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Social dynamics in emergency evacuations: Disentangling crowd's attraction and repulsion effects

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HIGHLIGHTS

- Investigating the social dynamics during emergency escape of crowds.
- Revisiting the accuracy of distance-based attraction/repulsion force categorisation.
- Distance not an accurate factor for formulating direction or magnitude of social force.
- Social forces do not act in isolation and are moderated by physical environmental factors.
- Social forces are also moderated by crowd's jam/move status.

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ABSTRACT

The social dynamics of crowds in emergency escape scenarios have been conventionally modelled as the net effect of virtual forces exerted by the crowd on each individual (as self-driven particles), with the magnitude of the influence formulated as decreasing functions of inter-individual distances and the direction of effect assumed to be transitioning from repulsion to attraction by distance. Here, we revisit this conventional assumption using laboratory experimental data. We show based on robust econometric hypothesis-testing methods that individuals' perception of other escapees differs based on whether those individuals are jamming around exit destinations or are on the move towards the destinations. Also, for moving crowds, it differs based on whether the escape destination chosen by the moving flow is visible or invisible to the individual. The presence of crowd jams around a destination, also the movement of crowd flows towards visible destinations are both perceived on average as repulsion (or disutility) effects (with the former showing significantly larger magnitude than the latter). The movement of crowd flows towards an invisible destination, however, is on average perceived as attraction (or utility) effect. Yet, further hypothesis testing showed that neither of those effects in isolation determines adequately whether an individual would merge with or diverge from the crowd. Rather, the social interaction factors act (at significant levels) in conjunction with the physical factors of the environments (including spatial distances to exit destinations and destinations' visibility).

In brief, our finding disentangles the conditions under which individuals are more likely to show mass behaviour from the situations where they are more likely to break from the herd. It identifies two factors that moderate the perception of social interactions, "crowds' jam/movement status" and "environmental setup". Our results particularly challenge the taxonomy of attraction–repulsion social interaction forces defined purely based on the distance of the individual to the surrounding crowd, by showing that crowds could be in far distance and yet be perceived as repulsion effect, or they could be in close distance and yet act as attraction effect.

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1. Introduction

In many contexts of decision making, individuals are exposed to the aggregate or disaggregate information from the choices and actions of other agents. It has been well documented in the literature that this social interaction can heavily affect the decision patterns emerged at macro-scale level in dynamic and adaptive systems [1,2]. This phenomenon has in particular, been investigated and modelled in financial decision-making contexts [3–6]. The tendency to imitate the actions and decisions of others is also referred to as "herd behaviour" in social sciences literature [7–9], and is believed to be a major source of volatilities and bubbles in financial markets [10,11]. The phenomenon is also often referred to as "behavioural contagion" [11,12] among social scientists.

A particular context of decision making in which the social interactions can be regarded as a major influential factor is when an emergency arises in a crowded confined space [13–15]. The crowd has to be evacuated and each individual has to make navigational choices that lead him/her out in the least amount of time. Individuals, however, are heavily exposed to the decisions of others by observing their movements and actions. Also, the normal capacities available per individual may drop as a result of the sudden and simultaneous rush of all occupants to exits, making decision makers encounter complex trade-offs in choosing their survival strategy. The question arises as to how the social interaction impacts on the evacuees' decision-making behaviour and whether or not this effect will give rise to an alignment of their decisions.

The complex social interactions of escaping crowds have been conventionally modelled by assuming escapes as self-driven particles whose movement decisions are determined by the net sum of the interplay between abstract forces exerted by the surrounding particles in conjunction with the direction of movement intended by the particle [16–19]. These interaction forces are typically classified into "repulsion", "attraction" and "friction" forces [13,16,20–28]. A large body of literature has suggested mathematical formulations of these forces as functions of spatial inter-participle distances [29,30]. These approaches have assumed that as distance increases the magnitude of repulsive forces decreases [16] and/or repulsion will transition to attraction [22]. The fact that these heuristic approaches are based on virtual non-measurable forces and that they are purely axiomatic modelling paradigms has made these underlying assumptions difficult to be validated against empirical evidence.

The literature on this topic also offers a great deal of anecdotal evidence suggesting that herd behaviour will emerge during emergency escapes of humans in crowded spaces [17], and this has largely been attributed to the so-called state of "panic" [31–33]. It has been assumed in a number of theoretical work that when escaping from a threat, "people show a tendency towards mass behaviour, that is, to do what other people do" [17]. In other words, herd behaviour has been assumed by a considerable body of literature (mostly theoretical studies) as a common default behavioural feature of pedestrian evacuees. This assumption has also exerted significant influences on many models of crowd simulation [17,22, 34–37].

To our knowledge, however, there is very little empirical knowledge about this problem and what we know so far is largely based on observation of this phenomenon (i.e. imitative behaviour) in other contexts such as the movements of animal groups [38–40], the actions of financial agents (in stock markets for instance) [41,42] or the leader–follower effect observed in consensus decision making of moving human groups (in experimental contexts) [43,44] that do not necessarily compare with the context of emergency escape. It can be plausible assumed that crowd evacuations are more similar to a complex adaptive system [45] in that agents compete for limited resources (here, capacities) rather than group consensus decision making. From this point of view, we also see significant contextual differences between decisions made during emergencies and those made in financial markets since financial decisions such as those made in stock markets might not necessarily represent the elements of competition for limited resources which is an inherent feature of crowd dynamics in emergencies.

In relation with our topic in hand, a growing body of literature has been emerging recently based on a limited number of empirical studies suggesting that navigational decisions in emergencies are outcomes of (possibly suboptimal but) rational trade-offs between a number of contributing factors, rather than purely panic-driven irrational or random behaviour [46–49]. It has been suggested that, rather than going through an inaction phase or purely random behaviour [50–54] people do make sensible decisions for their survival based on the amount of information available to them (which may or may not be the most accurate information and thus may or may not result in the best possible decision).

As one of the few studies that have addressed the particular effect of social interactions, Bode and Codling [46] concluded from their computer-based game-like experiments that evacuees' decisions are outcomes of trade-offs between a range of factors rather than being determined by single rules such as imitation. They did not observe any meaningful tendency of imitative behaviour in their experiments. Subsequent more recent studies based on hypothetical choice experiments by the authors of the current article further corroborated this finding [48,55–59]. A large criticism levelled at the studies based on hypothetical choice or game-type experiments, however, is that it is not clear how realistically they replicate the social interactions as a major contextual factor of evacuations. In addition, it has on the other hand been well documented in the literature of crowd dynamics that individuals try to avoid heavily crowded areas that cause extra delay for their escape [60]. In the context of exit choice in particular, the occupant density has been shown as a significant attribute that affect the desirability of an exit choice [60]. Yet, it is not clear how this effect can be assimilated with the herd-behaviour assumption that assumes agents to conform to the majority and thus join the heavy crowd flows. A major challenge towards addressing this question is how to disentangle the relative contribution of the various factors that might potentially impact on the navigational choices of evacuees, and how to create such interactions in laboratory environments.