Physica A 475 (2017) 129–141

Contents lists available at ScienceDirect

Physica A

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

Empirical study on social groups in pedestrian evacuation dynamics

Cornelia von Krüchten [a,*], Andreas Schadschneider [a,b]

[a] Institut für Theoretische Physik, Universität zu Köln, Germany
[b] Institut für Physik und ihre Didaktik, Universität zu Köln, Germany

HIGHLIGHTS

- Quantitative analysis of an empirical study on the influence of groups in evacuations.
- Increasing the group size can reduce evacuation times due to self-ordering phenomena.
- Introduction of group parameters considering the groups' centre of mass and shape.
- Social groups order along their direction of motion.

ARTICLE INFO

Article history:
Received 11 October 2016
Received in revised form 30 December 2016
Available online 11 February 2017

Keywords:
Pedestrian dynamics
Social groups
Empirical study
Evacuation scenarios

ABSTRACT

Pedestrian crowds often include social groups, i.e. pedestrians that walk together because of social relationships. They show characteristic configurations and influence the dynamics of the entire crowd. In order to investigate the impact of social groups on evacuations we performed an empirical study with pupils. Several evacuation runs with groups of different sizes and different interactions were performed. New group parameters are introduced which allow to describe the dynamics of the groups and the configuration of the group members quantitatively. The analysis shows a possible decrease of evacuation times for large groups due to self-ordering effects. Social groups can be approximated as ellipses that orientate along their direction of motion. Furthermore, explicitly cooperative behaviour among group members leads to a stronger aggregation of group members and an intermittent way of evacuation.

1. Introduction

The significance of social groups in pedestrian crowds is known for almost forty years. In 1977, Aveni [1] found that most pedestrians do not walk alone, but in pairs or groups. Likewise, more recent studies observed the dominance of groups in crowds of pedestrians [2–4]. Moussaïd et al. [5] reported that up to 70% of urban pedestrian traffic happens in social groups, whereas 95% of pedestrians were found to walk in groups at major events [6].

In this contribution, the term "crowd" describes the entire group of walking or evacuating people to distinguish it from smaller social groups. Groups of pedestrians that walk or stand together because of social relationships and interactions which will be referred to as "social groups" (see [5] and references therein). Using these terms, we do not want to imply collective behaviour as it is mentioned in [7]. The presence of social groups can influence the dynamics of pedestrian crowds. Social groups often move slower and reduce the walking speed of the pedestrians [3,8–10]. However, Manenti

* Corresponding author.
E-mail addresses: cvk@thp.uni-koeln.de (C. von Krüchten), as@thp.uni-koeln.de (A. Schadschneider).

http://dx.doi.org/10.1016/j.physa.2017.02.004
0378-4371/

et al. [11] observed that group members can walk faster than individuals in high density scenarios. The average walking speed decreases with increasing group size [3,5,6,12].

Pedestrians of social groups order in certain configurations depending on the surrounding density and the group size. Pairs and larger groups at lower density walk abreast. At higher densities, groups of three pedestrians often walk in a "V"-like shape. This configuration becomes "U"-like for groups with four pedestrians. Larger groups tend to split up to smaller groups of two or three members [3,5,13–15]. In pedestrian crowds the averaged minimum distance headway within a social group increases with increasing group size. This leads to a larger space requirement for larger groups [16].

Based on simulation results Reuter et al. [2] identify large social groups as "moving obstacles" amongst pedestrians. As a consequence, the authors assume that large cohesive groups inhibit fast evacuations. Köster et al. [12] performed an experimental study with students. They had to egress from their classroom starting at their desks and enter the room again afterwards. The authors of the study observed a negative impact of groups on egress times, but a positive impact on ingress times. The students entered the room starting in the same configuration of the crowd as it results from the egress process. Thereby, the separation of the participants into social groups caused the ordering of students in accordance with their position in the classroom before the ingress process started. The authors assume that this kind of ordering effect was responsible for the faster ingress with groups. A more recent study [17] also found that pairs can evacuate faster than individuals. Laboratory experiments performed by Bode et al. [18] have indicated that social groups of three evacuated slower compared to individuals due to a larger pre-movement time and larger time to reach the vicinity of the target.

In order to investigate social groups in pedestrian crowds further, this contribution presents the first results of laboratory experiments on social groups in evacuation scenarios. These experiments were part of a joint study by the Universities of Cologne and Wuppertal and the Forschungszentrum Jülich which aimed at the investigation of the influence of inhomogeneities on the fundamental diagram [19] and evacuation times. Here we report preliminary results from experiments on evacuation scenarios with pairs and larger social groups.

2. Experimental study

The experiments were performed in November 2015 and April 2015 in two schools in Wuppertal, Germany (Gymnasium Bayreuther Straße, "GymBay", and Wilhelm-Dörpfeld-Gymnasium, "WDG"). The pupils of different classes participated as part of project work (see also [20,21]).

2.1. Experimental concept

The experiments consisted of several evacuation runs. The focus was on varying the composition of the crowd of pupils. Different configurations helped to investigate the influence of different parameters. Overall, there were three quantities that specified the composition of the crowd:

- *Social group composition*: There were two classes of age: children (aged around 11 years) and young adults (aged around 16 years). The groups could therefore consist only of children, only of youths and of mixtures of both. A distribution of body height of the runs that are used in the analysis can be found in Appendix A.2.
- *Social group interaction*: The interaction between group members was specified in two ways:
  - *Bond between group members*: Members of the same social group could be connected either loosely or fixed. Loosely bonded groups had to try to stay together through eye contact, fixed bonded group members had to hold physical contact, e.g. hold each others' hands.
  - *Hierarchy of group members*: The hierarchy between group members could be flat, with each pupil treated equally. They had to leave the room as well as to stay together in their social group. Otherwise, one group member was declared as 'leader', the other ones as 'followers'. Leaders had to leave the room without regarding other members of the groups. Followers had to stay as close as possible to their leader.
- *Social group size*: The pupils evacuated individually, in pairs or in larger groups with four, six or eight participants per group.

Large groups were built successively. Two pupils were teamed up to pairs. Groups of four consisted of two pairs, groups with six participants of three pairs and groups of eight were built by four pairs (two groups of four). Members of larger groups were bound only loosely. If required, the leader was chosen randomly in age-matched pairs. In pairs or groups of mixed ages the older pupil or one of the older pupils were assigned as leader. For age-matched large groups there was no leader at all.

2.2. Experimental set-up

The experimental set-up consisted of a rudimentary room built in the schools' assembly hall. This room was a square area of 5×5 m^2 bounded by small buckets on three sides (see Fig. 1). There was a gap on one side that was used as an entrance to the experimental area. The fourth side was an artificial wall with an exit door of variable width. Door widths of 0.8 and 1.2 m were used. Behind the exit door more buckets formed an aisle that led to a waiting area in front of the entrance. In the centre of the experimental room a square starting area of 3×3 m^2 was marked. To record the experiments a video

Please cite this article in press as: C. von Krüchten, A. Schadschneider, Empirical study on social groups in pedestrian evacuation dynamics, Physica A (2017), http://dx.doi.org/10.1016/j.physa.2017.02.004