Modeling physical interactions in human crowds: a pilot study of individual response to controlled external pushes

Thomas Chatagnon, Anne-Hélène Olivier, Ludovic Hoyet, Julien Pettré, Charles Pontonnier

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T. Chatagnon[a*], A-H. Olivier[a], L. Hoyet[a], J. Pettré[a], C. Pontonnier[a].

[a] *Univ Rennes, Inria, CNRS, IRISA, M2S, France*

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1. Introduction

Dense crowds are complex environments in which obtaining meaningful metrics to understand and predict general behavior can be really challenging. Modelling such phenomena requires to consider local interactions such as local contacts and resulting motion. Dense crowds are generally found in cultural, social or religious events (concerts, pilgrimages, giant sales...) in which many stimuli (pushes) may come from many directions on individuals, resulting in large motions of the crowd that can have tragic outcomes. At the same time, individuals may be focused on many other cognitive distractions (e.g. music, video) that may affect their response to these stimuli.

Following works on push recovery and on reaction to external perturbations (Robert et al. 2018), we aimed at relating the response of a subject to external perturbations for several situations, including potential distractions (by controlling the availability of some of their sensory inputs).

2. Methods

2.1 Description of the experiment

A female participant (27yo, 54kg, 1.66m) was asked to stand still and relaxed in a straight position (no other instruction was given) while an experimenter applied a pushing force on her back using a wooden stick ended with a flat steel plate.

We manipulated the following factors:

- Location and angle of the force applied (as detailed in Figure 1). It has been decided to use symmetrical pushing positions on the back of the participant in order to evaluate any effect due to laterality.
- Intensity ranges of the forces: Low, Medium, High. These intensity ranges were qualitative information for the experimenter. The ideal behind this choice was to have a comparable range of forces for each location.
- Availability of participant's sensory input
  - VH: Vision + Hearing available
  - VNH: Vision + No Hearing
  - NVH: No Vision + Hearing
  - NVNH: No Vision + No Hearing

One trial corresponded to one push in the transverse plane (Figure 1). The experiment was performed by blocks of sensory input conditions. Within each block, the participant performed 24 randomized trials (only one repetition for each trial).

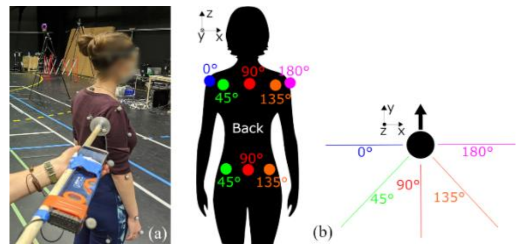

Figure 1 (a) The participant equipped with motion capture markers is about to be pushed at 135° by the experimenter. (b) Locations and angles of the pushes.

Before starting the experiment, a series of non-recorded pushes were performed to let the participant get used to the sensation experienced during the experiment. No prior contact between the participant and the stick occurred before pushes. The participant was able to clearly locate the experimenter using peripheral vision and hearing if no sensory impairment was applied.

2.2 Data collection & analysis

The pushing forces were recorded using a force sensor (U9C 0.5kN, HBK, Germany) mounted in between the plate and the wooden stick. The output signal was treated using a Butterworth low pass filter with a 5Hz cut-off frequency without phase shift. A torpedo level was also fixed to the stick to ensure that the forces applied remained in the transverse plane. Reflective markers (45 units) were placed on the participant, on standardised anatomical landmarks and their motion was captured using a 23 Qualisys camera system (200Hz). The force sensor was synchronised with the motion capture software.

Data analysis was performed using the CusToM library (Muller et al. 2019). We computed the Center of Mass (COM) and the momentum associated to the centre of mass (COM momentum) defined as:

$$\underline{p}_{COM} = m\, \underline{v}_{COM}\,. \qquad (1)$$

Where m is the mass of the participant, $\underline{v}_{COM}$ is the velocity of the COM. The COM momentum was then studied in a referential linked to the pushing force. Only the component collinear to the pushing force was analyzed. This choice was made to simplify the visualization of meaningful quantities and ease the comparisons between reaction to pushes with different angles. The temporal derivative of the COM momentum varies like the acceleration of the COM and can be compared to a force. Hence, we decided to compare this quantity (referred hereafter as the Momentum force) with the pushing force. This comparison enables us to investigate the momentum transfer arising from the pushes.

3. Results and discussion

The experimenter tried to vary only the intensity and not the duration of the pushes. Each push lasted for 0,65±0.29s . The pushes were bell shaped with average maximal intensities of 49±12N, 62±15N and 87±22N, respectively for the "Low", "Medium" and "High" intensity ranges of forces.

The aim of our analysis is to assess the impact of sensory impairment upon reaction in terms of momentum for comparable pushing situations. For instance, Figure 2.a and 2.b can be used to compare the pushing forces and the resulting Momentum force for two different configurations.

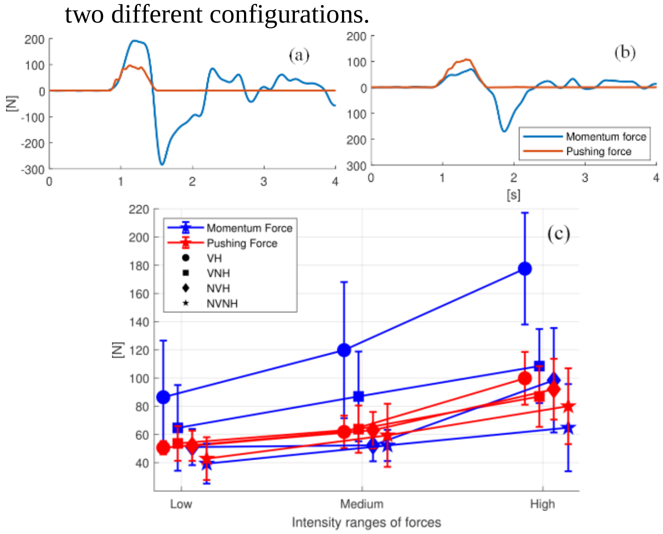

Figure 2 (a-b) Momentum force and pushing force for a lower push at 135°, high intensity range, condition: (a) VH, (b) NVNH. (c) Average over the 8 positions of the maximal values of Momentum forces and pushing forces for every block.

The second negative peak of the Momentum force in Figure 2.a-b corresponds to the restoring momentum initiated by the participant to return to her original position. As we do not know to what extent this motion is linked to the initial perturbation we decided not to analyze this feature.

We can see in Figure 2.a that the momentum force had a maximal value above the one of the pushing force when the participant had all sensory input available (VH). This may indicate that the participant initiated a voluntary motion, and that the participant's reaction was not only due to the external perturbation. On the other hand, when blindfolded and without any sound information (NVNH) the participant seemed to dissipate a part of the force received.

The participant may be adapting her reaction to pushes depending on the level of confidence in her motion. This behavior can be seen in Figure 2.c. In this figure we can see that the mean values of the Momentum force are higher than the pushing force for the configuration without constraint (VH). However, as soon as the senses of the participant were impaired, her Momentum force was decaying. This behavior could be linked to what ethologists call a ''freezing behavior". Such behavior has also been reported by Stins et al. (2011) and might be an element of the participant's reaction here. Let us note that the variability in the intensity of pushing forces and the order in which the blocks were performed may also have an influence on the reaction of the participant as the overall intensity in the NVNH condition is lower than in the VH condition.

3. Conclusions

The results of this preliminary study cannot be used to draw any strong conclusions due to their very early nature. However, gaining knowledge about reaction to perturbation in and out of the sagittal plane is crucial to study individuals' motion in crowds, as pushes can come from any direction. The lack of obstacles here allows us to obtain ground truth data that will be used to parameterize motion models. We also aim at comparing these experimental results to field data collected during future observatories. For all these reasons, the pilot experiment presented here appears to be a promising source of information for crowd modelling. A full experimental campaign following a similar protocol with two trial repetitions (but only considering peripheral vision and hearing impairment) will be conducted in the following months.

Acknowledgments

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***Corresponding author. Email: thomas.chatagnon@inria.fr**