral rate of change. Finally, interactions between a walker and the environment were modeled as coupled dynamical systems [18–20]. Heading is adapted according to the distance and the angle to stationary goals and obstacles.

However, few studies considered interactions between two human walkers [21–23]. Ducourant et al. [21] focused on leader-follower interactions between two participants walking back and forth, face to face. van Basten et al. [22] investigated the effect of gender and height on face-to-face situations of avoidance. More

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recently, the case of two humans walking along 90° colliding paths was studied [23]. Analysis was based on the Minimal Predicted Distance (MPD), which is the future distance of closest approach between two walkers if they continue walking straight and at constant speed: it is deduced by linearly extrapolating future trajectories from each walker's current position, heading and speed. The change of MPD in time showed that walkers adapt their trajectories only when MPD is initially low (<1 m). This shows the ability to predict future risks of collision and to react accordingly. Also, collision avoidance can be described as the task of mutually controlling MPD. Experimental observation of the temporal evolution of MPD(t) showed that collision avoidance presents 3 successive phases: the observation phase (low MPD) is followed by a reaction phase (MPD is increased to an acceptable value) and a regulation phase (the acceptable value is maintained). When the regulation phase starts, the avoidance is solved and then carried out: avoidance is performed with anticipation. The change of MPD in time is necessarily due to motion adaptation (non-linear trajectories), but how MPD(t) is individually controlled still needs analysis.

The purpose of the current study was to analyze collision avoidance adaptations between two walkers. In addition we explored the strategy (speed and/or heading adaptations) set by walkers to avoid future collisions. When do these adaptations take place? Is this avoidance task solved collaboratively?

We addressed these questions from several new perspectives. First, adaptations were quantified in terms of their *effect* on the future crossing distance. Second, we inspected the effect of the participants' *crossing order* (i.e., who is first, who gives way) on their individual avoidance strategy. Indeed, the participant giving way has the participant passing first in front of him/her, and the participant passing first has the second one to his/her side or behind him/her (Fig. 1). This asymmetric configuration leads us to emphasize asymmetric adaptations for collision avoidance. Indeed, as suggested by Gérin-Lajoie et al. [9], personal space has an elliptic shape. Collision risk should be perceived as being higher when the walker to avoid is in front compared to the side and therefore it should induce different avoidance adaptations

2. Materials and methods

2.1. Participants

Thirty participants (11 women and 19 men) volunteered for this experiment. They were 26.1 years old (±6.9) and 1.74 m tall (±0.09).

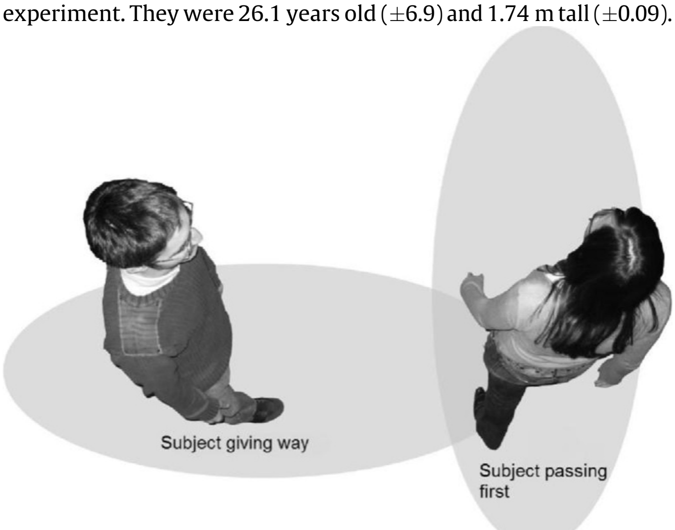

Fig. 1. Personal space configurations while crossing by extension of the results of Gérin-Lajoie et al. [9] on the elliptic shape of personal space.

They had no known vestibular, neurological or musculo-skeletal pathologies which would affect their locomotion. They had normal or corrected to normal vision. Participants gave written and informed consent before their inclusion and the study conformed to the Declaration of Helsinki.

2.2. Experimental protocol and apparatus

We asked participants to go from one corner to the opposite corner of a 15 m × 15 m square experimental area (Fig. 2A). There were five groups of six participants. Each participant interacted with each of the five other ones. Each participant performed 30 trials, (i.e., 6 interactions with each of the other participants). Therefore, the total number of trials performed, accounting for all paired interactions, was 450. However, 30 trials were suppressed because of motion reconstruction problems. Participants had neither instruction nor restriction about their gait speed and path. We synchronized their start signals to induce risks of collision. The presence of occluding walls prevented participants from seeing each other before reaching their comfort speeds. At visual contact, participants were about 6 m from the center of the area. This study focused on a subset of 260 trials for which an actual risk of collision was measured: risk of collision is true when the Minimal Predicted Distance (MPD) is smaller than one meter at visual contact as defined by Olivier and colleagues [23].

2.3. Analysis

3D kinematic data were recorded using the Vicon-MX system (120 Hz), reconstruction was performed using Vicon-IQ (Oxford Metrics®) and computations using Matlab (Mathworks®). We approximated participants' position by the middle of their shoulders (acromions). In the aim of computing MPD (see below) and to correctly estimate current speed and orientation, we filtered the stepping oscillations by applying a Butterworth low-pass filter (3rd order, dual pass, 0.5 Hz cutoff frequency). Velocity was computed as the discrete time derivative of the mid-shoulders position in the horizontal plane.

We computed *tsee*, *tcross* and *dmin* from experimental data as defined in [23] (Fig. 2A). (1) *tsee* is the time-value when participants are able to see each other, with respect to occluding walls geometry. (2) *dmin* is the actual minimum distance measured between participants. (3) *tcross* is the time-value when the distance dmin is reached by participants.

2.4. Minimal Predicted Distance

We computed Minimal Predicted Distance (MPD) as defined in [23]. MPD(t) is, at time t, the prediction of the future distance of closest approach between participants if they do not perform adaptation and keep their velocity vector constant.

MPD(*tsee*) is the predicted distance of closest approach at time *tsee*, when participants are able to have visual contact. MPD(*tsee*) varied in experimental data due to the variability in reaction time to the start signal and comfort speed among participants. Olivier and colleagues [23] showed that motion adaptations are observed during interaction only when MPD(*tsee*) was low (smaller than 1 m). We selected trials in which MPD(*tsee*) was smaller than 1 m to focus our study on data actually containing motion adaptations.

2.5. Temporal segmentation

It was shown that collision avoidance can be decomposed into 3 successive phases: observation, reaction and regulation [23]. Our study focused on adaptation strategy which occurs in the reaction phase. Thus, we considered the central portion of data where 80%