JÜLICH
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Bottlenecks and rewards
adding fuel to the fire

Crowds: models and control, CIRM Marseille, France
June 3-7 2019

June 3rd 2019 | Armin Seyfried

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and
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Overview

Introduction

Bottleneck flow (review)

- Spatial structure of the boundaries (width and length)
- Cooperation vs. competition, clogging and flow

Density in front of bottlenecks

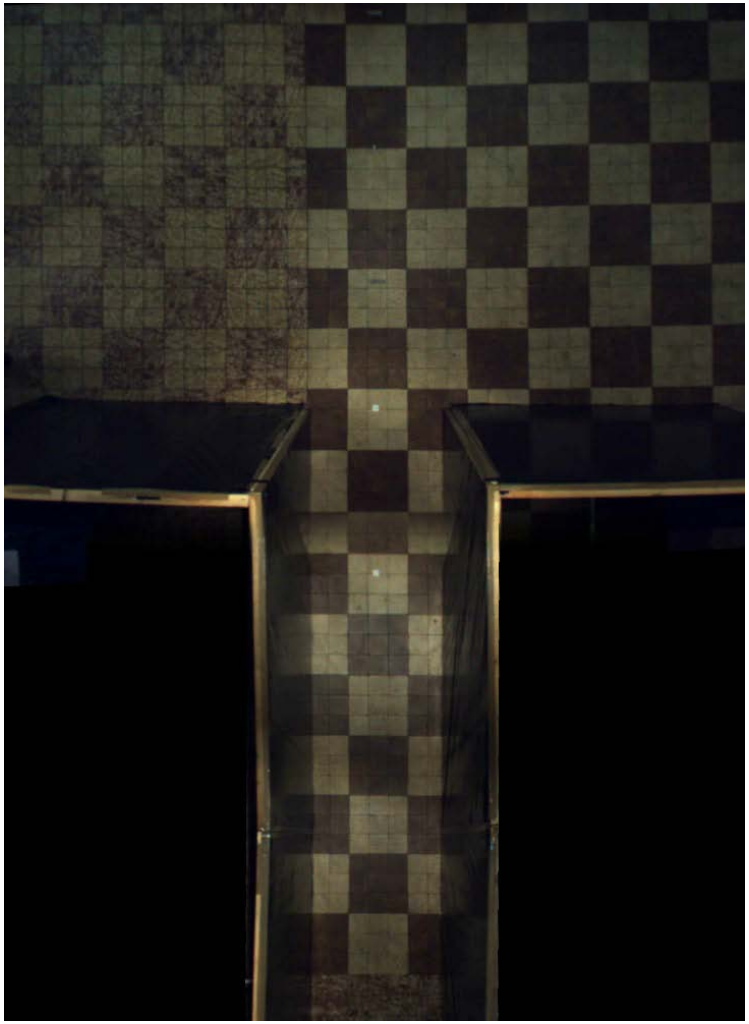
- Experiment I
  - Density and flow
  - Questionnaire
- Experiment II

Summary and outlook

Introduction

Process and definitions

- Unidirectional movement of pedestrian passing a bottleneck
- Incoming flow J_{in} outgoing flow J_{out}
- Width / length of the bottleneck
- Width of the room / corridor leading the bottleneck



Introduction

Process and definitions

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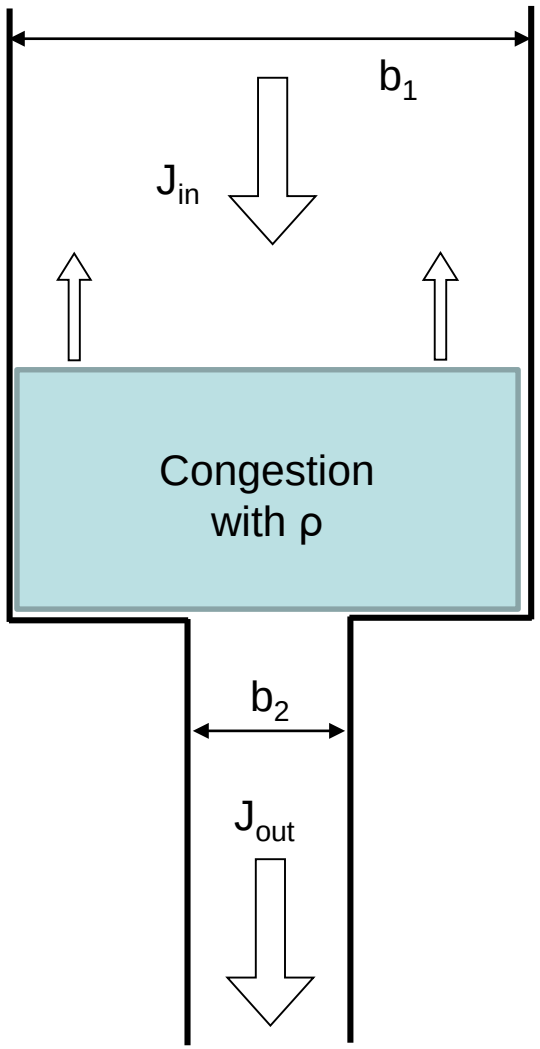


Phenomena

- $J_{in} > J_{out}$: Congestion
- Density increases till a certain threshold ρ, then the congested area grows in the opposite direction of movement
- Clogging

Competition and cooperation

https://youtu.be/xG-meaGqg-M

Competition and cooperation

https://youtu.be/IFFCLtCB7Ag

Introduction

The experiment of Mintz*

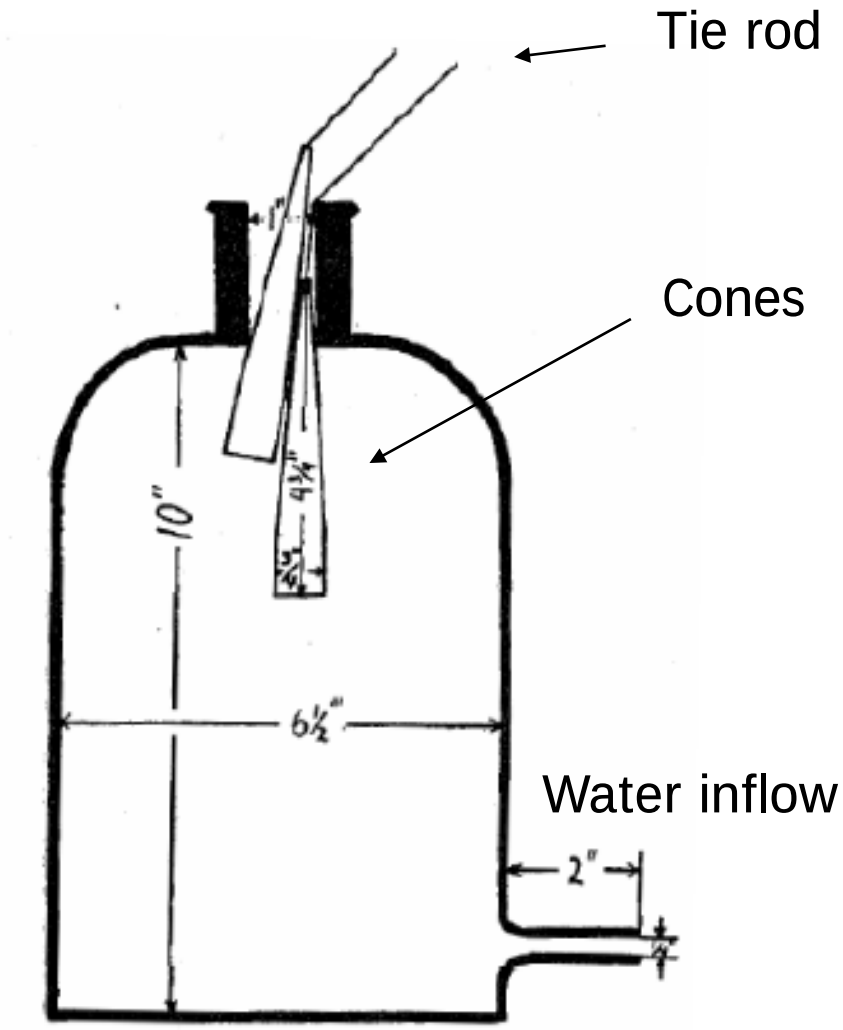
- Groups of 15-21 students
- Task: Pulling out cones dry
- Only one cone at a time
  - otherwise clogging

Different setups and instructions

- With and without individual rewards (little money)
- With and without the opportunity to discuss
- With and without special arousal (swearing and noise)

Without reward: No clogging

With reward: clogging



* A. Mintz, Non-adaptive group behaviour, The Journal of abnormal and social psychology 46 150 (1951)

Introduction

Clogging of pedestrians at bottlenecks

Video: Experiments performed by Majid Sarvi, University of Melbourne, Australia, 2018

Introduction

Bottleneck flow, incentives, rewards, motivation, cooperation, competition, clogging, …

Cooperation at bottlenecks

- Mostly people cooperate (weak incentive, no reward)
  by keeping distance, giving way or stopping
- In a **cooperative** setting clogging is very unlikely
  (only by chance or by misunderstandings)

Competition at bottlenecks

- Special incentives or rewards trigger **competitive** behavior
- In crowds the incentives initiating competition could be
  seemingly small (e.g. a place in a train, a bargain on sail, …)
  but also very high (e.g. survival in a dangerous situation)
- In competitive setting people moving fast, getting closer and filling gaps,
  or even start pushing and shoving using their elbows

Introduction

Competition, clogging and flow

- Due to the competitive behavior (moving fast, filling gaps, pushing) the probability of clogs increase
- But even if the probability of clogs increase, it is an open question whether the flow decrease in comparison to a cooperative setting

Questions

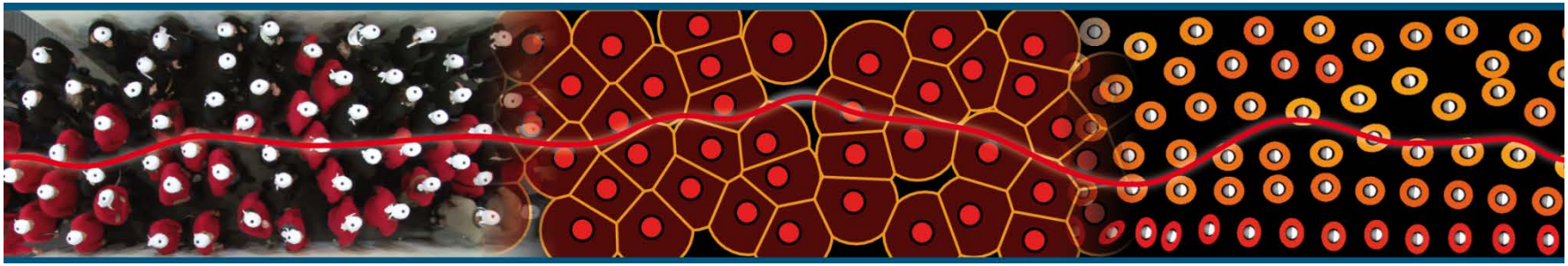
Influence of the

- spatial structure of the boundaries
- motivation (triggered by incentives / rewards)

on

- flow
- probability of clogs
- density in front of the bottleneck

Bottleneck flow in cooperative settings: spatial structure of the boundaries



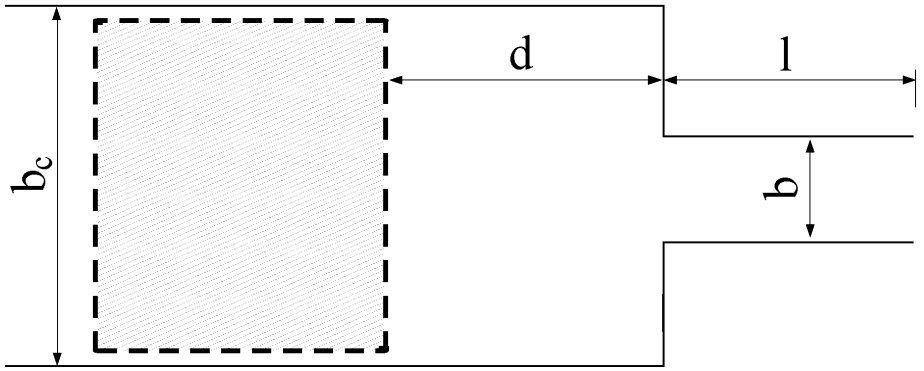
Experiment

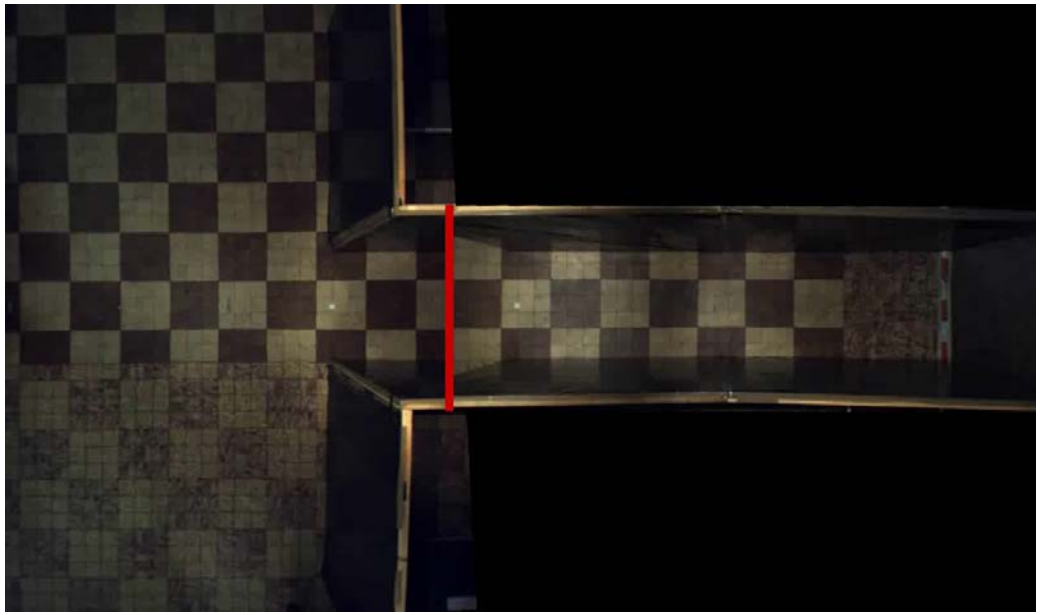
Setup

- Test persons: 250 soldiers
- Instruction: Move without haste but purposeful
- Bottleneck width **b**

  0.8, 0.9, 1,0, 1,2, …, 2.5 m
- Bottleneck length **l**

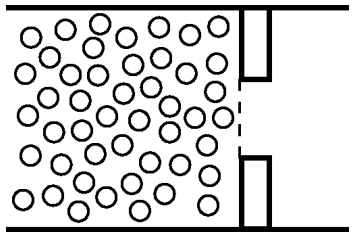
  0.1, 2.0, 4.0 m





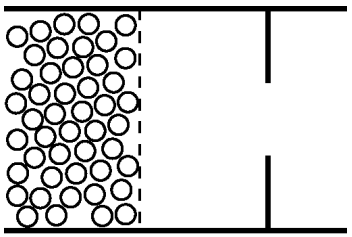
*Seyfried and Schadschneider, Empirical Results for Pedestrian Dynamics at Bottlenecks, PPAM 2009, LNCS, Vol. 6068, p.575, Springer, 2010

Bottleneck flow



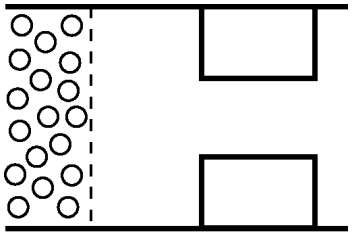
Kretz et al.

J. Stat. Mech., P10014 (2006)



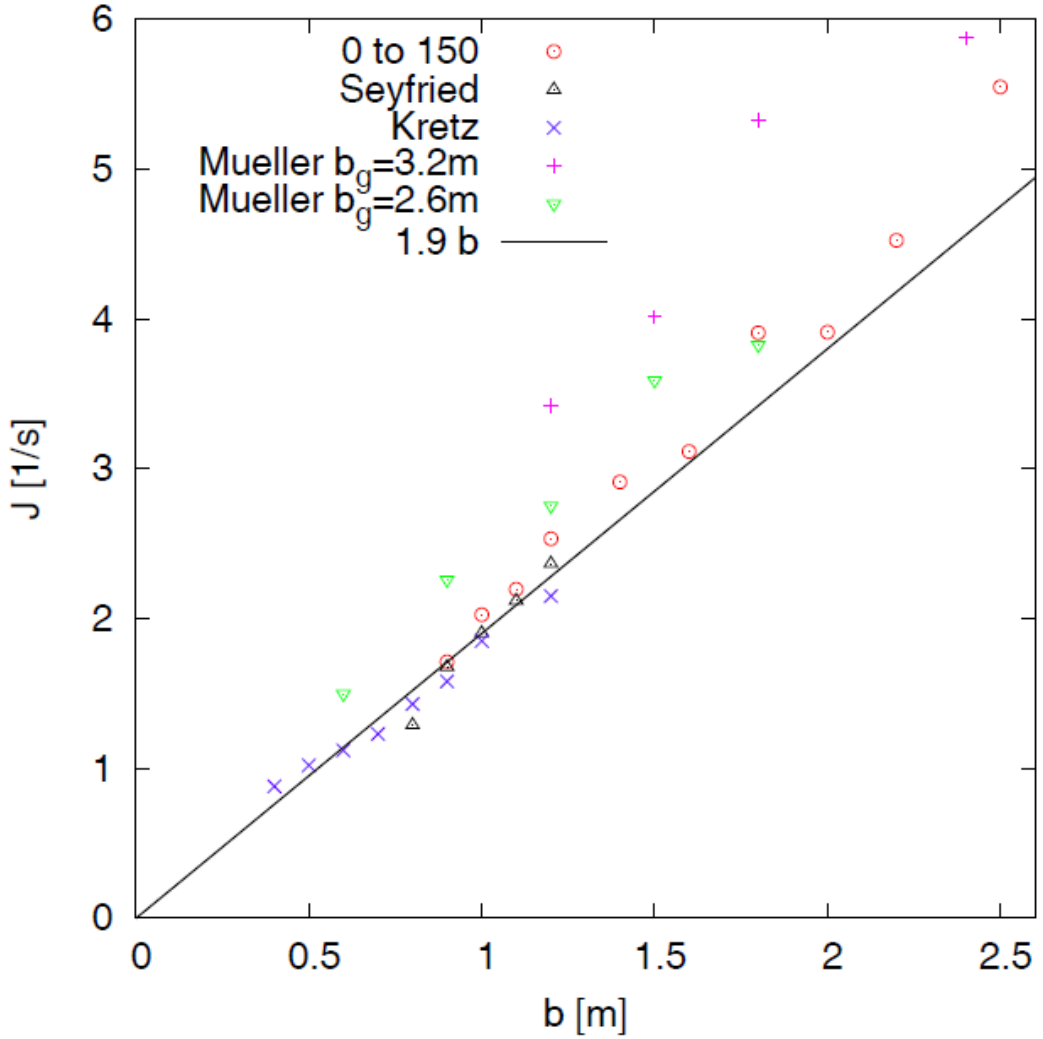
Mueller K.

Dissertation, Magdeburg (1981)



Seyfried et al.

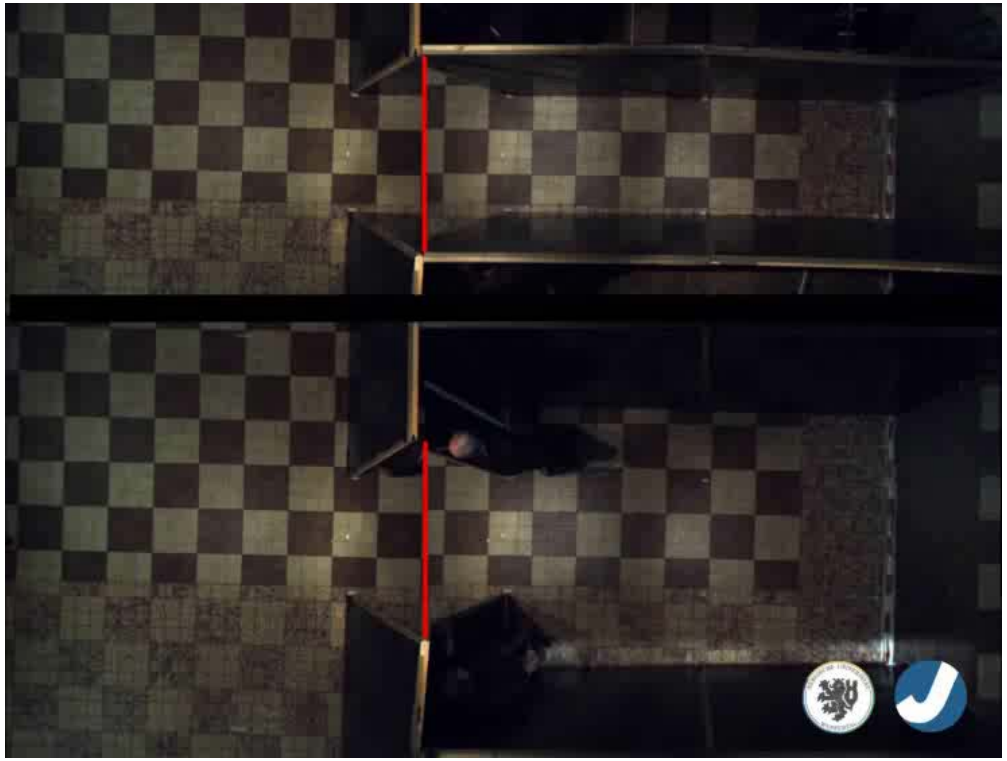
Trans. Sci., 43, 395-406 (2009), …

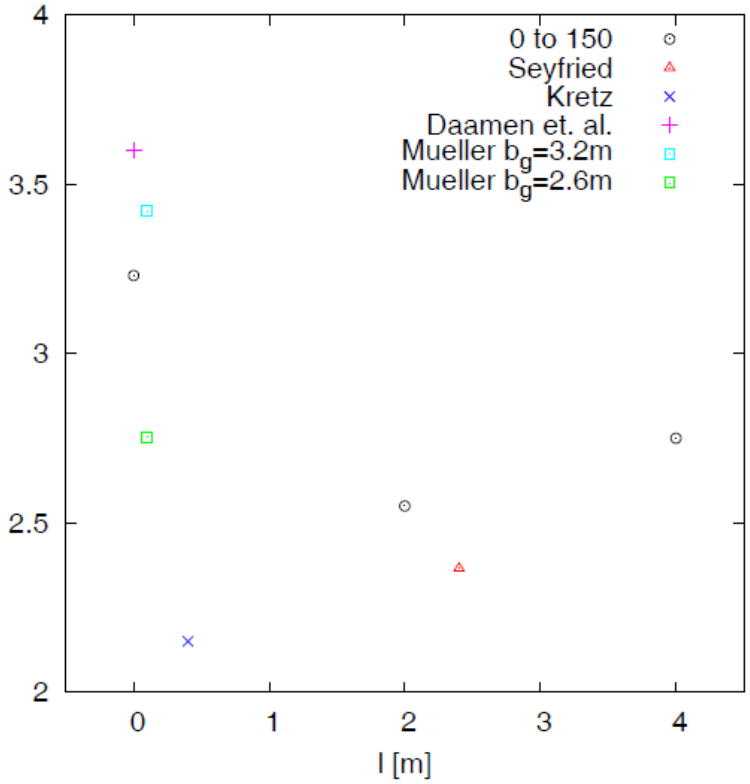


Bottleneck flow J(l)

Setup

- Bottleneck width **b = 1,6 m**
- Bottleneck length **l** = 0.1, 2.0, 4.0m



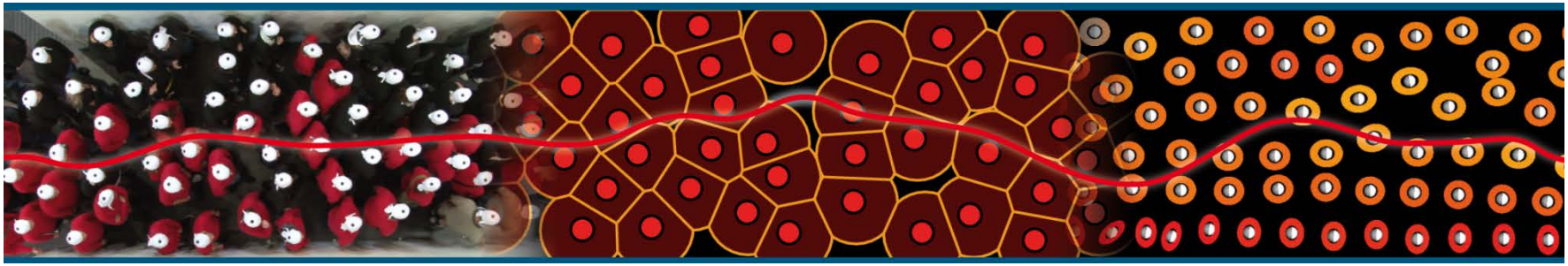


Bottleneck – clogging

Summary: Flow under cooperative setting

- The flow increases continuously with bottleneck width
- Short bottleneck lead to larger flows than long bottlenecks

Bottleneck flow:
cooperation and competition



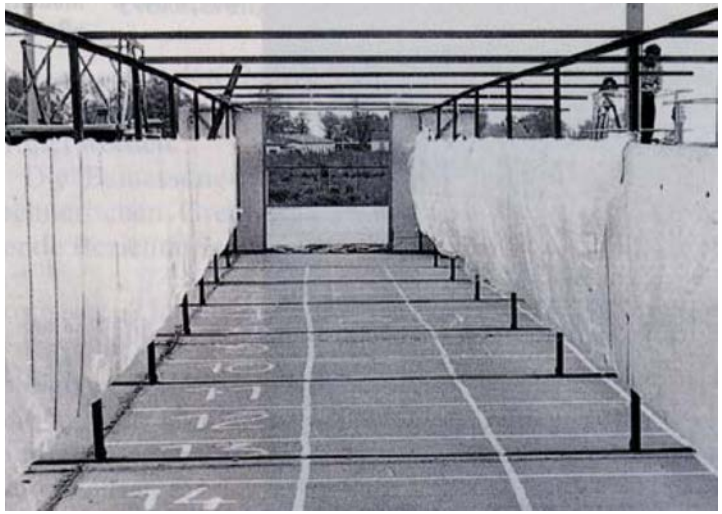
Experiments of Müller, 1981*

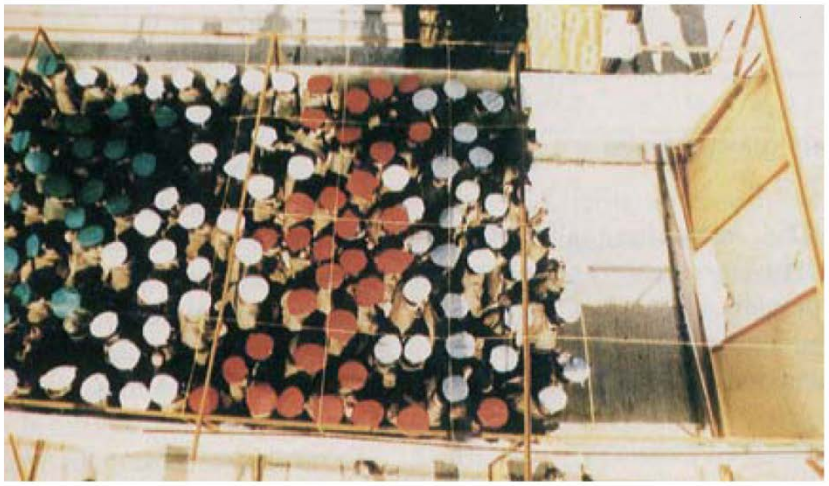
Variations of

- N = [150,190] test persons (soldiers)
- b_{cor} = [3.8, 3.2, 2.6 2.0] m
- b_{bck} = [3.3, 2.7, 2.4, 1.8, 1.5, 1.2, 0.9, 0.6] m
- Normal (No) and danger (Ge)
- Start density 6 [1/m²]

Instruction to the test persons

- Normal: smooth movement, mutual consideration
- Danger: run for you lives





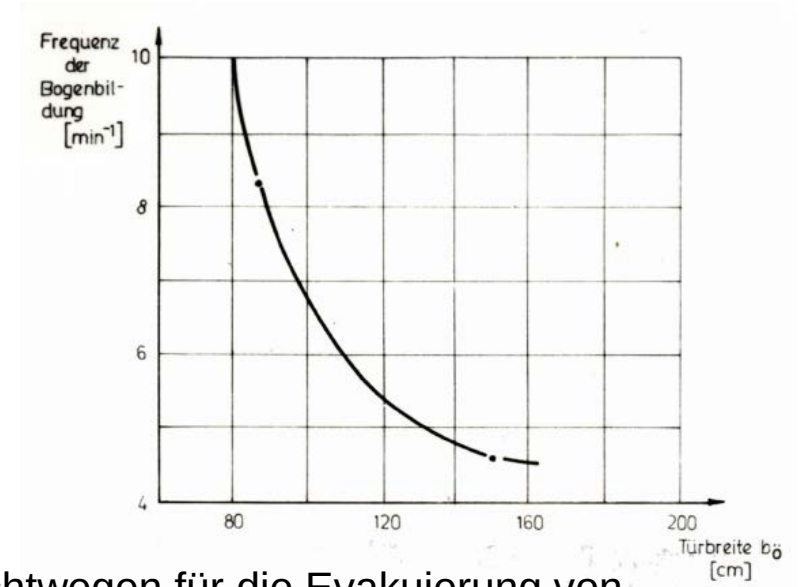
*K. Müller, Die Gestaltung und Bemessung von Fluchtwegen für die Evakuierung von Personen aus Gebäuden, Dissertation Technische Hochschule Magdeburg 1981

Experiments of Müller (1981)

The frequency of clogs appearing at competitive settings depend on the width of the bottleneck

Clogging

- $b_{bck} \leq 1.1$ m: clogs in short frequencies. Flow stops temporarily
- $b_{bck} \approx 1.2$ m: Pulsing flow
- $b_{bck} \geq 1.6$ m: No clogs observable, fluent and homogenous flow



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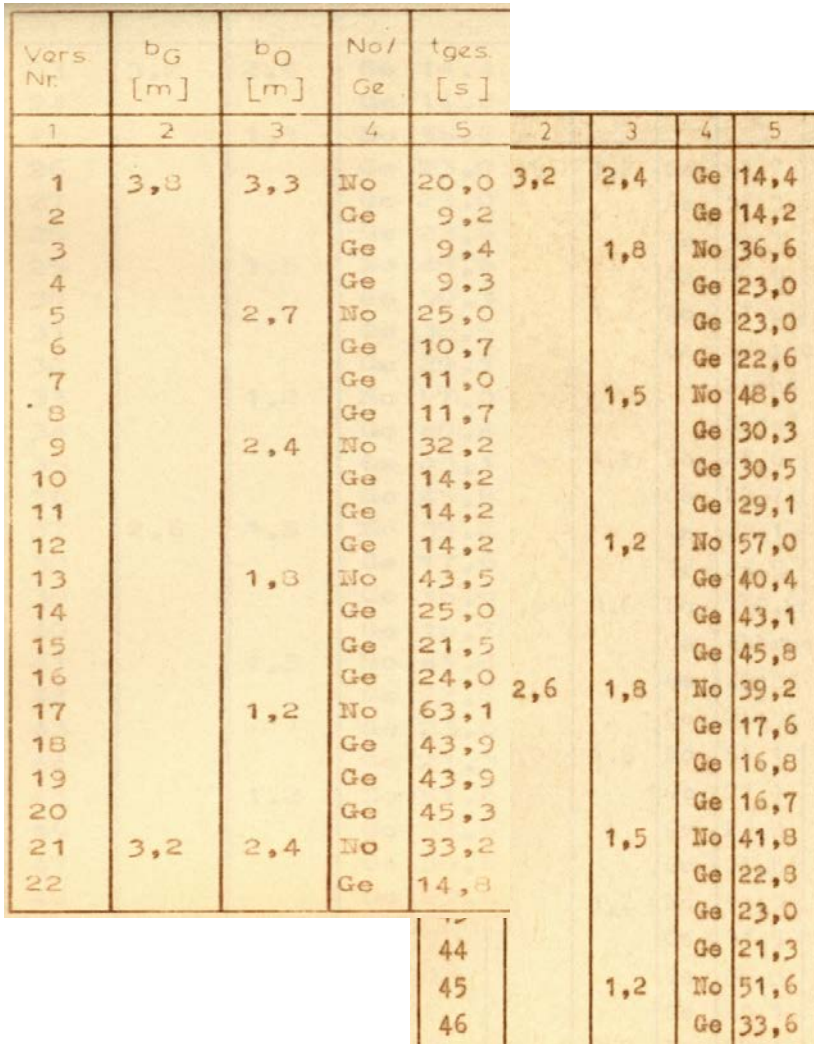
Results for the flow

- For every b_{cor} and every b_{bck} the clearance time ($t_{evak} = 1/J$) was significantly smaller for runs with high motivation



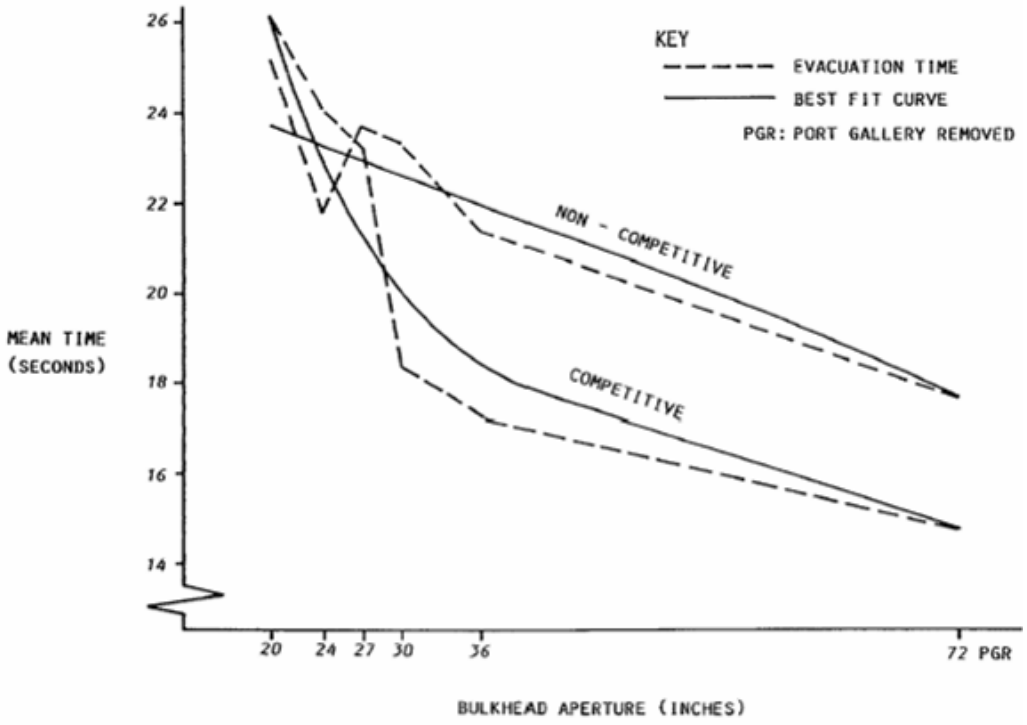
Vers. Nr.	b_G [m]	b_O [m]	No/ Ge	t_{ges} [s]				
1	2	3	4	5	2	3	4	5
1	3,8	3,3	No	20,0	3,2	2,4	Ge	14,4
2			Ge	9,2			Ge	14,2
3			Ge	9,4		1,8	No	36,6
4			Ge	9,3			Ge	23,0
5		2,7	No	25,0			Ge	23,0
6			Ge	10,7			Ge	22,6
7			Ge	11,0		1,5	No	48,6
8			Ge	11,7			Ge	30,3
9		2,4	No	32,2			Ge	30,5
10			Ge	14,2			Ge	29,1
11			Ge	14,2			Ge	57,0
12			Ge	14,2		1,2	No	40,4
13		1,8	No	43,5			Ge	43,1
14			Ge	25,0			Ge	45,8
15			Ge	21,5			Ge	39,2
16			Ge	24,0	2,6	1,8	No	17,6
17		1,2	No	63,1			Ge	16,8
18			Ge	43,9			Ge	16,7
19			Ge	43,9			Ge	41,8
20			Ge	45,3		1,5	No	22,8
21	3,2	2,4	No	33,2			Ge	23,0
22			Ge	14,8			Ge	21,3
							Ge	51,6
44						1,2	No	33,6
45							Ge	
46								

*K. Müller, Die Gestaltung und Bemessung von Fluchtwegen für die Evakuierung von Personen aus Gebäuden, Dissertation Technische Hochschule Magdeburg 1981

Experiments of Muir et al. 1996

Experiments in airplanes
with rewards, amount of money
(competitive)
and
without rewards
(non-competitive)

- Variations of the bottleneck width (gallery kitchen)
- For small widths (arcs and clogging) non competitive runs are faster
- For large widths competitive runs are faster
- **Crossover of exit times! (Exit times ~ 1/J)**



Muir et al., Effects of Motivation and Cabin Configuration on Emergency Aircraft Evacuation Behavior and Rates of Egress, The Int. J. of Aviation Psychology, 6, 1996

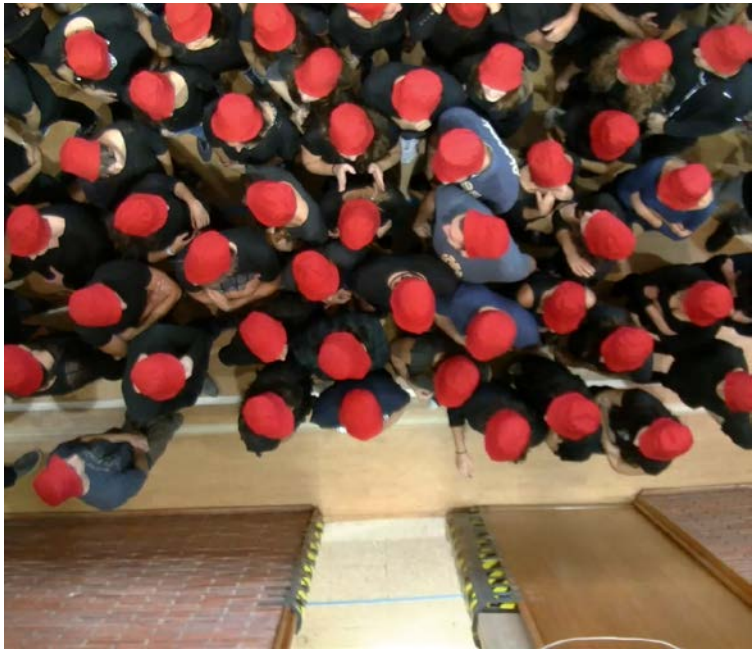
Experiments Garcimatin et al. 2016*

Two width 0,69 m and 0,75 m

Three level of competitiveness: low, medium and high

Instruction: Exit the room and follow these rules

- Low: avoid intentional contact
- Medium: soft physical contact is allowed
- High: moderate pushing is allowed



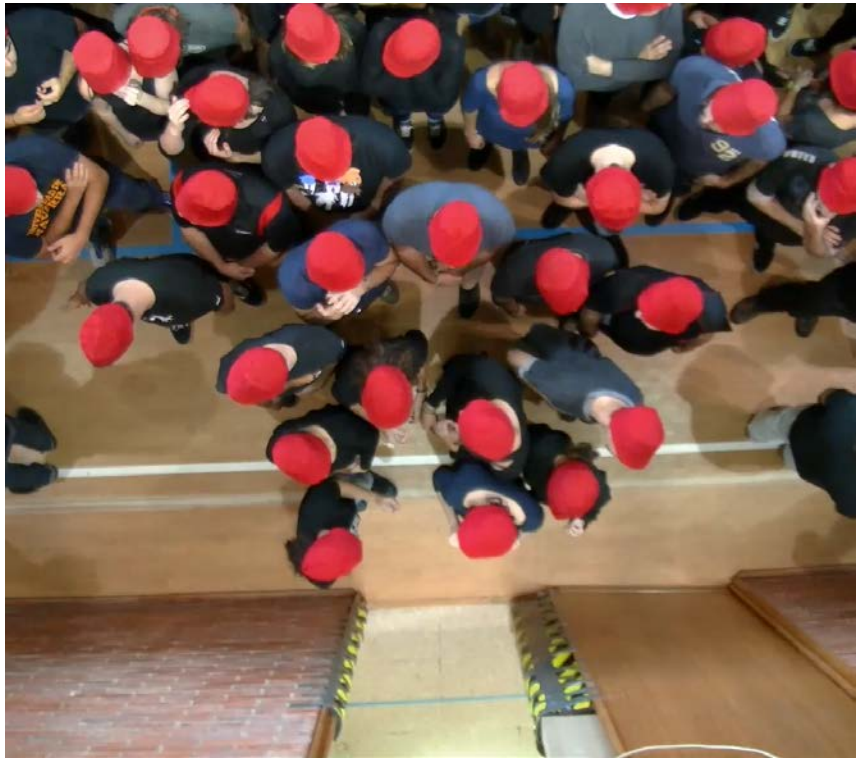
Video by: A Garcimartín *et al* 2018 *New J. Phys.* **20** 123025

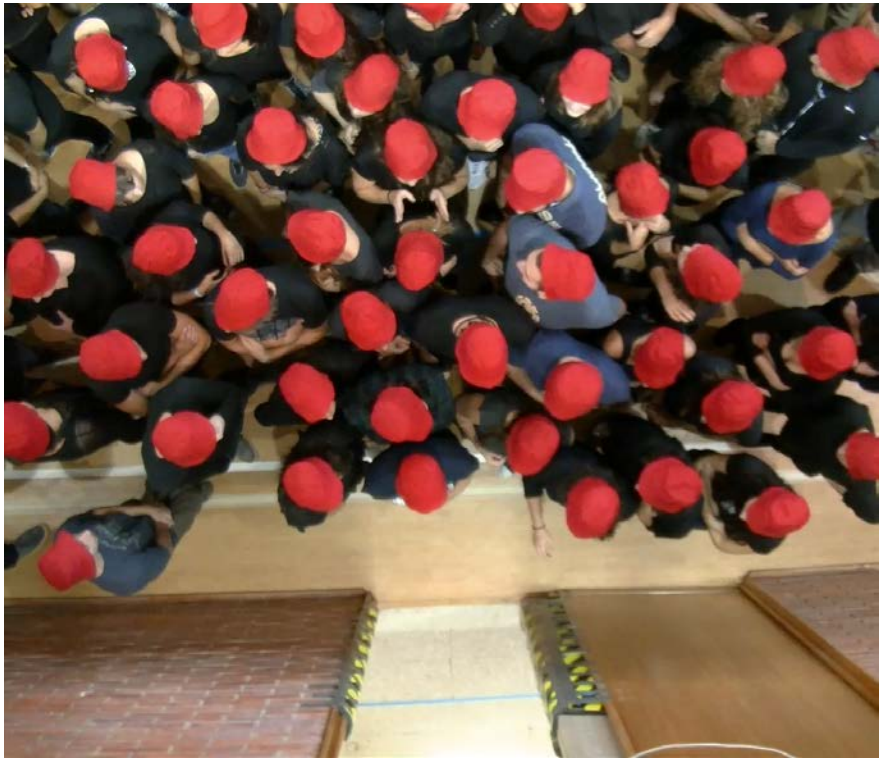
Table 1. Number of runs and passage times for each experimental situation.

	LD HC	LD LC	SD HC	SD MC	SD LC
Number of runs	8	5	13	10	10
Total number of passage times	682	420	1241	970	920

*Garcimartín, Parisi, Pastor, Martín-Gómez, Zuriguel, Flow of pedestrians through narrow doors with different competitiveness, J. Stat. Mech, 043402, 2016

Experiments Garcimatin et al. 2016*





Videos by: A Garcimartín *et al* 2018 *New J. Phys.* **20** 123025

*Garcimartín, Parisi, Pastor, Martín-Gómez, Zuriguel, Flow of pedestrians through narrow doors with different competitiveness, J. Stat. Mech, 043402, 2016

Experiments Garcimatin et al. 2016*

Probability of blockages increase with the level of motivation / competition

Low motivation *Medium motivation* *High motivation*

Figure from Garcimatin 2016, see *

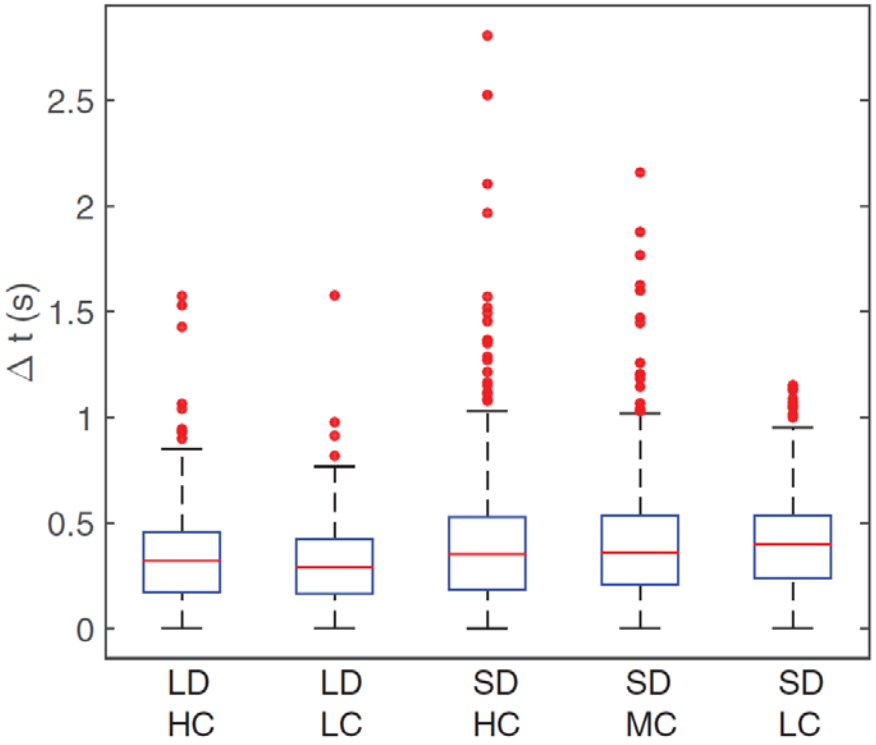
*Garcimartín, Parisi, Pastor, Martín-Gómez, Zuriguel, Flow of pedestrians through narrow doors with different competitiveness, J. Stat. Mech, 043402, 2016

Experiments Garcimatin et al. 2016*

The probability of clogs increases leading to extreme events with large interruptions of the flow Δt

But even if high competition increase the probability of clogs it does not change the flow significantly.

$$J = \frac{1}{\overline{\Delta t}}$$



LD door width 0,75 m
SD door width 0,69 m
HC, MC LC: High, Medium and Low competitiveness

Figure from Garcimatin 2016, see *

*Garcimartín, Parisi, Pastor, Martín-Gómez, Zuriguel, Flow of pedestrians through narrow doors with different competitiveness, J. Stat. Mech, 043402, 2016

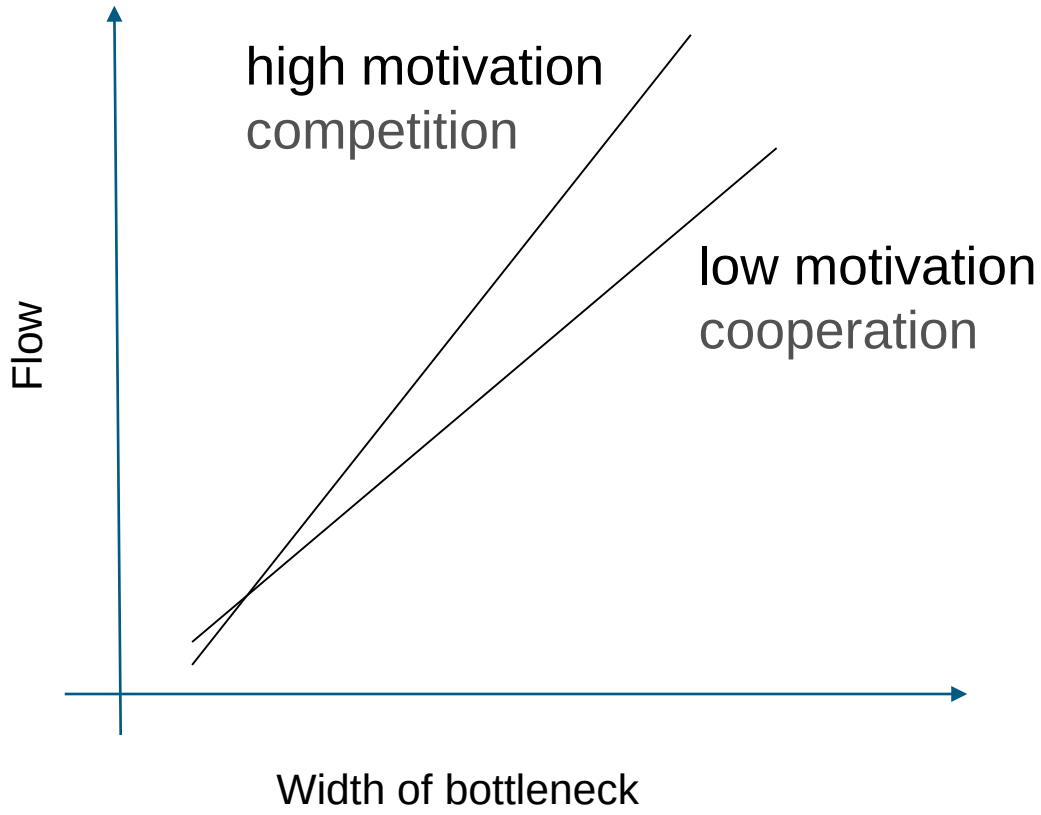
Bottleneck flow, motivation and clogging

Summary: motivation, clogging and flow

- In general a high motivation improves the flow
  (people move faster, fill gaps, get closer)
- High motivation and competition could increase the probability of clogs
- Probability of clogs depend on the width of the bottleneck. At wide bottlenecks the probability is very low. Only for small width the probability increases
- A negative effect of motivation on the flow is only evident
  at bottlenecks of small width ($b \approx < 1$ m) and in competitive settings.

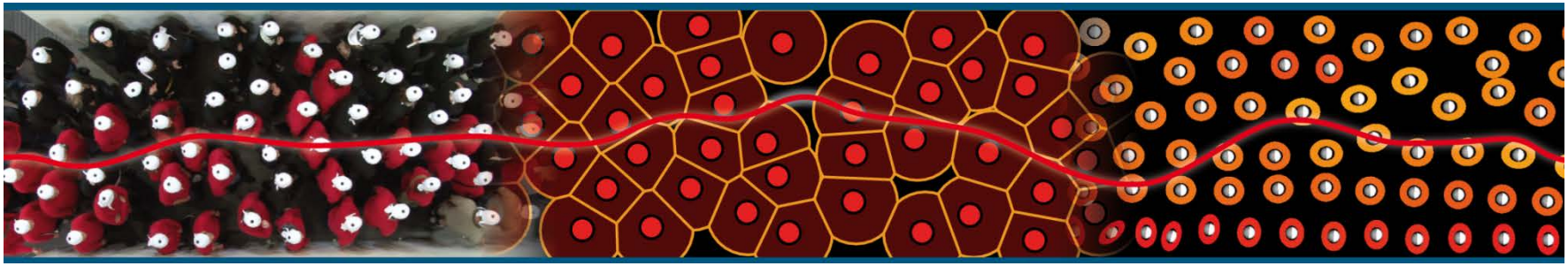
Summary

Principle sketch for the relation of the bottleneck width and the flow for different degrees of motivation



Density in front of the bottleneck

Experiment I



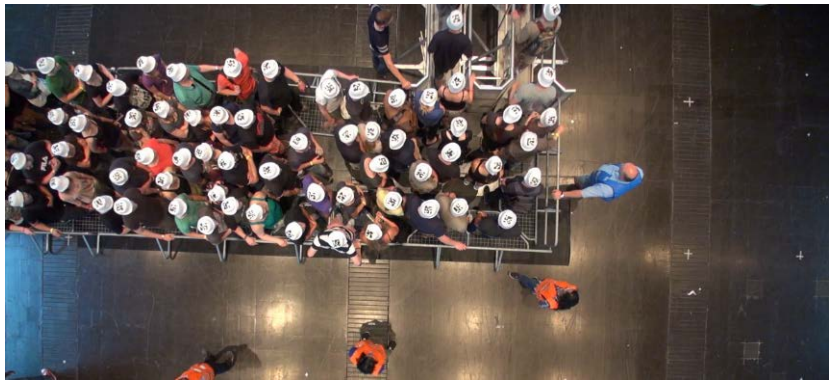
Spatial structure and behaviour of visitors (concert)

Spatial structure of the barriers

- Simple barrier with entrances, Test persons form a semicircle
- Corridor leading to the entrances

Advise to test person

- "… *concert of your favorite artist … you want to get a place near to the stage … try to be one of the first passing the entrance...*"



*Sieben, Schuhmann, Seyfried, Collective phenomena in crowds - Where pedestrian dynamics need social psychology, PLoS ONE 12(6): e0177328, 2017

Spatial structure and behaviour of visitors (concert)

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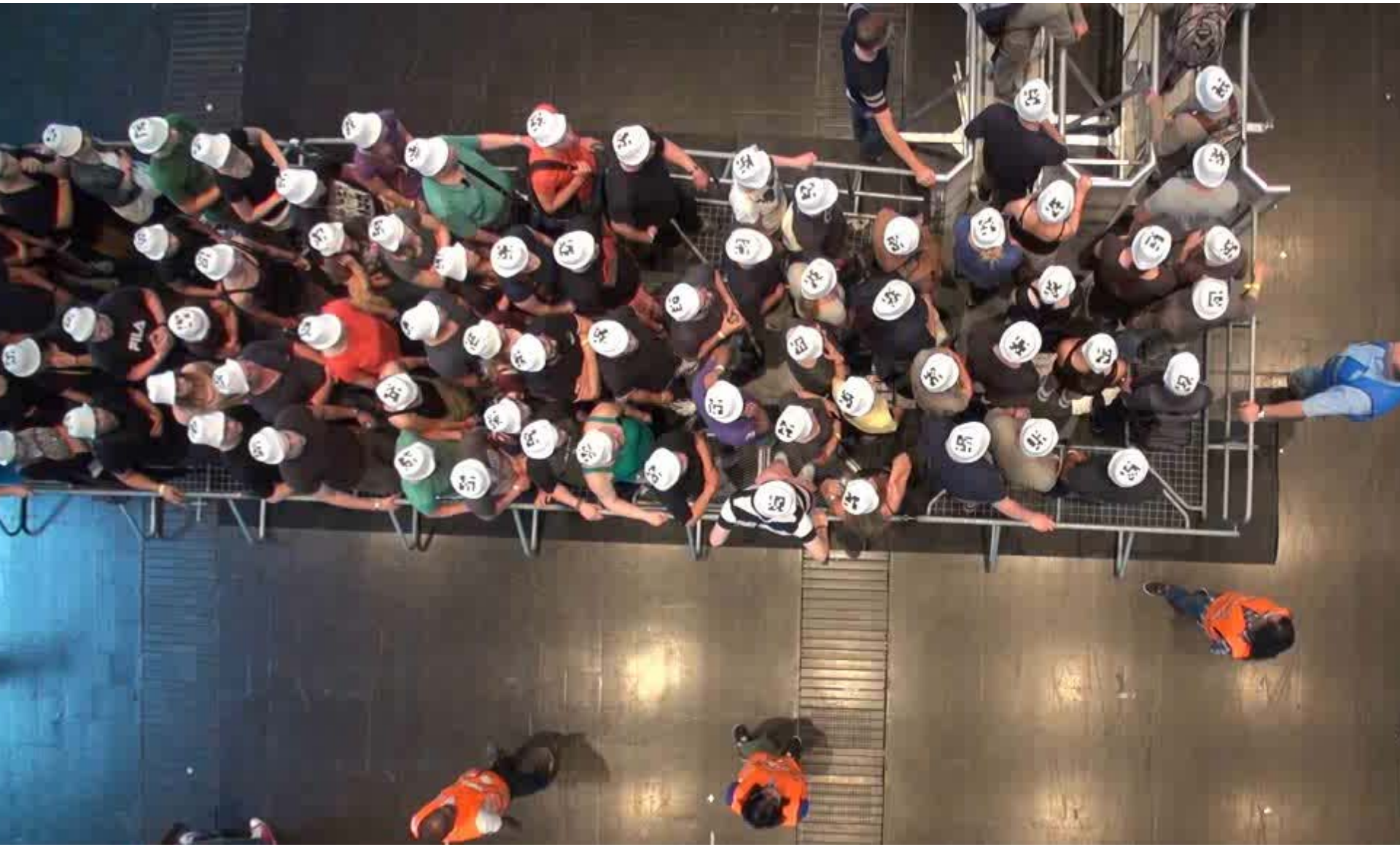
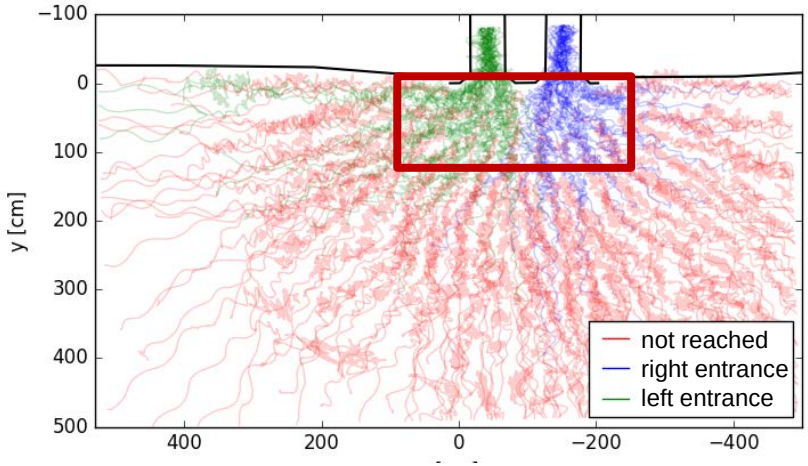
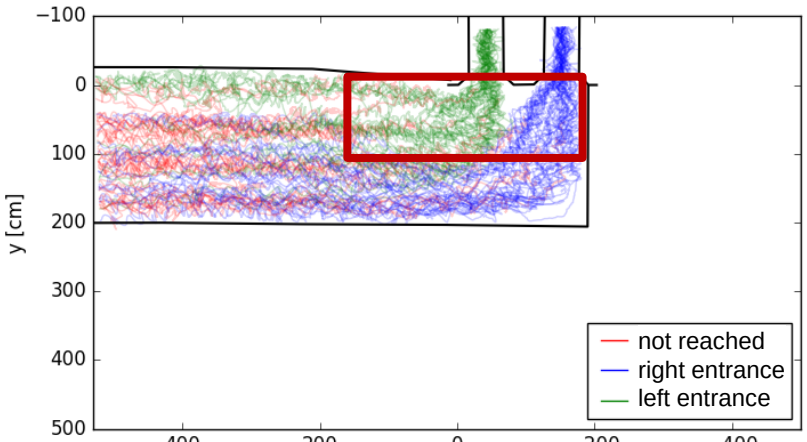
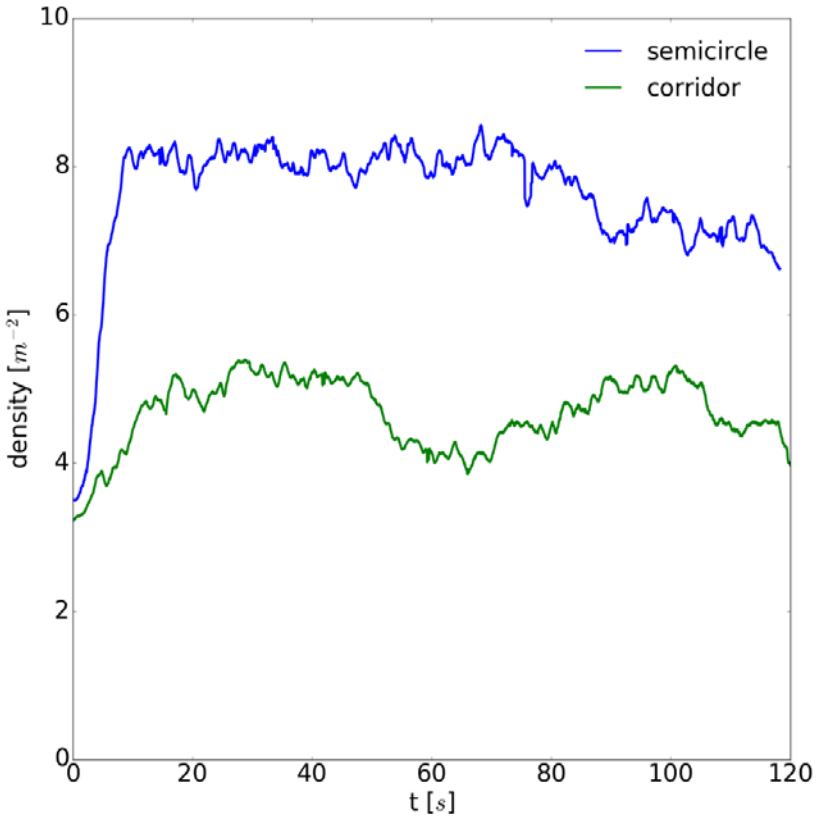


Density and fairness of the procedure

Trajectories and time series of the densities







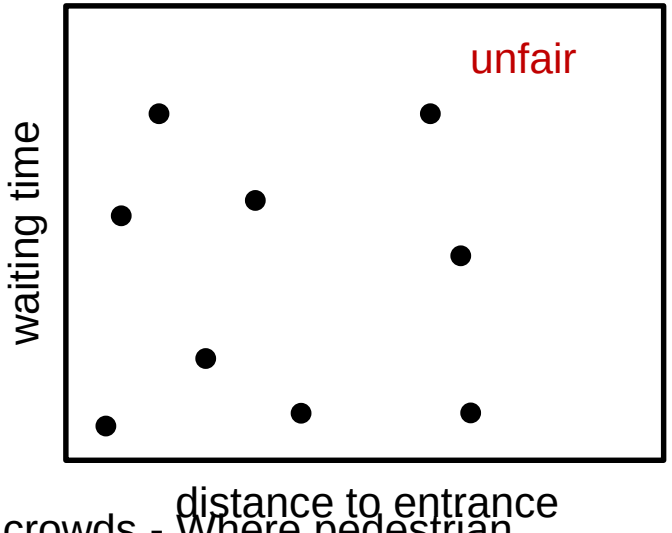
*Sieben, Schuhmann, Seyfried, Collective phenomena in crowds - Where pedestrian dynamics need social psychology, PLoS ONE 12(6): e0177328, 2017

Density and fairness of the procedure

Fairness

(given a position at t=0 in front of the entrance)

- Correlation between waiting time and distance to the entrance
- Fair procedure -> strong correlation
- Unfair procedure -> no correlation

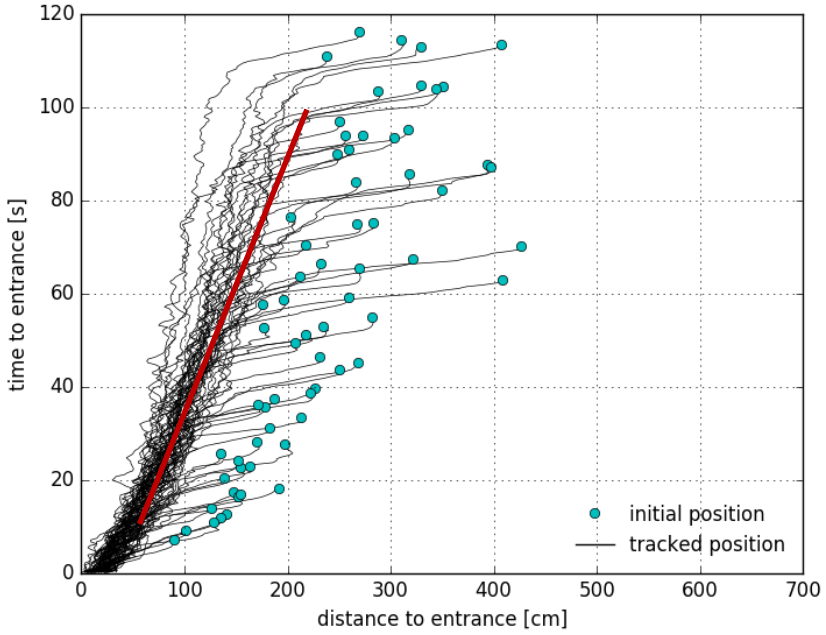


*Sieben, Schuhmann, Seyfried, Collective phenomena in crowds - Where pedestrian dynamics need social psychology, PLoS ONE 12(6): e0177328, 2017

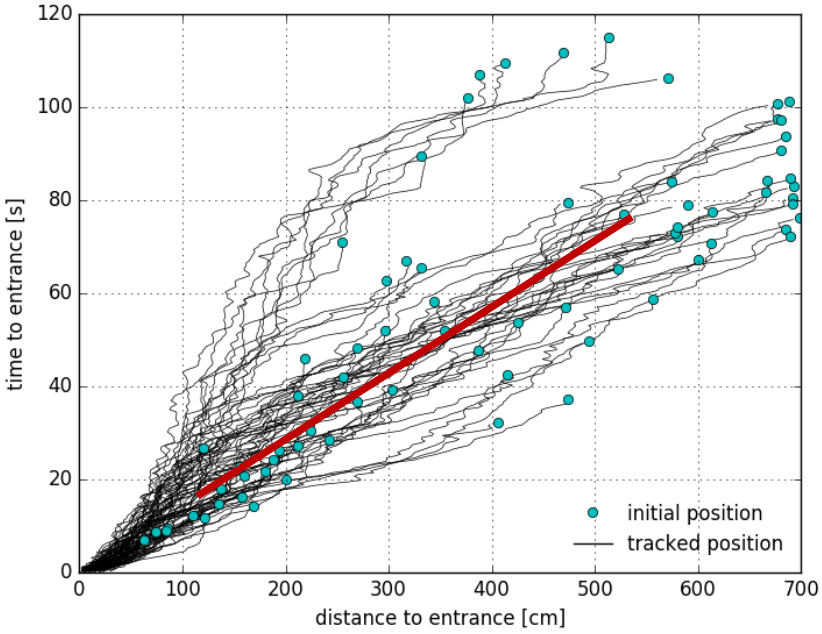
Density and fairness of the procedure

Fairness: correlation between waiting time - distance to the entrance

Semicircle



Corridor

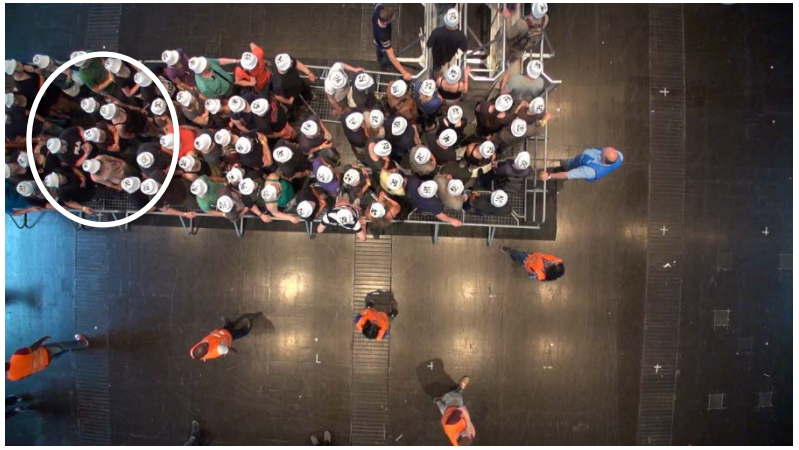


	Semicircle		**Corridor**	
	Slope	Cor. coef.	Slope	Cor. coef.
Time interval [20s,80s]	0.51 [s/cm]	0.91	0.13 [s/cm]	0.82

Questionnaire study – design

In follow-up to the experiments (around one year later):

Freeze frames and videos were shown to 60 students (Sociology and Civil Engineering). Instruction: Imagine to be located somewhere in the ellipses



freeze frames semicircle → questionnaire „before“ → video semicircle → questionnaire „after“

freeze frames corridor → questionnaire „before“ → video corridor → questionnaire „after“

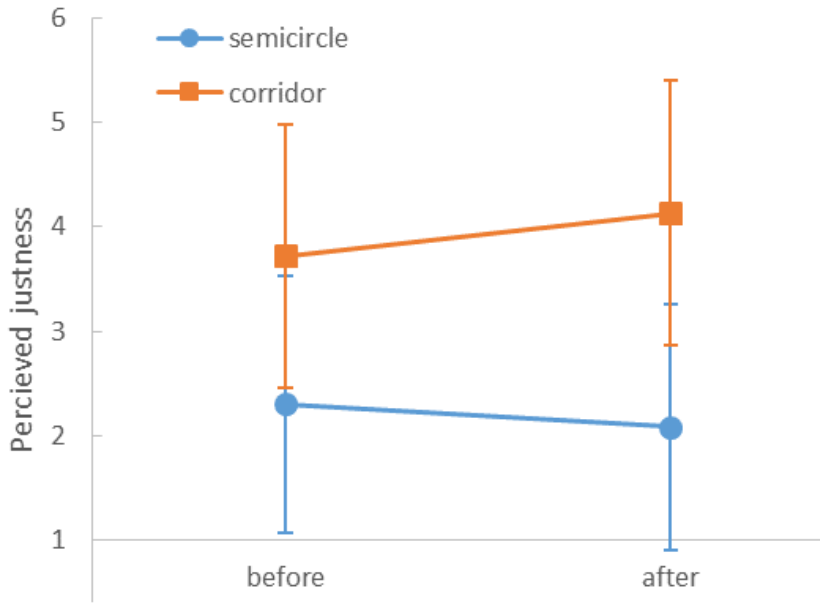
Questionnaire study – design

The questionnaire (originally in German) contains four main items: justness, progress, comfort, contribution to access faster

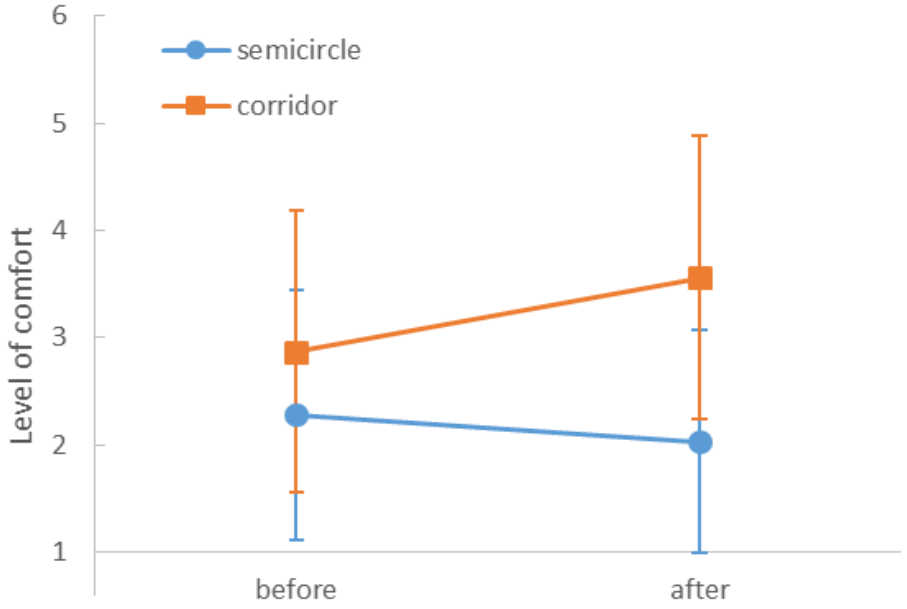
1. How just is this entrance procedure?
   (6-point scale, 1=very unjust, 6=very just)
2. How likely is it that you will be one of the first 100 who are able to access the concert?
   (6-point scale, 1=very unlikely, 6=very likely)
3. How comfortable do you feel?
   (6-point scale, 1=very uncomfortable, 6=very comfortable),
4. Can you contribute to accessing the concert faster?
   (yes/no)
   and in addition strategies for being faster were requested
   (open-ended question),
5. Which rules apply? (open-ended question)

Questionnaire study – results

Question 1: Perceived justness (scale 1 to 6)



Question 3: Level of comfort (scale 1 to 6)



Questionnaire study – results

Questions: Forms of inappropriate behaviour

Semicircle	Corridor
• pushing and shoving (35)	• pushing and shoving (16)
• pushing someone aside (11)	• slightly pushing and shoving (4)
• jostling (9)	• jostling (3)

Question: Strategies to contribute for faster access

Semicircle	Corridor
• pushing and shoving (25)	• pushing and shoving (21)
• using and filling gaps (10)	• staying on the left hand side (11)
• using elbows/arms/shoulders (9)	• using and filling gaps (4)

Questionnaire study – results

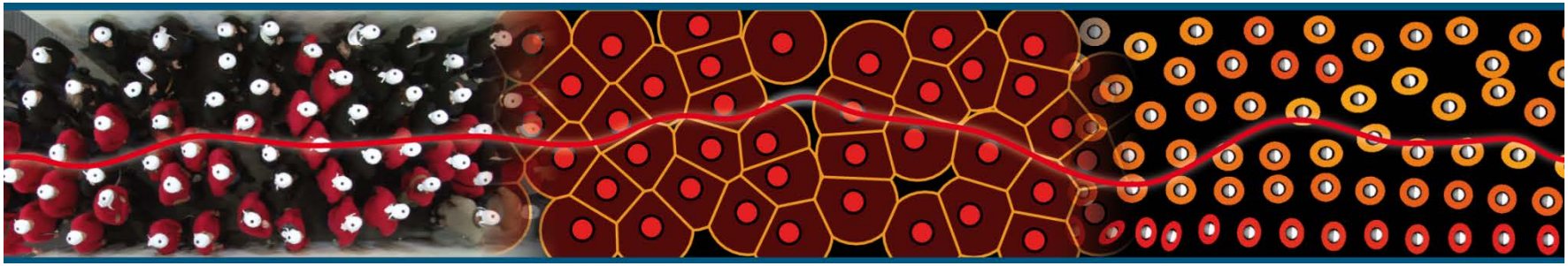
Questions: Which rules apply?

Semicircle	**Corridor**
• The strongest wins / right of the strongest (15) • No rules (15) • First come, first served (7)	• Norm of queuing / lining up (16) • Orderly behavior (11) • Pushing and shoving are forbidden (10)

(#) frequency of occurrence;
three most frequently mentioned only

Density in front of the bottleneck

Experiment II

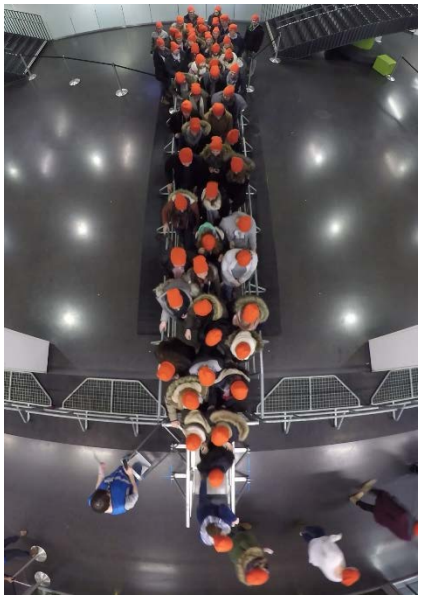


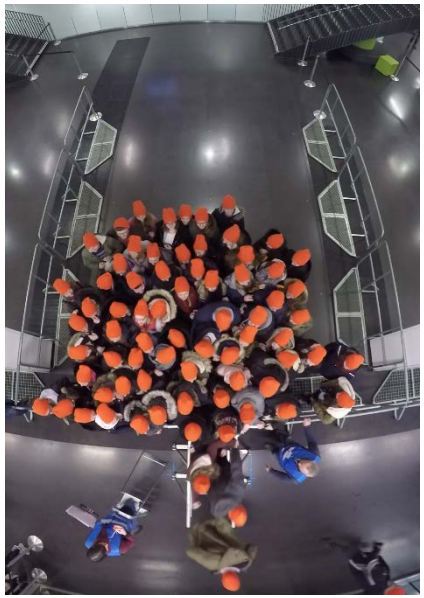
Experiment II

Question: When do participants queue and when do they start pushing?

Investigation:

- Influence of corridor width and motivation on
- density and waiting time
- velocity
- queuing or pushing





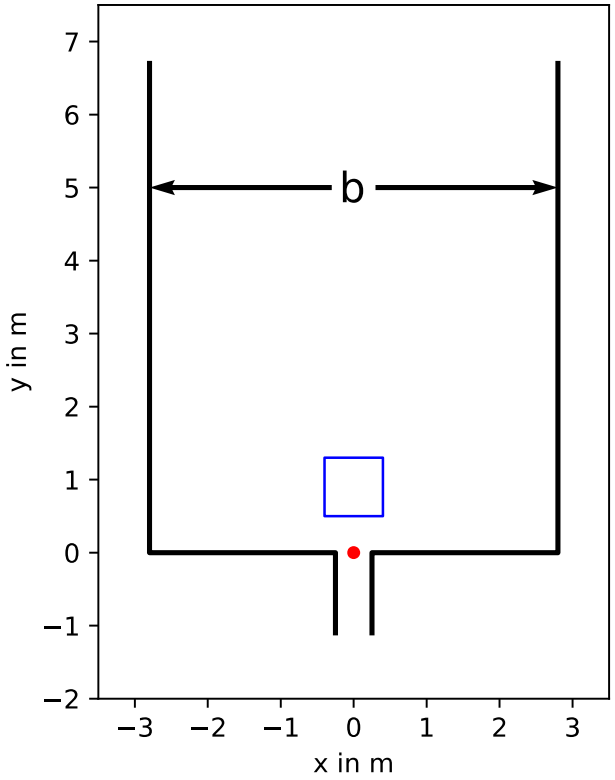
Experiments performed January 2017 at the University of Wuppertal with students (between two lectures)

Experiment II

Setup of the boundaries and variations

b	1.2 m	2.3 m	3.4 m	4.5 m	5.6 m
N	11, 24, 25, 63	20, 42	22, 67	42, 42	57, 75
h	hi, lo	hi, lo	hi, lo	hi, lo	hi, lo

- ***b*****:** corridor width
- ***N*****:** number of participants
- ***h*****:** degree of motivation



Motivation

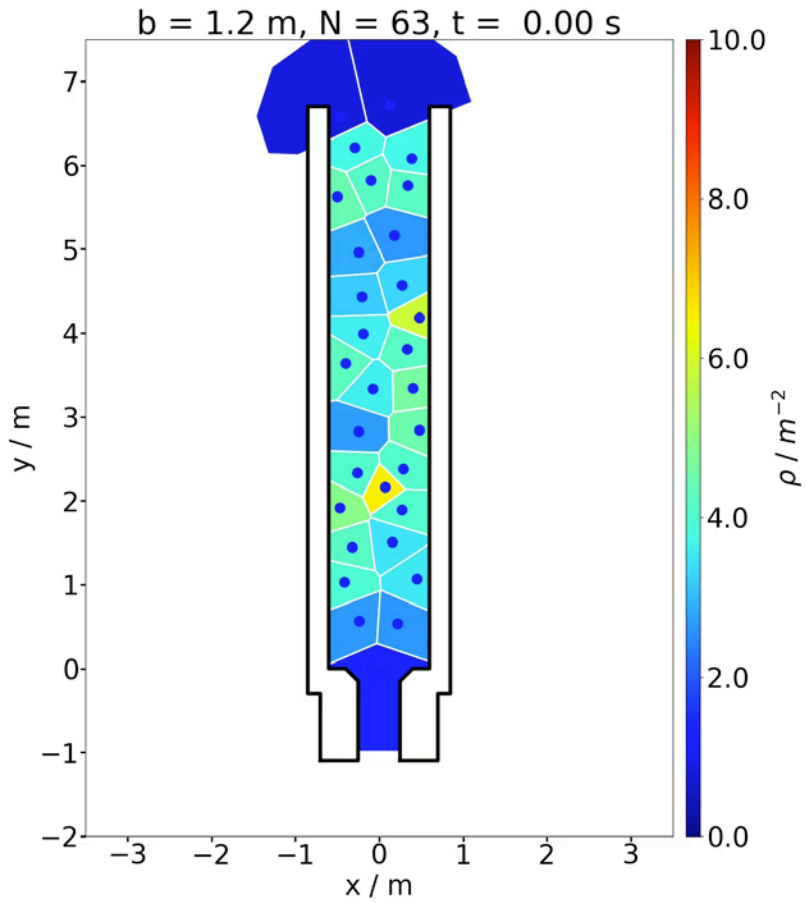
- **Scenario:** entrance to the concert of a favorite artist/band
- **High Motivation:** only the first of the audience will have an undisturbed view of the stage
- **Low Motivation:** the complete audience will have an undisturbed view of the stage

Experiment II

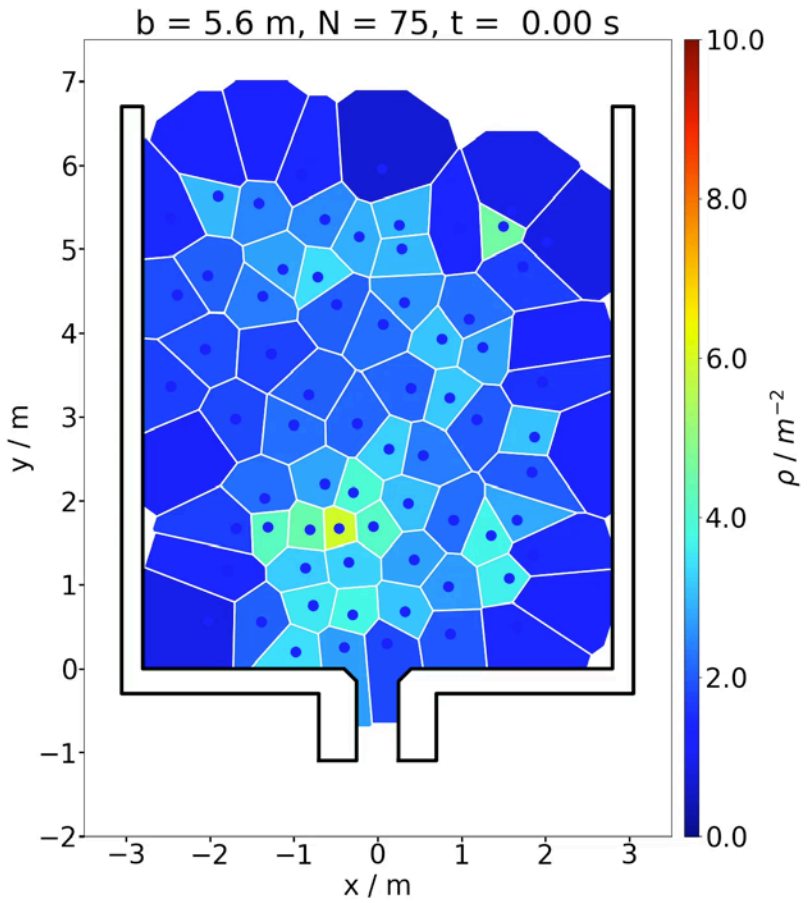
***b* = 1.2 m, *N* = 63, *h* = high**

***b* = 5.6 m, *N* = 75, *h* = high**

Experiment II



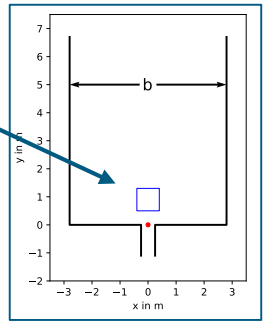
***b* = 1.2 m, *N* = 63, *h* = high**



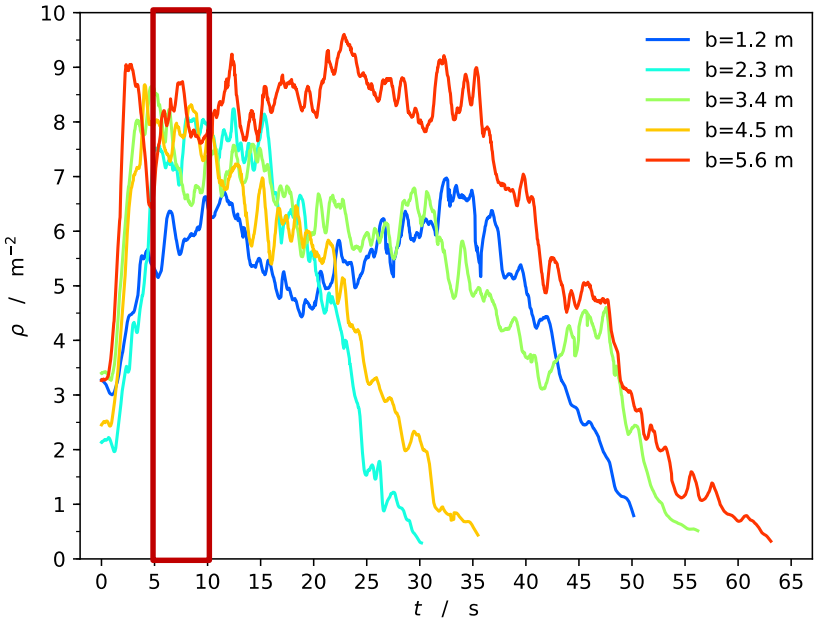
***b* = 5.6 m, *N* = 75, *h* = high**

Experiment II – Density time-series

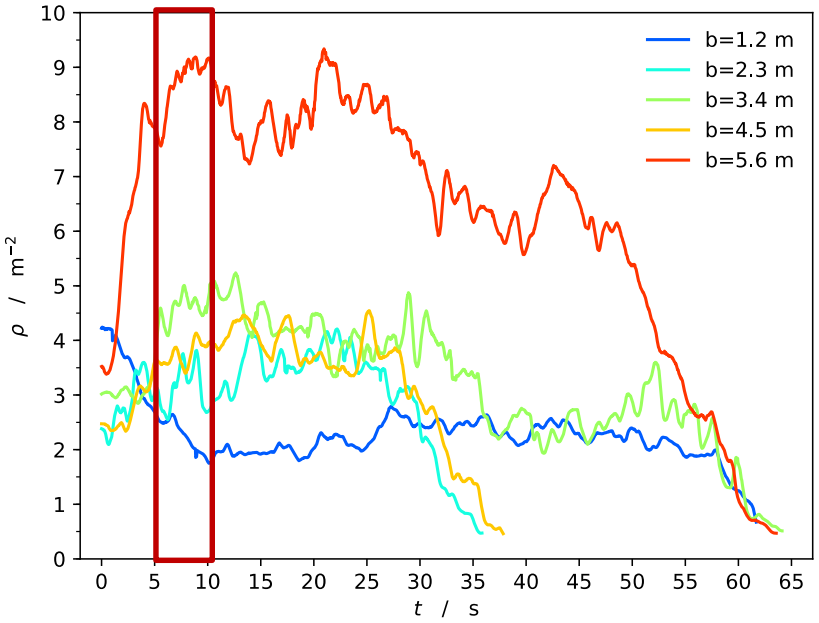
Mean density within the measurement area



High Motivation



Low Motivation



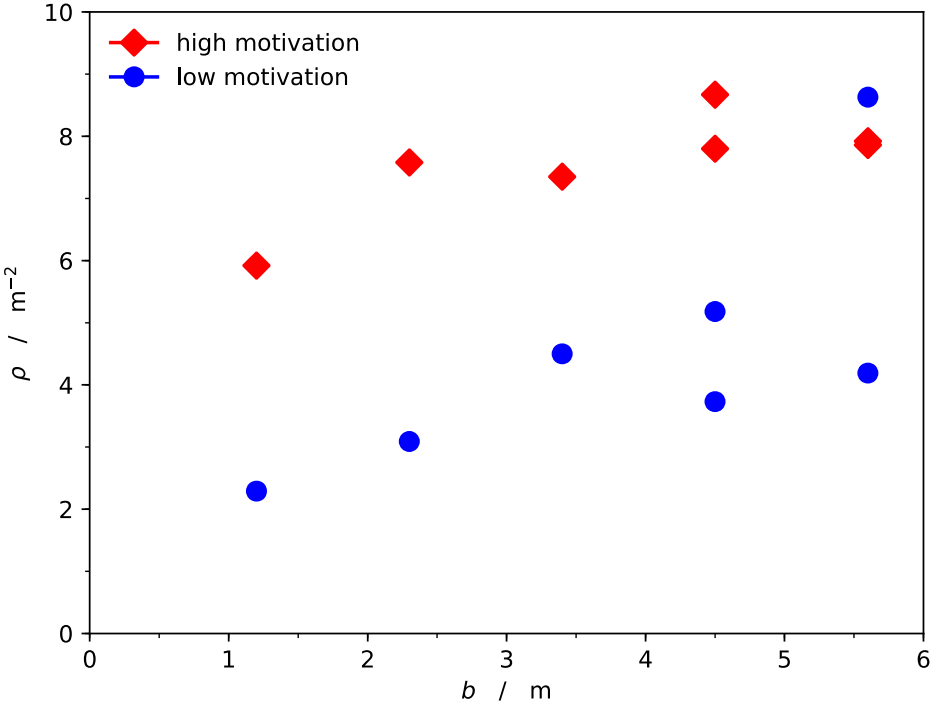
Experiment II – Mean density (5-10 s)

Results

- Density increases with increasing corridor width
- 2 Density-Levels: dependent on degree of motivation

Assumption

- Higher density rather indicates a pushing than a queuing behavior!

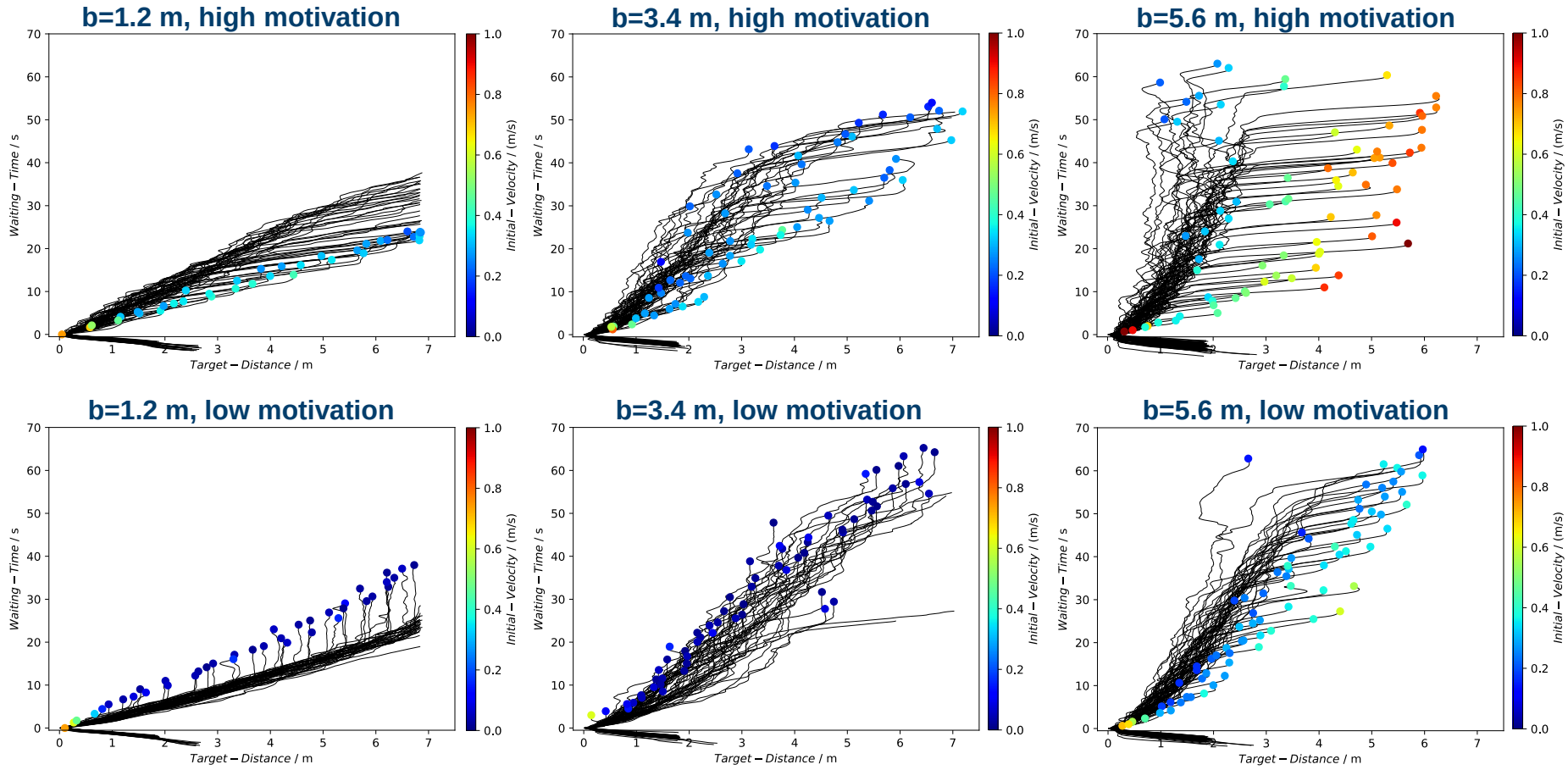


Experiment II – Mean density (5-10 s)

High Motivation

Low Motivation

Experiment II – Waiting time



Summary and outlook

We observed both, queuing and pushing behavior

Pushing is indicated by

- high density
- high initial velocity

High density is facilitated by

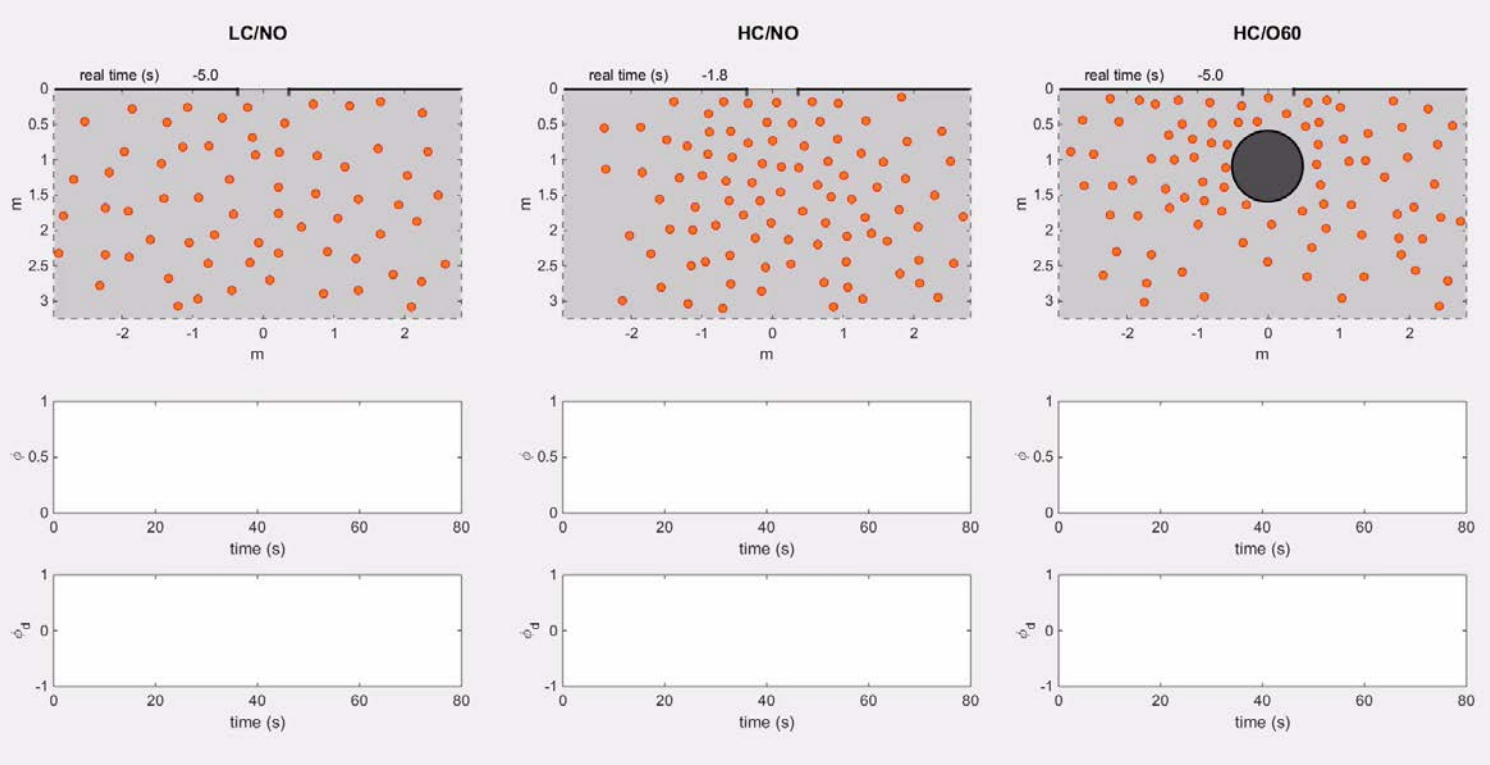
- increasing the corridor width
- increasing the degree of motivation (e.g. by introducing rewards)

Clogging only at small doors with minor relevance for large crowds

Summary and outlook

Other risks in densely packed crowds

- Collective transversal movement
- Tripping and falling



Video by: A Garcimartín *et al* 2018 *New J. Phys.* **20** 123025

Summary and outlook

Other risks in densely packed crowds

- Collective transversal movement
- Tripping and falling

Video: Experiments performed by Majid Sarvi, University of Melbourne, 2018

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