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How do walkers avoid a mobile robot crossing their way?

Christian Vassallo[a,b], Anne-Hélène Olivier[c], Philippe Souères[a,b], Armel Crétual[c], Olivier Stasse[a,b], Julien Pettré[d,*]

[a] CNRS, LAAS, 7 Avenue du colonel Roche, F-31400 Toulouse, France
[b] Univ de Toulouse, LAAS, F-31400 Toulouse, France
[c] M2S lab (Mouvement Sport Santé), University Rennes 2 - ENS Rennes - UEB, Avenue Robert Schuman, Campus de Ker Lann, 35170 Bruz, France
[d] Inria Rennes, Centre de Rennes Bretagne Atlantique, Campus universitaire de Beaulieu, 35042 Rennes, France

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ABSTRACT

Robots and Humans have to share the same environment more and more often. In the aim of steering robots in a safe and convenient manner among humans it is required to understand how humans interact with them. This work focuses on collision avoidance between a human and a robot during locomotion. Having in mind previous results on human obstacle avoidance, as well as the description of the main principles which guide collision avoidance strategies, we observe how humans adapt a goal-directed locomotion task when they have to interfere with a mobile robot. Our results show differences in the strategy set by humans to avoid a robot in comparison with avoiding another human. Humans prefer to give the way to the robot even when they are likely to pass first at the beginning of the interaction.

1. Introduction

Robots and humans will have to share the same environment in a near future [6,11]. To this end, roboticists must guarantee safe interactions between robots and humans during locomotion tasks. In this direction, the following paper studies how humans behave to avoid a mobile robot crossing their way.

There is an extensive literature describing how walkers avoid collisions. Several studies considered how walkers step over [16] or circumvent [18] static obstacles. More recent ones focused on how humans avoid each other. It was shown that walkers are able to predict the risk of collision since they adapt their motion only if the future crossing distance is below a certain threshold [13]. This future distance is increased before the crossing point and maintained constant during a regulation phase, demonstrating anticipation in avoidance [13]. Trajectory adaptations are performed both in speed and orientation [8,14]: they depend on the crossing angle and the walking speed [7]. These strategies do not maximize smoothness [1], they result from a compromise between safety and energy [8]. Moreover, these adaptations depend more on situations than personal characteristics [10].

The crossing order during collision avoidance is an interesting parameter to consider. Indeed, it has been shown that trajectory adaptations are collaboratively performed [13] but are role-dependent. The walker giving way (2nd at the crossing) contributes more than the one passing first. This role attribution appears to contribute positively before the interaction [10,14] and can be predicted with 95% confidence at 2.5 m before crossing, even before any adaptation [10].

Studies resulted into simulation models of navigation and interaction. Warren and Fajen [20] proposed to model the walker and the environment as coupled dynamical systems: the walker paths result from all the forces acting on them, where goals are considered as attractors and obstacles as repellors. This model is based on the distance to the goal and to the obstacles as well as the sign of change of the bearing angle. An integration of the bearing angle theory into some artificial vision system for crowd simulation was proposed by Ondrej et al. [15].

These studies reached common conclusions about the human ability to accurately estimate the situation (crossing order, risk of collision, adaptations), and considered interactions with a moving object. The kinematics of adaptation by a walker avoiding a moving obstacle (a mannequin mounted on a rail) are studied in [3,5]. Trajectories crossing at 45° resulted into adaptations both in the antero-posterior and medio-lateral planes, with successive anticipation and clearance phases [5]. Analysis is based on the notion of

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* Corresponding author at: Inria, Campus de Beaulieu, 263 avenue du Général Leclerc, 35042 Rennes, France.

E-mail addresses: cvassall@laas.fr (C. Vassallo), anne-helene.olivier@univ-rennes2.fr (A.-H. Olivier), soueres@laas.fr (P. Souères), armel.cretual@univ-rennes2.fr (A. Crétual), ostasse@laas.fr (O. Stasse), julien.pettre@inria.fr (J. Pettré).

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personal space modeled as a free elliptic area around walkers. When trajectories are collinear (the mannequin comes from front), a 2-step avoidance strategy is observed: participants first adapt their locomotion in heading, followed by speed [3]. These experiments with mannequins were not designed to study the question of the crossing order (either participants were forced to give way, or there is order in a collinear situation). Other studies investigated human interactions with robots. It was shown that it is easier to understand and predict the behavior of robots if they are human-like [2,12]. Some studies demonstrated that human-like behaviors [4,9] improve on many levels the performance of human-robot collaboration. Nevertheless, the benefit of programming a robot with human-like capabilities to move and avoid collision with a human walker has not been demonstrated yet.

In this paper, we use a robot to interfere with a pedestrian. We control the robot to reproduce similar kinematic conditions of interaction than the ones studied in [13] (in terms of relative angle, position, and velocity) and apply a similar analysis. While the nature of the interaction is changed, we show differences in the strategies set by participants with respect to previous observations.

2. Materials and methods

2.1. Participants

Seven volunteers participated in the experiment (1 woman and 6 men). They were 26.1 (±5.4) years old and 1.78 m tall (±0.21). They had no known vestibular, neurological or muscular pathology that would affect their locomotion. All of them had normal or corrected sight and hearing. Participants gave written and informed consent before their inclusion in the study. The experiments respect the standards of the Declaration of Helsinki (rev. 2013), with formal approval of the ethics evaluation committee Comité d'Evaluation Ethique de l'Inserm (IRB00003888, Opinion number 13–124) of the Institut National de la Santé et de la Recherche Médicale, INSERM, Paris, France (IORG0003254, FWA00005831).

2.2. Apparatus

The experiment took place in 40 m × 25 m gymnasium. The room was separated in two areas by 2 m high occluding walls forming a gate in the middle (Fig. 1). Four specific positions were identified: the participant starting position PSP, the participant target PT, and two robot starting positions RSP1 and RSP2. A specific zone between PSP and the gate is named Motion Estimation Zone MEZ. MEZ is far enough from PSP for the participants to reach their comfort velocity before entering the MEZ. The point of intersection between the robot path [RSP1, RSP2] and the participant path [PSP, PT] is named Hypothetical Crossing Point HCP. It is computed by hypothesizing that there is no adaptation of the participant trajectory.

2.3. Participant task

Participants were asked to walk at their preferred speed from PSP to PT by passing through the gate. They were told that an obstacle is moving over the gate and could interfere with them. One experimental trial corresponds to one travel from PSP to PT.

2.4. Recorded data

3D kinematic data were recorded using the motion capture Vicon-MX system (120 Hz). Reconstruction was performed using Vicon-Blade and computations using Matlab (Mathworks®). The experimental area was covered by 15 infrared cameras. The global position of participants was estimated as the middle point of reflective markers set on the shoulders (acromion anatomical landmark). The stepping oscillations were filtered out by applying a Butterworth low-pass filter (2nd order, dual pass, 0.5 Hz cut-off frequency).

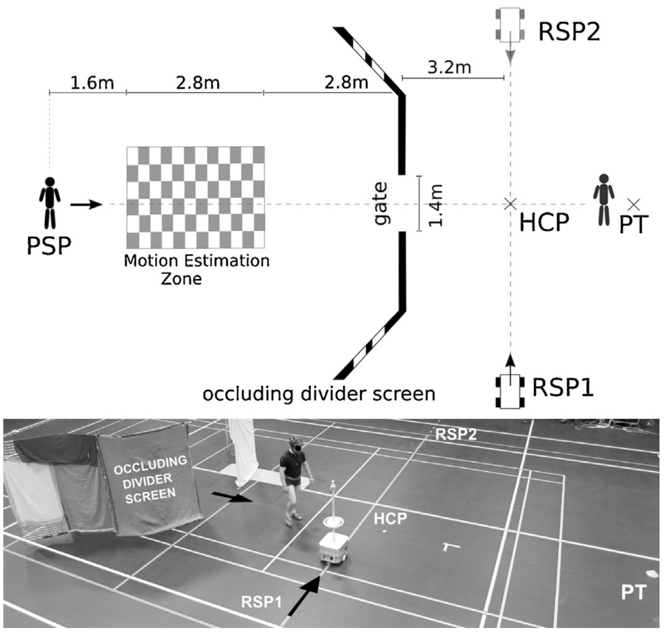

Fig. 1. Experimental apparatus and task. In this trial the robot was moving from RSP1 to RSP2. Participant decided to pass behind the robot.

2.5. Robot behavior

We used *RobuLAB10* robot from the *Robosoft* company (dimension: 0.45 × 0.40 × 1.42 m, weight 25 kg, maximal speed $\sim 3\,\mathrm{m\,s^{-1}}$). The robot position was detected as the center point in its base. We programmed the robot to execute a straight trajectory between RSP1 and RSP2 at constant speed ($1.4\,\mathrm{m\,s^{-1}}$). The robot was controlled to generate specific interactions with the participant. In particular, the robot was either: a) on a full collision course (reach HCP at the same time than the participant), b) on a partial collision course (the robot reaches HCP slightly before or after the participant), or c) not on a collision course. To this end, we measured the participant's speed through MEZ and estimated the time *t_hcp* when HCP was reached. We deduced the time *t_rs* at which the robot should start to reach HCP at *t_hcp*. We finally added an offset Delta to *t_rs*, randomly selected from the range [−0.6, 0.6 s], to create the desired range of interactions.

2.6. Experimental plan

Each participant performed 40 trials. Robot starting position (50% in RSP1, 50% in RSP2) was randomized among the trials. To introduce a bit of variability, in 4 trials the robot did not move and the participant did not have to react. Only the 36 trials with potential interaction were analyzed.

3. Analysis

3.1. Kinematic data

For each trial we computed *t_rob*, the time at which the robot reaches its constant cruise speed (when the acceleration