Journal Pre-proof

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PII: S0379-7112(20)30062-X

DOI: https://doi.org/10.1016/j.firesaf.2020.103018

Reference: FISJ 103018

To appear in: *Fire Safety Journal*

Received Date: 10 January 2020

Accepted Date: 28 April 2020

Please cite this article as: A. Cuesta, O. Abreu, A. Balboa, D. Alvear, Alone or with others: Experiments on evacuation decision making, *Fire Safety Journal* (2020), doi: https://doi.org/10.1016/j.firesaf.2020.103018.

Alone or with others: experiments on evacuation decision making

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Highlights:

- Individuals alone and with others are compared in evacuation experiments.
- Large groups perform better than small groups and isolated individuals.
- Social influence determines exit choice behaviour.
- Future research may focus on social ties and leadership behaviour.

Abstract:

A common assumption is that the way occupants respond in fires will be significantly influenced by whether they are alone or with others. However, experimental evidence of this is limited. Here we compare the evacuation decision-making of isolated individuals vs individuals in small-groups of 5 and 12-13 members. Experiments reveal that large groups are significantly more efficient than smaller groups and individuals alone. We also find that social influence is determinant for exit choice behavior in individuals. The results are consistent with recent findings attesting to the positive/negative effects of the social influence during evacuation.

Keywords: Human behaviour; Social influence; Experiments; Fire safety.

Nomenclature listing table:

j	experimental condition: isolated (j_1); five-person group (j_5); twelve-person group (j_{12}).	ξ_E	uniformity of exit selection ($0.5 \leq \xi_E \leq 1$)
t_{exit}	room exit time (s)	γ_{BC}	behavioural cohesion coefficient (from 0 to 1)
E_i	available equivalent exit (i=1,2)		

1. Introduction

In case of fire, individuals have to make decisions, for example about which protective actions to perform, when to perform them and which direction towards a safe location. Thus, understanding how such decisions are made is of crucial importance. Indeed, the study of evacuation decision-making has been of interests to researchers across different disciplines including psychology, sociology, computer science and engineering [1].

An important focus in the literature is the investigation of social interactions assessed via multiple approaches. First, analysis of collective evacuation behaviour has shown that individuals interact collectively to redefine the new situation [2], create new norms and propose actions, which are product of a milling and keynoting process [1, 3,4]. People cooperate [5-7], form groups during response and movement phases of evacuation [3, 4, 8-13], care of one another in their group [14, 15] and can put themselves in danger while helping others [16].

Second, analysis of affiliative behaviour has shown that individuals with close psychological ties will attempt to escape with other group members and maintain group cohesion during evacuation movements [17, 18]. Third, analysis of social influence has shown that person's role influence on the group actions [19] and that individuals are less likely to react if others were not reacting [20] but likely to begin evacuation if they see others evacuating [4, 14, 21]. Based on these results, one can state that the response of evacuees in a group is likely to be different than the response of evacuees in isolation. Experimental studies to contrast and compare the behaviour of groups and individuals have been conducted in several disciplines (for references see [22-29]). While some results provide evidence that groups are more effective than individuals other studies report no difference or even worse performance of groups. However, to our knowledge, there is a lack of experimental evidence on this in the field of human behaviour in fire.

To address this, we conducted laboratory evacuation experiments. The primary goal of this study was to draw conclusions about the influence of social interactions during the pre-evacuation period. The question of interest was whether others produce a significant change in evacuation decision-making of individuals. Participants either alone, in groups of 5 or in groups of 12-13 were performing a bogus task in the centre of a small room with two equivalent exits. Suddenly, a fire alarm went off. The exit time and the exit door used by each participant were observed and statistical analyses were conducted to compare evacuation decision-making of individuals across the different conditions. A post-experiment questionnaire allowed us to investigate participants impressions and behaviours during the experiment, previous experience and training and possible suspicious about the experimental procedure.

Our experimental design was intended to be simple and easy for replication. The dependent variables were directly related to evacuation decision-making and straightforward to collect and measure. Participants were unaware of the experiment's purpose and they had little interaction with the experimenters. However, based on our experience in evacuation experiments, a simple alarm sounder is likely to be insufficient to trigger evacuation [10,11]. Therefore, we provided some additional cues to ensure participants acted as expected. The groups were defined to be small enough to facilitate intragroup communication (i.e. all group members can interact with each other).

2. Method

2.1 Participants

A deliberate effort was made to recruit a representative sample of population. Seventy-five able-bodied participants between 18 and 60 years (28 male; M=34.46, SD= 13.46 and 47 female; M=40.6, SD=13.40) were included in the experiments. They were volunteers recruited by a company and covered with casualty insurance. Written consent was obtained, and all participants were paid for participation. They were randomly assigned to three groups (25 per group). A third of the participants each were assigned to alone condition (j_1), five-person group condition (j_5) and twelve-person group condition (j_{12}). Table 1 displays the number, age and gender of participants in each experiment. 58 % of participants had gotten some training in fire safety. The majority of participants (90.2%) never or hardly ever been in the building. The average degree of familiarity between participants was M=0.34(SD=0.24) for j_5 condition and M=0.30(SD=0.15) for j_{12} condition on a scale of 0 to 1.

The study was approved under the University of Cantabria Human Research Ethics Board, and all participants signed informed consent documents upon commencing the protocol.

	Alone (j_1)	Five-person (j_5)	Twelve-person (j_{12})	Total (%)
Female	15	17	15	62.66
Male	10	8	10	37.33
Age [M(SD)]	40.04(13.30)	33.92(15.67)	40.52(11.08)	38.16(13.63)

Table 1. Demographics of participants per experiment.

2.2 Procedure

The experiments took place on 24th November 2018 at a building of the University of Cantabria, Spain. Participants registered at the waiting room and were given a colored vest with a number in order to be identified during the experiment (Figure 1). Then, they received basic information (e.g. following the instructions, withdraw rights and not using their mobile phones) and were given evacuation charts of the waiting room and the experiment room, as required by the safety unit of the university. However, participants were naïve as to the purpose of the experiment as they were told that they were going to fill out a questionnaire and being interviewed afterward. After given consent, participants were accompanied by two experimenters from the waiting room to the experiment room (Figure 2).

Fig. 1. Giving instructions to groups of participants after registration in the waiting room.

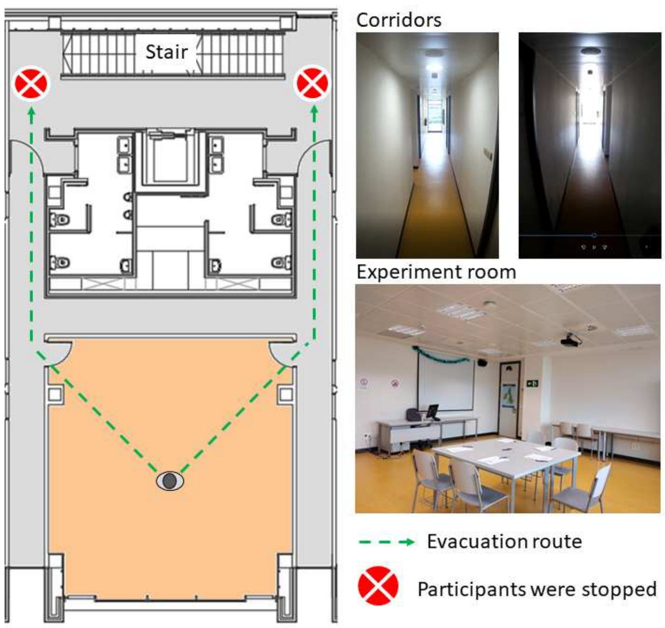

Fig.2. The experiment room consists of a small room (8.2 x 8.86 m) with two exits (0.8 m wide) leading to corridors towards a stair. The exit doors are visible and equidistant.

Experimenters did not interact with participants and gave single word responses or shrug when asked. In the experiment room, participants were explicitly told that they should sit down and fill out a questionnaire that was actually a bogus task to engage them in an activity while avoiding their tendency to ignore the alarm. Hence, the questionnaire included questions about basic data (age, gender, vest colour and vest number), evacuation related tasks (i.e recognition of fire emergency signals from images and a simple evacuation maze) and personal perception of safety & security (current level of terrorism alert and actions in case of a terrorist attack). Two minutes later, the alarm (an annoying siren) sounded. The trials were finished when participants left the room and the experimenter stopped participants as soon as they reached the stair (Figure 2).

The same procedure was conducted for three blocks of trials (Figure 3). The first block involved 25 trials to test individuals in alone condition (j_1), the second block involved five trials to test individuals in five-person condition (j_5) and the third block involved two trials to test individuals in twelve-person condition (j_{12}). Note that this block involved two groups of 13 and 12 members respectively. Finally, participants were administered a short questionnaire. Example of common questions from the questionnaire are: 1) previous knowledge before the experiment, 2) first thought when the alarm went off, 3) secondary cues considered to evacuate, 4) stress level perceived (four-point Likert scale from *none* to *high*). Additionally, example of questions for small groups are: 1) group members you are familiar with, 2) perception of group decision mechanism (*unanimous/ majority*/*leader* and 3) own role perception in decision-making (*leader/follower*).

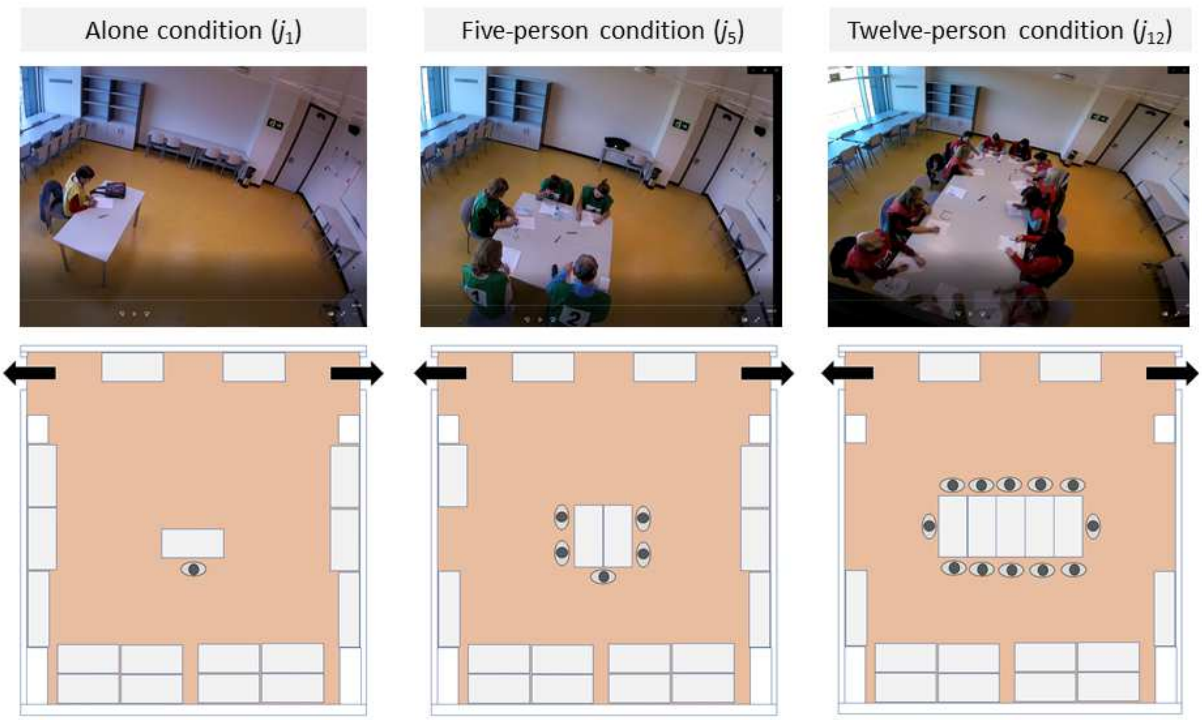

Fig. 3. Participants were seated in the centre of the room. For five-person (j_5) and twelve-person (j_{12}) conditions participants were seated in a pattern that facilitated the visual/verbal communication.

2.3 Measures

The exit time defined as the length of time each participant remained in the room before leaving to evacuate the building was the main dependent variable of the study. This variable is used to measure the efficiency of evacuation decision-making. Additionally, we consider as dependent variable the exit used by each participant to leave the room. This variable is used to measure the social influence in exit choice behaviour.

Five video-cameras were used to capture the response of participants. The cameras were positioned at ceiling height to improve the vantage point and hid with Christmas decorations. Three cameras were placed in the experiment room (two cameras over the exits and one camera on the projector attached to the roof in the centre of the room) and other two cameras outside the experiment room over the doors of the corridors. The video-recordings (images at 30 frames/s) were analysed. The exit time was taken at a specific frame when the body of each participant crossed the exit door. The frames associated were then noted and the associated times logged to establish the sample values (in sec). The exit used by each participant was also registered from the video recordings. The datasets generated and analyzed during the current study are available from corresponding author upon request.

We treated each participant as providing independent data in our statistical analysis. To test data for normality we conducted Anderson Darling test from which the following p-values obtained: j_1 condition, $p<0.01$, j_5 condition, $p<0.001$, and j_{12} condition, $p= 0.327$. The majority revealed significant deviations from normality, necessitating the use of non-parametric testing procedures. For each measure we thus conduct Mann-Whitney U test (MW) and two samples Kolmogorov-Smirnov test (KS) to compare the independent samples. We selected these two tests in order to perform a more rigorous analysis because KS is sensitive to any differences in the two distributions and MW is mostly sensitive to changes in the median. We also conduct two tests to compare variances Levene's test (L) and Brown-Forsythe test (BF). While L test assesses the statistical dispersion around the mean BF test uses the dispersion around the median which if useful when samples are expected to be very skewed (skewness <-2 or >2). We used an alpha level of 0.05 for all statistical tests.

Confident intervals of the population proportion that use a given exit is calculated for isolated individuals and hypothesis test for a proportion conducted (H0: p=0.5, α=0.05, two tailed). The uniformity of the selection of a given exit E_i (i=1,2) for m group members is measured ($\xi_E = m_{E_i}/m$). Obviously $0.5 \leq \xi_E \leq 1$, where a 0.5 value corresponds with heterogeneity and a value of 1 denotes total consensus and uniformity in exit selection (i.e. all group members choose the same exit).

2.4 Results

Data from two participants were removed because they reported in the questionnaire that they were fully aware of the evacuation beforehand. As a result, 23 isolated individuals (j_1 condition) were included in the final analysis.

All participants evacuated the experiment room. This is *conditio sine qua non* for the current analysis. Apart from the alarm, the secondary cues reported by participants were: *evacuation charts provided beforehand* (j_1=71%; j_5=64%; j_{12}=52%), *questions of the bogus task* (j_1=19%; j_5=0%; j_{12}=4%), *emergency signs* (j_1=10%; j_5=12%; j_{12}=0%), *and actions of others* (j_5=24%; j_{12}=44%).

In the post-experiment questionnaire, participants also reported lower perceived stress in j_{12} condition compared to j_1 condition ($p<0.0001$, Fisher' exact test), but no difference was found between j_5 and j_1 conditions ($p=0.5842$, Fisher' exact test).

Figure 4 shows the box plot for exit times and Table 2 the statistical characteristics of the samples of the independent samples for experimental conditions.

Table 3 displays the statistical tests results. The comparison of the empirically observed exit times show that participants in j_5 and j_{12} conditions on average left the room faster than isolated participants j_1. Here we obtain null results for j_1 vs j_5 condition. However, this difference is significant for j_1 vs j_{12} condition.

Our comparison of the Standard Deviation across conditions show that the amount of variation systematically differ in j_1 from j_5 and j_{12} conditions (Table 3). The statistical dispersion which denotes behavioural variability is lower for group members than isolated individuals.

Characteristics	**Condition**		
	j_1	j_5	j_{12}
Sample size	23	25	25
Mean	61.48	26.94	30.78
Median	17.45	22.39	29.00
StDev.	78.29	10.06	7.82
Asymmetry	1.37	0.35	0.17
Skewedness	0.25	-1.52	-1.25
95th percentile	221.06	41.99	43.27
Minimum	12.31	14.41	18.78
Maximum	254.31	43.81	44.41

Table 2. Statistical characteristics of exit times (s).

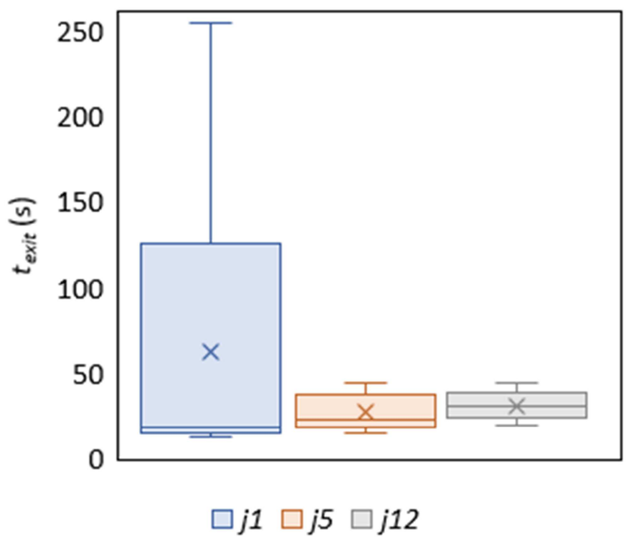

Fig. 4. Box plot of exit times.

Pair of conditions	**MW**	**KS**	**L**	**BF**
j_1 vs j_5	H_0: 1.55 < 1.96	H_0: 0.26 ≤ 0.39	H_1: 40.865 ≥ 4.001	H_1: 5.798 ≥ 4.001
j_1 vs j_{12}	H_1: 2.38 ≥ 1.96	H_1: 0.48 ≥ 0.39	H_1: 44.549 ≥ 4.001	H_1: 6.373 ≥ 4.001

Table 3. Hypothesis testing results when comparing independent samples (α=0.05).

To further explore the behaviour of individuals in group we perform the method proposed in [10]. First, we test the following statistical hypothesis to confirm collective behaviour of participants:

$$H_0: UCV_i < LCV_t$$
$$H_1: UCV_i \nless LCV_t$$

Where UCV_i is the upper confidence interval for the coefficient of variation of the exit times in the *i-th* group (CV_i) and LCV_t is the lower confidence interval for the coefficient of variation of the same variable of all groups formed for each condition (CV_t.) There are various methods available in the literature for estimating the confidence interval for the CV [30,31]. Here we used Median Modified Miller Estimator (Med Miller) [32, 33] and the Median Modified Curto and Pinto's with iid assumption (Med C&P) [34]. The null hypothesis failed to reject in most cases providing a *prima facie* evidence of collective behaviour in participants (Table 4).

Second, we measure the behavioural cohesion by a coefficient γ_{BC}= 1- (CV_i / CV_t) to determine the degree of dispersion in individual exit times i.e. the closer the γ_{BC} value to 1 the lower the dispersion (i.e. the greater cohesiveness in participants).

Results reveal a strong behavioural cohesion of groups in j_5 condition and a moderate behavioural cohesion in participants of groups under j_{12} condition (Figure 5).

Condition-trial	CV_i	CV_t	**Med Miller**			**Med C&P**		
			UCV_i	LCV_t	H_0:	UCV_i	LCV_t	H_0:
j_5-1	0.051	0.381	0.086	0.478	F	0.083	0.486	F
j_5-2	0.044	0.381	0.076	0.478	F	0.073	0.486	F
j_5-3	0.050	0.381	0.084	0.478	F	0.081	0.486	F
j_5-4	0.037	0.381	0.064	0.478	F	0.061	0.486	F
j_5-5	0.113	0.381	0.193	0.478	F	0.185	0.486	F
j_{12}-1	0.143	0.267	0.201	0.186	R	0.184	0.188	F
j_{12}-2	0.109	0.267	0.154	0.186	F	0.141	0.188	F
F= Fail to reject; R= Reject								

Table 4. Statistical test results for collective behaviour (α=0.05).

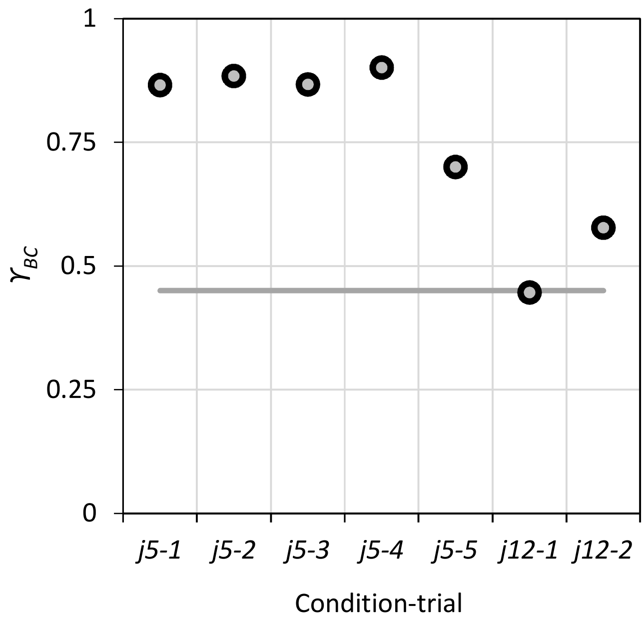

Fig.5. Behavioural cohesion of groups (j_5 and j_{12} conditions) during experiments. The closer the γ_{BC} coefficient to 1 the more uniformity of group members. Horizontal dashed lines indicate the minimum threshold to confirm collective behaviour (γ_{BC} > 0.45).

In line with these results, the decision mechanism perceived by participants was for j_5 condition *unanimous* (64%), *majority* (36 %), *leader* (0%) and for j_{12} condition: *unanimous* (48%), *majority* (48 %), *leader* (4%) with a significant difference between conditions (p=0.01418, Fisher-Freeman-Halton exact test). The own perceived role in decision-making reported by participants *leader/follower* differs between conditions with more *follower* roles in j_{12} condition than j_5 condition (p=0.04207, Fisher' exact test).

Next, we examine exit choice behaviour. Note that the exits are equivalent (i.e. identical and equidistant). The only difference between both exits is that participants entered the experimental room by one of them. For individuals in j_1 condition, two related hypotheses are tested: Hypothesis 1: Everyone leaves by the exit they entered and Hypothesis 2: Exit choice is equiprobable.

12 individuals left the experiment room by the exit the entered (p = 0.5217±0.2041) and 11 by the other exit (p = 0.4783±0.2042). Thus, Hypothesis 1 can be immediately rejected. A Tests with One Sample, Dichotomous Outcome is conducted to test Hypothesis 2 (H_0: $\hat{p}_{E_1}$ = 0.5; H_1: $\hat{p}_{E_1} \neq 0.5$). The condition is $min\left(n \cdot \hat{p}_{E_1}, n \cdot \left(1 - \hat{p}_{E_1}\right)\right) = min(11{,}12) \geq 5$, where n is the number of exits and $\hat{p}_{E_1}$ is the proportion of participants using one exit. Hence:

$$z = \frac{\hat{p}_{E_1} - 0.5}{\sqrt{\frac{0.5 \cdot (1-0.5)}{n}}} = -0.2081 \tag{1}$$

and for a significance level of α=0.05 (z*= 1.96), |z|<z*, therefore in j_1 condition individuals are equally likely to selected one or another exit.

Finally, we investigate exit choice behaviour for j_5 and j_{12} conditions. All participants from each group of the independent trials reached a consensus decision regarding the exit used to leave the room (ξ_E=1). Individuals of groups $j_{5\text{-}3}$ and $j_{12\text{-}1}$ left the experimental room by the exit they entered and the rest of individuals from groups $j_{5\text{-}1}$, $j_{5\text{-}2}$, $j_{5\text{-}4}$, $j_{5\text{-}5}$ and $_{j12\text{-}2}$ used the other exit.

3. Discussion

The aim of this study was to investigate the influence of social interactions on evacuation decision-making of individuals. We used a simple room-evacuation test with participants either alone (j_1) or with others in groups of five (j_5) and twelve (j_{12}). We examined two main measures: the time to start a purposive evacuation and the exit choice behavior.

Our results show that the number of people around (group size) may affect individual evacuation behaviors. The decisions made by evacuees collectively in large groups were more effective than decisions made by evacuees in smaller groups and evacuees alone. Note that all groups were small enough to provide the possibility to direct intragroup communication at any time. Participants in groups of twelve (j_{12}) started evacuation significantly faster than participants alone (j_1). However, this difference was not significant in groups of five (j_5). These exploratory findings put us in the position to suggest that evacuation performance may improve as the group size increases. In other words, that social interactions are likely to help evacuation decision of individuals. However, when interpreting these results, readers should keep in mind the limitations such as the groups composition with some participants who knew each other (degree of familiarity M=0.34(SD=0.24) for j_5 condition and M=0.30(SD=0.15) for j_{12} condition on a scale of 0 to 1) and the fact that information was common to all group members (i.e. clues provided beforehand) thus the fire alarm was unexpected but less ambiguous than in a real fire situation.

Pre-existing social structure (e.g. family members, work mates and friends, strangers) influence on evacuation decision-making [5, 9]. Also, in a fire situation there can be different unfamiliar/ambiguous cues (e.g. smoke, lighting fails, text messages, sirens). Groups may perform better when the information is common to all group members rather than when there is a need of information sharing within the group [35]. It therefore remains an open question for further research to investigate the impact of pre-existing social relationships in small-groups under different threat cues, which has not been considered in this study.

We hope that the present results contribute to the literature on human behavior in fire. Previous research on social influence mostly focused on negative consequences (i.e. individuals are less likely to react if others were not reacting) [20]. Nevertheless, as reported by the authors this prediction shows nothing about the original question of behaviour of freely interacting groups. Overall, the presented results are consistent with recent studies demonstrating the potential benefits of interacting with others and the notion that social influence can improve evacuation decision-making [21].

Interestingly, observations indicate large amounts of variance in isolated individuals contrasted with behavioural cohesion of group members. This can be interpreted in two ways. First, an isolated evacuee may respond faster or slower than the average group members depending on for example whether he/she is well-trained or not. This suggests that evacuees who are alone not always respond more rapidly to an emergency [20]. Second, the lower variability denotes that attitudes within groups tend to converge and that each individual is likely to be guided by the reactions of others. While some participants assumed a leadership role, other participants copied their reactions. After the alarm was triggered, most participants stopped the bogus task, looked around and started to talk to each other whereas others continued the bogus task. But the decision to start evacuation was dictated by few participants who stood up first closely followed by the rest of participants. This observed leadership role appears to be a central mechanism to positively encourage individuals to start the evacuation. The reported decision mechanisms (*unanimous/majority/leader*) and own roles perceived (*leader/follower*) were significantly different between j_5 and j_{12} conditions. Participants in smaller groups (j_5 condition) reported playing a more active role in group decision-making and being more stressed than participants in large groups (j_{12} condition). However, this contrast with the observed evacuation efficiency. A possible explanation of this might be that the larger the group the smaller the proportion of informed individuals (leaders) needed to achieve an efficient decision-making [36]. Future research should investigate this, for example, testing the efficiency of democratic vs despotic decision-making in the context of fire evacuation.

Additionally, the experiments allowed us to examine the exit choice behaviour. Participants had a binary choice of two equivalent exits with the difference that they were slightly familiar with one of them (i.e. they used it to access the experiment room). We found no preference in the exit selection for isolated participants (j_1 condition). Both exits were equally likely to be used.

Moreover, we confirmed that social influence can be a major contributing factor in exit selection. In each trial of j_5 and j_{12} conditions all participants chose the same exit to leave the room. This result is consistent with previous research [10, 37-39] suggesting that individuals interpret the exit selection of others as the correct one and they do not want to choose the alternative (equivalent) exit not previously chosen by the majority. However, the impact of others in evacuation route selection may have negative effects, for example, people may choose a congested exit or longer and even dangerous evacuation routes.

The current study has several strengths. First, it adds to the literature of evacuation behaviour, which predominantly has been concerned with individual outcomes. In addition, it is important to extend our understanding of social influence on decision-making beyond the pre-evacuation period. Second, the experimental design used in this study balances tight experimental control (precise and independent measurements of individual and group performance) with transparency (straightforward to be accurately reproduced or replicated by interested parties). Third, rather than undergraduate students the present study involves a representative sample with participants of age ranged between 18 and 60 years. Fourth, we proposed and used two novel methods to: 1) measure the behavioural cohesion among evacuees and 2) test the exit choice behaviour that can be applied in other studies.

The current study also has its limitations. First, small sample sizes were used n=23 in j_1 condition, n=25 in j_5 condition and n=25 in j_{12} condition. Further replication of this experiment involving more participants is highly desirable. Second, the sample lacks gender balance with most female participants (62.33 %). Third, non-parametric tests were used having less power in predictions. Fourth, fire alarm was unexpected but less ambiguous than in a real situation. Fifth, the groups formed were mixed (individuals who knew each other and individuals who did not know each other). Therefore, neither the response of individuals in groups with strong affinity between members nor the response of individuals in groups with no affinity are addressed in this study. As mentioned, it therefore remains an open question for further research to investigate the impact that pre-existing social relationships can have upon the emergency decision and protective actions.

Practical implications of our findings can be divided in two directions. First, despite social influence is important, most of current evacuation models simulate agents as if they were not influenced by others. One agent can start the evacuation while others remain in the same room/place [40]. In other words, no social influence is represented. There are methods for modelling the collective behaviour. However, to our best knowledge, this is not supported by empirical data. This paper aims to contribute to the field of human behaviour in fire by providing data and empirical evidences for evacuation modelling approaches. For instance, implementing the same pre-evacuation time distribution to all occupants/agents could be a good approach for some scenarios but potentially unrealistic for other scenarios [11, 12]. Similarly, evacuation routes selected by agents should not be only based on minimum distances applied by the current models. The impact of familiarity and social influence should be considered to represent evacuation behaviour. Second, our results suggest that the actions and decisions of others can have positive and negative effects during evacuation. Individual factors influence decision-making of others during building fires. An important factor identified in this study is training. 58 % of participants had gotten some training in fire safety. It is argued here that few trained persons can assume leadership roles likely to have a positive effect on several of their nearby neighbours [21]. This needs to be tested and confirmed in the future.

4. Conclusions

Primary questions concerning human behaviour during evacuation process include how individuals interact and how this impact on life safety. Using a simple experimental approach, the current study analyses evacuation decision-making of individuals suggesting positive and negative effects of other people in the same conditions. Overall, our findings show that experience of interacting with others may lead evacuees to respond faster but may limit their escape alternatives. This paper provides an exciting opportunity to promote the importance and study of social influence and group behaviour in fire safety science.

5. Acknowledgements

The authors would like to thank the European Commission for the LETS-CROWD project received funding from the Horizon 2020 Research and Innovation Programme under the grant agreement Nº 740466 and the Spanish Ministry of Economy and Competitiveness for DEFENDER Project Grant, Ref: BIA2015-64866-R, co-funded by ERDS funds. Moreover, authors thank the suggestions, experiences, and comments from LEAs involved in LETS-CROWD project.

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Figure captions

Fig. 1. Giving instructions to different groups of participants after registration and before the experiments in the waiting room.

Fig. 2. The experiment room consists of a small room (8.2 x 8.86 m) with two exits (0.8 m wide) leading to corridors towards a stair. The exit doors are visible and equidistant.

Fig. 3. Participants were seated in the centre of the room. For five-person (j_5) and twelve-person (j_{12}) conditions participants were seated in a pattern that facilitated the visual/verbal communication.

Fig. 4. Box plot of exit times.

Fig.5. Behavioural cohesion of small-groups (j_5 and j_{12} conditions) during experiments. The closer the γ_{BC} coefficient to 1 the more uniformity of group members. Horizontal dashed lines indicate the minimum threshold to confirm collective behaviour (γ_{BC}> 0.45).