On the Influence of Group Social Interaction on Intrusive Behaviours

Adrien Gregorj, Zeynep Yücel, Francesco Zanlungo, and Takayuki Kanda

Abstract Having extensively investigated the influence of social bonding on the spatial dynamics of two-people groups (i.e. dyads), we more recently studied the impact of group social relation on the dynamics of individual pedestrians (i.e. non-groups) in their proximity, and, reciprocally, groups' reaction to such encounters. In the present work, we extend this analysis to additionally study the effect of the groups' intensity of social interaction (i.e. talking to each other, performing hand gestures, or maintaining eye contact) in similar situations. Specifically, using trajectories of uninstructed pedestrians observed in an ecological setting, we analyse encounters between a dyad annotated with an intensity of interaction ranging from 0 (not interacting) to 3 (strongly interacting) and a non-group coming in the opposite direction. We compute the *undisturbed minimum distance* between them and compare it to the actual minimum distance. To account for the correlation between the intensity of interaction and the size of a group (i.e. the interpersonal distance between the group's members), the two distances are normalized by the average size of groups with similar intensities of interaction. In line with our previous findings, we demonstrate that avoidance dynamics is more pronounced for groups with higher levels of interaction, while groups that interact less, or not at all, are more likely to be intruded into.

Keywords: Collective human behaviour, Social psychology, Intrusion, Social interactions, Pedestrian dynamics

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1 Introduction and Objectives

A crowd is defined as a large group of people that are gathered or considered together [8]. It has a heterogeneous structure and is composed of various components with distinct dynamics, with individuals and groups commonly regarded as its building blocks. Indeed, more than a bare collection of individuals, group motion is shaped by numerous factors, such as individual factors (e.g, age, gender, height), group factors (e.g, social relation, intensity of interaction, gestures), environmental factors (e.g, density, obstacles, flow direction) or social factors (e.g, manners, social acceptability) [14].

As a matter of fact, some of our previous studies are focused on characterising the effect of social bonding on group dynamics, especially in the case of two-people groups (i.e. dyads). In particular, it was shown that social relation and social interaction have a significant impact on the dyad's motion, with, for instance, members of strongly bonded groups (i.e. couples, friends, or people interacting strongly) being found to walk slower and closer to one another.

Nonetheless, the impact that the internal parameters of the group has on the dynamics of other pedestrians that move in its vicinity (i.e. close enough to require collision avoidance manoeuvres) has yet to be investigated. To shed some light on this matter, we propose to analyze the particular situation of non-groups (i.e. pedestrians that are alone and not part of any group) frontally encountering dyads, by using trajectory data of uninstructed, free-moving pedestrians.

In particular, we study the relation between the intensity of interaction inside the group and the deviation/intrusion behaviour of the non-group. To that end, we compute the *undisturbed minimum distance*, i.e. the distance between the dyad and the non-group assuming that they will walk in a straight line without performing any collision avoidance. Then, we compare it to the actual observed minimum distance. This allows quantifying the effective mutual avoidance performed and correlating it with the intensity of interaction inside the dyad.

2 Related Work

The problem of generating socially compliant trajectories, for instance for autonomous agents capable of averting collisions with other agents or pedestrians, is essential. Physics-based methods, such as the classic Social Force Model [4], propose to solve this by using repulsive forces to reproduce collision avoidance. More recently, data-driven methods, such as [1, 3] used neural networks to predict socially plausible trajectories by training them on publicly available trajectory data sets.

Various works have examined the influence that social groups have on the dynamics of the crowd, particularly in the case of evacuation scenarios [10, 9, 7]. Their effect on unidirectional [5], bidirectional [12, 16] or multi-directional flows of pedestrians [15] has also been recently studied. It was found that social groups keep a larger distance from other pedestrians, overtake less often [5] and make fewer detours when walking toward a defined goal [6]. In [16], the authors studied various collision avoidance strategies with regard to the size of the groups and pedestrian density. They notably showed that bigger groups are more likely to split into subgroups to accommodate conflicting pedestrians.

Nonetheless, to the best of your knowledge, no study has yet considered the impact of the social bonding of the group on the avoidance dynamics with non-groups, which we propose to do here.

3 Data Set

We use the DIAMOR data set, which contains pedestrian trajectories recorded over 8 days in an underground pedestrian street network in Osaka, Japan [13]. In this experimental campaign, we collected trajectories of uninstructed pedestrians[1] and were walking freely in a 200 m^2 environment, allowing continuous tracking for approximately 50 m. Depth data was collected with laser range finders and video data was simultaneously captured for annotation of social groups [2] and their intensity of social interaction. This intensity was annotated on a scale ranging from 0 (i.e. no interaction) to 3 (i.e. strong interaction).

The trajectories are first processed to ensure that they are suitable for our study. First of all, for the sake of simplicity, the trajectories of the dyad members are reduced to a single mobile agent (as average positions the members). We then consider trajectories for which the number of observations is deemed sufficient, i.e. with more than 16 points[2]. Additionally, we only retain the trajectories for which the velocity is between realistic boundaries for walking motion, i.e. [0.5, 3] m/s.

Besides, since we are interested in studying the effect of the intensity of interaction on collision avoidance dynamics, we require that the dyad d and non-group n get close enough so that such an effect might sensibly be detected. Specifically, we consider encounters, for which the instantaneous distance between d and n gets smaller than 4 m.

Finally, we confine our analysis to *frontal encounters*, where d and n walk in opposite directions such that n can acquire sufficient information about the intensity of social interaction of d. This condition can be enforced by measuring the unsigned angle between the velocity vectors of d and n, $\alpha = |\angle \mathbf{v}_d, \mathbf{v}_n|$, and retaining those encounters, where α is (on average) between $3\pi/4$ and π.

Since d and n are mobile, the (static) environment reference frame is not the most suited to study their relative positions. Thus, for the sake of clarity and ease of interpretation, we adopt a *dyad-centred reference frame*. In particular, (i) we translate the trajectories of d and n such that d is positioned at the origin at all times and (ii) we rotate them such that the velocity of the dyad $\mathbf{v}_d$ lies along x^+ at all times.

[1] A sign board informed pedestrians that they were being recorded as part of an experiment. The experimentation is reviewed and approved for studies involving human participants by ATR ethics board (document number 10-502-1).

[2] The sampling interval Δt is 500 ms, and, thus, 16 samples correspond to 8 seconds of observation.

4 Trajectory Deviation and Intrusion

Our analysis relies on the hypothesis that, in the vicinity of d (specifically, a $4\times4\,^2$ m area around it), n would follow an effortless straight-line trajectory, would there be no d on its path[3]. Consequently, the deviation from this straight line can be attributed to an effort for collision avoidance.

To measure this deviation, we compute two distances, (i) the *straight-line distance* r_b and (ii) the *observed minimum distance* r_0. The straight-line distance r_b is defined as the distance between the theoretical straight-line trajectory of n and the origin (i.e. the position of d in the *dyad-centred reference frame*). We compute this as the straight line connecting the positions of n where it enters and exits d's vicinity. On the other hand, the observed minimum distance r_0 is simply the actual smallest distance between d and n. It can simply be computed as the minimum distance between pairs of trajectory samples. However, since the sampling interval is relatively large (i.e. $\Delta t = 500\,\text{ms}$) we interpolate the position of n between consecutive time steps using its velocity $\mathbf{v}_n$ to refine the accuracy of the computation[4]. This procedure allows us to detect minimum distances not only exactly at sampling instants but also at intermediate time points between consecutive samples, which yields a more accurate estimation of r_0. Comparing r_b and r_0, we can quantify the deviation due to collision avoidance.

In addition to quantifying the deviation with regard to social interaction, studying these distances allows us to investigate the particular case of *intrusions*, i.e. when the non-group n passes between the two members of the dyad d.

However, note that while dealing with intrusions, one needs to be careful with the group breadth. In [11] we showed that there is a strong relationship between the intensity of interaction of d and the interpersonal distance between its members. Namely, higher levels of interaction correspond to smaller interpersonal distances, while lower levels correspond to larger distances. Therefore, the preference of n to intrude into d or not depends also on the available space between the members of d. To alleviate this effect, we normalise r_b and r_0 by the average interpersonal distance for groups with the same intensity of interaction. Henceforth, these normalised values are referred to as $\bar{r}_b$ and $\bar{r}_0$, respectively.

Given the previously described normalisation, we point out that values of r_0 smaller than 1 indicate that n is at a distance from the centre of mass of d smaller than the distance between the two members of this dyad. This is likely to correspond to n passing through d. To determine whether this likelihood is conditioned on the intensity of interaction of d, we study the proportion of cases where $\bar{r}_0 < 1$.

[3] Vice-versa is valid too. In addition, pedestrian trajectories are, in general, not perfectly straight, but over relatively small distances and for the geometry of the environment in focus (a straight corridor), we argue that this assumption is reasonable.

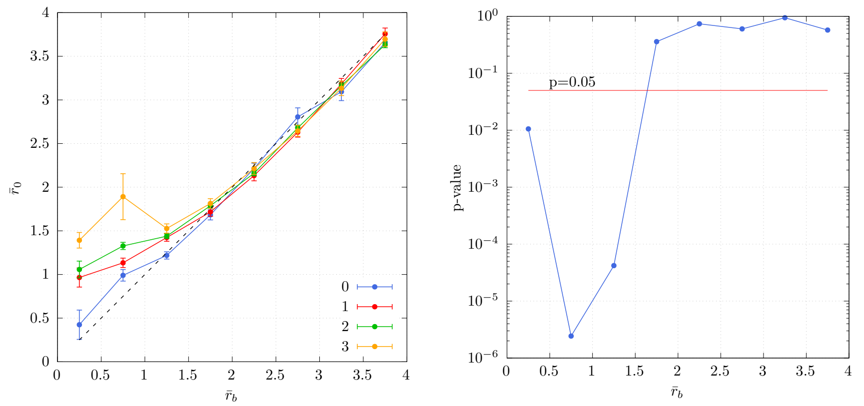
[4] We check whether the distance between the origin and the line, which passes through the position of n at t_k, $p_n(t_k)$ and is directed along its velocity $\mathbf{v}_n(t_k)$, is smaller than the distance between the origin and $p_n(t_k)$. In order for that new distance to be acceptable as the smallest distance between n and d, n must reach the position on the line that verifies this distance in a time shorter than the sampling interval Δt.

Specifically, we compute the probability

$$P(\bar{r}_0 < 1|I) = \frac{|e \in \mathcal{E}_{\bar{r}_b \in I} : \bar{r}_0 < 1|}{|\mathcal{E}_{\bar{r}_b \in I}|}, \quad (1)$$

where I is a given interval for the distance $\bar{r}_b$ and $\mathcal{E}_{\bar{r}_b \in I}$ is the set of encounters such that $\bar{r}_b$ is in that interval. In practice, we compute this probability for quantised values of $\bar{r}_b$, i.e. the intervals I are non-overlapping bins of equal size.

5 Results and Discussion

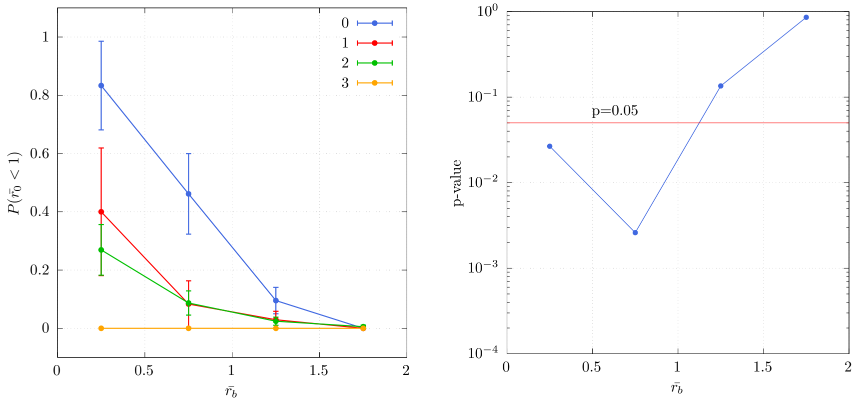


(a) (b)

Fig. 1 **a** $\bar{r}_0$ against $\bar{r}_b$ for various intensities of interaction. **b** Corresponding ANOVA p-values (in logarithmic scale).

Figure 5-(a) shows the average value of $\bar{r}_0$ over quantised values of $\bar{r}_b$, for different intensities of interaction of d. On the right part of the graph ($\bar{r}_b > 2$), all curves follow closely the $y = x$ line (in black dashes). This means that, when n's straight-line trajectory would bring it at a distance $\bar{r}_b$, which is larger than twice the size of the group, it does not undergo any additional avoidance, regardless of the intensity of interaction of d. In other words, groups' social interaction does not affect collision avoidance dynamics, when the trajectories are separated by a large enough distance (more than twice the size of the group).

On the other hand, observing the left part of the graph ($\bar{r}_b < 2$), the curves are seen to drift from the $y = x$ line, as avoidance behaviours take place. Even more remarkably, the intensity of this deviation seems to be conditioned on the level of interaction of d. As a matter of fact, increasing levels of interaction correspond to more pronounced avoidance dynamics. The significance of this result can be assessed by observing the p-values shown in Figure 5-(b) for $\bar{r}_b < 1.5$, indicating that the null hypothesis (that the mean values are all equal) can be safely rejected.



(a) (b)

Fig. 2 **a** Probability for $\bar{r}_0 < 1$ for various intensities of interaction of the dyad d. **b** Corresponding p-values from Pearson's χ^2 test (in logarithmic scale).

Regarding intrusive behaviours, Figure 5-(a) shows the probability of $\bar{r}_0$ being lower than 1, $P(\bar{r}_0 < 1)$, for quantised values of $\bar{r}_b$. Remarkably, we see that there is a direct link between the intensity of interaction of d and the probability that n intrudes into d. Namely, non-groups are more likely to intrude into dyads with lower levels of interaction. In Figure 5-(b), we show the p-values obtained from Pearson's χ^2 test corresponding to a null hypothesis that the proportion of values of $\bar{r}_0$ smaller than 1 are not significantly different across intensities of interaction. We see that these p-values are smaller than 0.05 for $\bar{r}_b < 1.5$, confirming the statistical significance of the difference observed in $P(\bar{r}_0 < 1)$.

Similar to the deviation distance, we believe that this might possibly be an unconscious behaviour causing pedestrians to judge more acceptable to pass through non-interacting groups, as it might be considered as causing less disturbance than for an interacting group.

6 Conclusion

In this study, we studied the effect of the intensity of interaction of dyads d on their collision avoidance with non-groups n. Remarkably, we found that, when d and n are in a colliding path, the magnitude of the deviation of the non-group is contingent on the intensity of interaction of the dyad. As a matter of fact, the deviation is shown to increase with intensifying levels of interaction. What is more, we found that the probability of intruding into a dyad was also correlated with social interactions. Namely, the more the dyad interacts, the less likely the non-group is to intrude into it.

We believe that these findings can be explained by social norms and conventions. It seems that it is regarded as more acceptable to come closer, or even intrude into, groups not engaged in strong social interaction.

We argue that these findings are strengthening our understanding of pedestrian dynamics and specifically of the unspoken social conventions characteristic of human locomotion. They could be applied to help in developing more realistic crowd simulation models (such as social force models) with a wide variety of applications (infrastructure design, disease spread predictions, etc.). Additionally, autonomous agents (i.e. guiding robots, autonomous wheelchairs, etc.) could benefit from navigation algorithms implementing rules derived from our results. Beyond the ability to plan and follow paths among moving, interacting pedestrian, following social conventions is a requirement when conceiving mobile devices that will make human users feel comfortable.

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