Gait & Posture 60 (2018) 188–193

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

How do walkers behave when crossing the way of a mobile robot that replicates human interaction rules?

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ARTICLE INFO

Keywords:
Human-robot interaction
Locomotion
Collision avoidance
Gait adaptation
Mobile robot

ABSTRACT

Previous studies showed the existence of implicit interaction rules shared by human walkers when crossing each other. Especially, each walker contributes to the collision avoidance task and the crossing order, as set at the beginning, is preserved along the interaction. This order determines the adaptation strategy: the first arrived increases his/her advance by slightly accelerating and changing his/her heading, whereas the second one slows down and moves in the opposite direction. In this study, we analyzed the behavior of human walkers crossing the trajectory of a mobile robot that was programmed to reproduce this human avoidance strategy. In contrast with a previous study, which showed that humans mostly prefer to give the way to a non-reactive robot, we observed similar behaviors between human-human avoidance and human-robot avoidance when the robot replicates the human interaction rules. We discuss this result in relation with the importance of controlling robots in a human-like way in order to ease their cohabitation with humans.

1. Introduction

In everyday life, we walk by constantly adapting our motion to our environment. In past work, the relation between the walker and the environment was modeled as a coupled dynamical system. The trajectories result from a set of forces emitted by goals (attractors) and obstacles (repellers) [17]. Collision avoidance between pedestrians has also received a lot of attention either using front-on [3] or side-on approach trajectories [7,8,11,12]. Olivier et al. showed that walkers adapt their trajectory only if a future risk of collision exists [11]. This adaptation depends on the order of arrival of pedestrians that defines their order of passage. The first walker that arrives maintains or increases his/her advance by slightly accelerating and changing his/her direction to move away from the other participant. The second one slows down and moves in the opposite direction to reduce the risks of a collision. Huber et al. focused on how trajectories are adapted using speed and heading modifications depending on the crossing angle [7]. Future crossing order (who is about to give way or pass first) is quickly and accurately perceived and preserved until the end of the interaction [8,12]. This shows that walkers take efficiency into account since an inversion of the crossing order would result in suboptimal adaptations of higher amplitude. In addition, it was shown that the participant giving way contributes more to solving the collision avoidance [12]. Finally, behavior is influenced by the number of pedestrians to interact with and the potential to have social interactions with them [3].

Because humans and robots will have to share the same environment in the near future [5,9], recent studies focused on tasks involving walkers and a moving robot. Vassallo et al. [16] performed an experiment in which participants had to avoid collision with a passive wheeled robot (moving straight at constant speed), crossing perpendicularly their direction. In contrast to a human-human interaction, several inversions of the crossing order were observed, even though this behavior was not optimal. Such a behavior was observed when the walker arrived ahead of the robot with a predictable future crossing distance between 0 and 0.6 m but, despite this advance, finally gave way. This result was linked to the notion of perceived danger and safety, and to the lack of experience of interacting with such a robot.

Because of its design, the main limitation of Vassallo et al. study [16] was its inability to conclude whether the modification of the walker behavior was due to the lack of adaptability of the moving

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https://doi.org/10.1016/j.gaitpost.2017.12.002
Received 4 May 2017; Received in revised form 29 November 2017; Accepted 1 December 2017
0966-6362/

obstacle or solely to its artificial nature. Nonetheless, it was shown in [15] that the robot trajectory can be read and understood by humans in a task where a robot moves towards a human to initiate a conversation based on an approach linked to public and social distances. Furthermore, in a face-to-face task with a moving robot, humans behave similarly whether they are told or not what the robot trajectory will be [1], showing their ability to actually read the robot motion.

Given these results, the question addressed in this paper is: "How would humans behave if they have to cross the trajectory of a robot programmed to replicate the observed human-human avoidance strategy?" Would humans understand that the robot adapts its trajectory and then adapt their own strategy accordingly, or would they give way to the robot as observed in [16]?

2. Materials and methods

2.1. Participants

Ten volunteers participated in the experiment (2 women and 8 men). They were 28.8 (± 9.5) years old and 1.77 m tall (± 0.12). They had no known pathology that could affect their locomotion. All of them had normal or corrected sight and hearing. All participants were naïve to the studied situation. Participants gave written and informed consent before their inclusion in the study. The experiment conformed to the Declaration of Helsinki, with formal approval of the ethics evaluation committee of INSERM (IRB00003888, Opinion number 13-124), Paris, France (IORG0003254, FWA00005831).

2.2. Apparatus

The experiment took place in a 40 m × 25 m gymnasium. The room was separated into two areas by 2 m high occluding walls forming a gate in the middle (Fig. 1). Four specific positions were defined: the participant starting position PSP, the participant target PT, and two robot starting positions RSP1 and RSP2, to generate situations where the robot approached from the right or from the left of the participants. Two virtual guidelines r_a and r_b, parallel to the line (RSP1, RSP2) and respectively located at a distance of 0.5 m and 1.0 m from the gate, were used as reference for guiding the robot to pass behind or ahead the participant during the avoidance phase. A specific zone between PSP and the gate was named Motion Estimation Zone (MEZ), far enough from PSP to let the participants reach their comfort velocity before they entered the MEZ. The intersection point between the robot and the initial path of the participant was named Hypothetical Crossing Point (HCP) as this is the point where the participant and robot would cross if they do not modify their trajectory.

2.3. Task

Participants were asked to walk at their preferred speed from PSP to PT passing through the gate. They were told that a robot could be moving beyond the gate and could obstruct them, meaning that the robot could adapt its trajectory according to the participants' one. One experimental trial corresponded to one travel from PSP to PT. We defined t_{see}, the time at which the participant passed through the gate and saw the robot moving, and t_{cross}, the time of closest approach, when the human-robot distance was minimal (i.e., the "distance of closest approach"). The crossing configuration and the risk of future collision were estimated using the Signed Minimal Predicted Distance, noted smpd, which gives, at each time step, the future distance of closest approach if both the robot and the participant keep a constant speed and direction [16]. A variation of smpd means that the participant or/and the robot are performing adaptation. The sign of this function depends on who, between the participant and the robot, is going to pass first: positive if it is the participant and negative otherwise. A change of smpd sign means a switch of the future crossing order.

2.4. Recorded data

3D kinematic data was recorded using a 16 infrared cameras motion capture Vicon-MX system (120 Hz). Reconstruction was performed with Vicon-Blade and computations with Matlab (Mathworks®). The global position of participants was estimated as the centroid of the reflective markers set on a helmet they were wearing. The stepping oscillations were filtered out by applying a Butterworth low-pass filter (2nd order, dual pass, 0.5 Hz cut-off frequency).

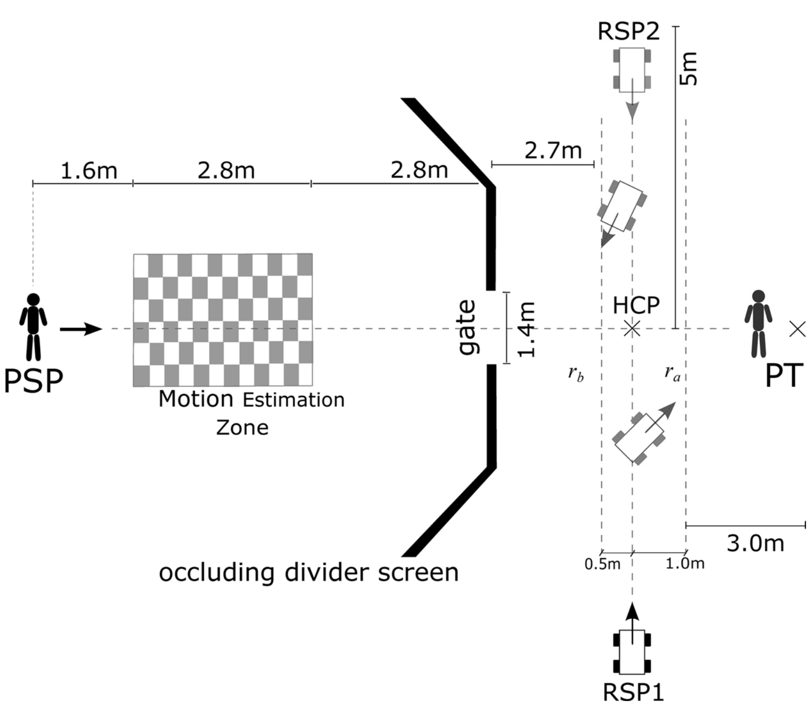

Fig. 1. Experimental apparatus and task. The robot moves from RSP1 to RSP2 (or vice versa), following the lateral path r_b or r_a to pass respectively behind or ahead the participant.