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Sparnaaij, Martijn; Duives, Dorine C.; Hoogendoorn, Serge P.

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Rotation behaviour of pedestrians in bidirectional and crossing flows

Martijn Sparnaaij[1], Dorine C. Duives[1], and Serge P. Hoogendoorn[1]

Department of Transport & Planning, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands,
M.Sparnaaij@tudelft.nl

Abstract. Rotating ones body is a strategy pedestrians commonly use to avoid collisions. Even though this behaviour impact capacity heavily, this rotation behaviour is seldomly studied. This research aims to increase insight into rotation behaviour of pedestrians in high density bidirectional and crossing flows. Based on data from the CrowdLimits experiments, the effect of density, movement base case, flow ratio and disturbances on the rotation behaviour of pedestrians are studied. The main findings are that all these four factors impact the number of rotations in a flow. Yet, further research is necessary to better identify to what extend and when these factors impact the rotation behaviour most.

Keywords: Rotation behaviour, pedestrians, high density, bidirectional, crossing

1 Introduction

One of the core features of any microscopic pedestrian model is the replication of the collision avoidance behaviour of a pedestrian. In these models, the most popular way to represent pedestrians is by using a circle and collision avoidance is performed by changing the speed and/or direction of the pedestrians. However, pedestrians also use body rotation as a strategy to avoid collisions [1] and this cannot be modelled using the circular representation. So, this begs the question; how important is it to be able to represent this body rotation behaviour in our models?

Rotation behaviour has not been studied extensively [1] and this is also the case for both bidirectional and crossing flows. Both [2] and [1] studied body rotations in bidirectional flows but neither looked at the relationship with density. For crossing flows, [1] did look at the relationship between body rotation and density. Their two main findings were that body rotations in the range of [0,20] degrees were observed in a wide range of densities and that large body rotations were only found in the case of (local) densities smaller than 2.5 ped/m^2.

So, to get more insight into how relevant it is to be able to represent this rotation behaviour in models, this paper aims to provide more insight into the rotation behaviour of pedestrians in bidirectional and crossing flows and how the rotation behaviour relates to the density, the flow ratio and disturbances.

Furthermore, the differences between these two movement base cases will also be studied.

The paper is organised as follows. Section 2 introduces the CrowdLimits experiment which provides the data used in this study. Section 3 accordingly explains how the rotations are extracted from the video data. Section 4 discusses the results and lastly section 5 provides the conclusions and a discussion of the results.

2 CrowdLimits experiment

The CrowdLimits experiments are large pedestrian experiments performed at the Delft University of Technology in June 2018. The goal of the experiment was to investigate pedestrian behaviour in high density bidirectional and crossings flows. However, given the setup of the experiment, the collected data can also be used to study rotation behaviour of pedestrians in these two flow scenarios. A short summary of the setup of the experiment will be given in the remainder of this section. For a more detailed description the reader is referred to [3].

The experiments consisted of two evenings, whereby on the first evening a bidirectional flow was replicated and on the second evening a two-way crossing flow. Each evening 12 runs were performed whereby two different flow ratios where tested and three different movement assignments. This research uses only 8 of the total of 24 runs and details on these 8 runs can be found in table 1.

Table 1. Overview of the eight runs that are used within this research

Nr.	Scenario	Flow ratio	Assignment	Dimensions
1.	Bidirectional	50-50	None	w=2.4m
2.	Bidirectional	80-20	None	w=2.1m
3.	Bidirectional	50-50	[C] 10% Fast walk	w=2.4m
4.	Bidirectional	80-20	[C] 10% Fast walk	w=1.8m
5.	Two-way crossing	50-50	None	w=1.8m, l=1.8m
6.	Two-way crossing	70-30	None	w=2.4m, l=1.4m
7.	Two-way crossing	50-50	[C] 10% Fast walk	w=1.8m, l=1.8m
8.	Two-way crossing	70-30	[C] 10% Fast walk	w=2.4m, l=1.8m

Every run took approximately 5 minutes whereby every minute the inflow was increased in a step-wise manner. The inflow into the infrastructure was controlled using queuing areas with lanes and stop-go lights. All participants were asked to enter the corridor or crossing and exit on the other side and walk as they normally would. After having walked through the infrastructure the participant joined the queue again. In the case that assignment C was active, about 10% of the participants who got this assignment were asked to pretend like they were in a hurry and thus walk faster than they normally would. The aim of this assignment was to include a disturbing element to the scenario.

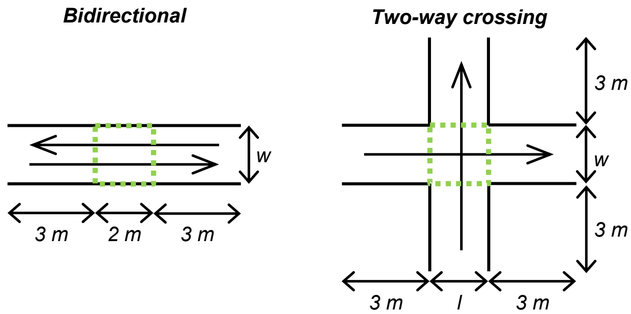

Fig. 1. Lay-out of the scenarios including the dimensions, the walking directions and the areas of interest

The location of the experiments was a large indoor hall. To construct the corridor and the crossing four l-shaped wooden elements were used whereby in the case of the corridor two additional 2-meter wide panel were used. All these elements had a height of 2.4 meters to ensure that the participants had the feeling they were in an enclosed space. The exact lay-out and dimensions can be found in figure 1 and in table 1.

Per evening, approximately 130 people participated, who formed a heterogeneous population consisting of 55% males and 45% was females with age an average of 30.5 (ranging from 18 to 70) and a mean height of 1.76 (ranging from 1.40 to 2.04) meters. 74% of the participants was Dutch and the remainder featured a mixture of different nationalities.

The movement of the participants was captured from above using multiple cameras. To aid the tracking every participant got a red cap and a white t-shirt. To mark the shoulder points blue dots were stuck on the t-shirt to mark the participants' shoulders. See figure 2 for an example of the camera view.

3 Extracting the rotations from the video data

After the experiments the rotation of the participants had to be extracted from the videos. This section details the three-step process that is used to extract the rotations and densities from the videos.

The first step is to determine an area of interest within which the rotations and density will be measured. Figure 2 a) shows an example of the area of interest. Figure 1 shows the size and location of the area of interest for both scenarios. The areas are chosen such that we only capture the rotations of the pedestrians related to the movement base cases of interest and not those in the unidirectional flows leading to and from the crossing or the entering and exiting cases at the boundaries of the infrastructure.

The second step is to annotate the shoulders of the participants. This is done for one frame every second for every single person that resides in the area of interest. The choice for using only one frame per second, instead of doing this

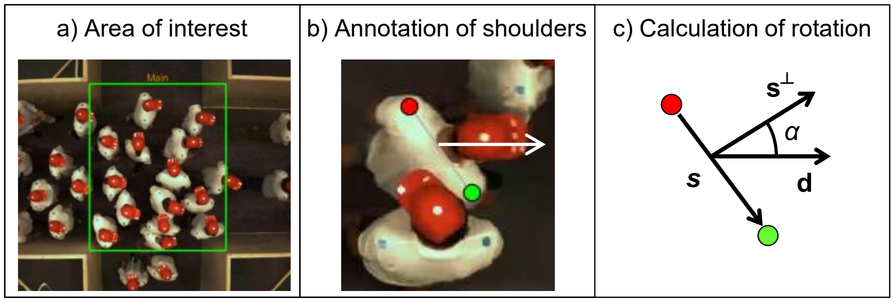

Fig. 2. Figure showing the three stages performed to extract the rotations. The green rectangle in a) shows the area of interest. The red dot in b) annotates the left shoulder and the green dot the right shoulder and the white arrow indicates the assumed walking direction. c) shows how the rotation α is determined based on the two shoulder points and the assumed walking direction

for every frame, is the fact that the annotation had to be done manually and doing so for every frame would have been too time-consuming. Figure 2 b) shows an example of a pedestrian whose shoulders have been annotated whereby the left shoulder is annotated by the red dot and the right shoulder by the green dot.

The third and final step is to, based on the annotated shoulders and the area of interest, calculate for every frame both the density in the area of interest and the rotations of all participants in the area of interest. The density is the number of pedestrians in the area of interest over the size of the area of interest. Figure 2 c) depicts how the rotation is calculated. The rotation α is calculated by taking the angle between the assumed direction of movement $\mathbf{d}$ and the perpendicular vector $\mathbf{s}^{\perp}$ of the vector connecting the left shoulder point to the right shoulder point $\mathbf{s}$. The assumed directions of movement are displayed in figure 1. These assumed directions of movement are used instead of the actual directions of movement as trajectory data was not yet available. The influence this assumption has on the results will be discussed in more detail in the last section of the paper.

Using the method described above, the videos of all eight experiments were processed. This resulted in eight datasets which each contained all rotations captured in the video of the respective experiment. The next section discusses what insight these datasets provide.

4 Results

Figure 3 depicts the results for all eight cases. Graphs 3.a) and 3.b) clearly show that, though in all eight cases the distribution shape is similar, there are some differences between the eight cases regarding how the rotations are distributed. The graphs also show that the large majority of the rotations are small (i.e.

≤ 20°). Previous research [2, 1] suggest that these small rotations are likely not the results of interactions with other pedestrians. To confirm that this is also the case for these datasets, the shoulders of several pedestrians, who were walking in a free flow condition in one of the arms leading to the crossing, were annotated. The results of this analysis are in line with the finding from previous research and confirm that rotations smaller than 20 degrees are likely not the result of interactions with other pedestrians. Hence, only rotations larger than 20° will be used in the remainder of this analysis.

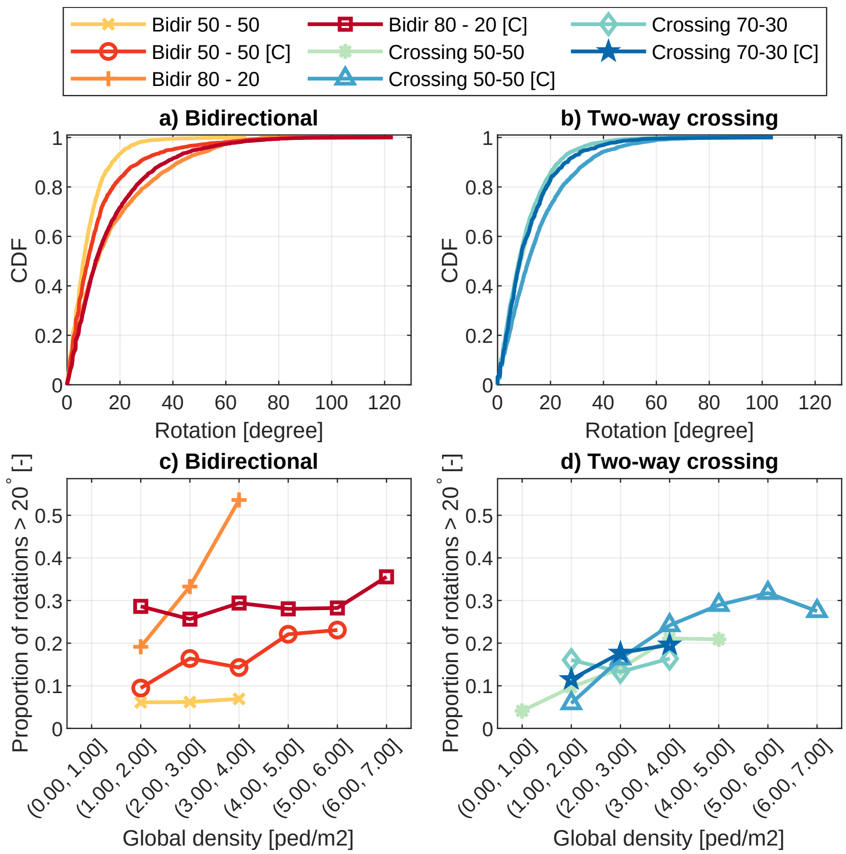

Fig. 3. The results whereby graphs a) and b) show the cumulative distribution of the rotations per case and graphs c) and d) the proportion of rotations per density bin

Graphs 3.c) and 3.d) show how the rotations larger than 20° relate to the global density ($k = N/A$). In the bidirectional case, graph 3.c) clearly shows differences between the four cases. These differences show up in the relation between the rotations and the density, as well as in the relation between the total amount of rotations and the density. Both the 50-50 case as the 80-20 [C] case show little correlation between the density and the amount of rotations. Yet there are clearly more people rotating in the 80-20 [C] case. The 50-50 [C] and 80-20 cases show some correlation to the density whereby the amount of rotations increases as the density increases. How strong the relation is and how many rotations this involves is different for the two cases. Overall, there are clear indications that in the bidirectional case the flow ratio and the assignment affect the number of times people rotate their body and affect how this relates to the density.

The differences between the crossing cases are much smaller according to graph 3.d). Generally the number of rotations increases as the density increases. Furthermore, within the individual density bins the differences between the four cases are small as well. The main difference is the range of densities that occur whereby the ranges in the 50-50 [C] case and the 70-30 case are smaller than those of the other two cases. This indicates that the flow ratio and the assignment do not necessarily impact the rotation behaviour.

Comparing graphs 3.c) and 3.d) it is clear that the movement base case affects the rotation behaviour. For example, both the amount of rotations and the correlation of the rotations to the density is clearly different in the crossing 50-50 case compared to the bidirectional 50-50 case.

5 Conclusions and discussion

The data of the CrowdLimits experiment clearly indicates that all four factors considered in this research (i.e. density, movement base case, flow ratio and assignments) impact how many people rotate their bodies to solve conflicts. However, this study does not have enough power to determine to what degree these factors influence the amount of rotations and in which cases they exactly influence the amount of rotations. Furthermore, this study was also limited by the fact that the assumed walking directions were used to calculate the rotations instead of the actual walking directions. Future research will aim at enhancing the insights by using the actual walking directions, including the other 16 runs, coupling individual rotation behaviour to socio-demographic variables and the assignments and lastly by performing statistical analyses.

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