Emergency evacuation in a supermarket during a terrorist attack: towards a possible modelling of the influence of affordances on the evacuation behavior of agents in a complex virtual environment

Satya Lancel, Vincent Chapurlat, Gérard Dray, Sophie Martin

Journal of Safety Science and Resilience 4 (2023) 139–150

Science Press

Contents lists available at ScienceDirect

Journal of Safety Science and Resilience

journal homepage: http://www.keaipublishing.com/en/journals/journal-of-safety-science-and-resilience/

Emergency evacuation in a supermarket during a terrorist attack: towards a possible modelling of the influence of affordances on the evacuation behavior of agents in a complex virtual environment

Satya Lancel[1,*], Vincent Chapurlat[2], Gérard Dray[3], Sophie Martin[1]

[1] EA 4556 EPSYLON, Univ Paul Valéry Montpellier 3, EPSYLON EA 4556, F34000, Montpellier, France
[2] Laboratoire des Sciences des Risques (LSR), IMT Mines Ales, Ales, France
[3] EuroMov Digital Health in Motion, Univ Montpellier, IMT Mines Ales, Ales, France

ARTICLE INFO

Keywords:
Human behavior in emergency situations
environmental affordances
multi-agent systems
signage
emergency exits
supermarkets

ABSTRACT

During a terrorist attack on a supermarket, the use of emergency exits is essential for effective evacuation and saving lives. However, people tend to ignore emergency situations. This behavior can lengthen evacuation times, endanger individuals, and even prove fatal. In this context, we conducted a series of experiments to explore the links between cognition and the dynamics of human capabilities in a complex and changing environment. In a series of behavioral experiments and computer simulations, we found that active guidance by green flashing lights at emergency exits impacts the behavior of individuals in an emergency evacuation situation in a supermarket; this tested our hypothesis that changing the environment in turn changes the evacuation behavior of individuals. We also show that environmental modification can help in decision-making in an emergency situation. Furthermore, the results of computer simulations support a possible modeling of the influence of affordances on the evacuation behavior of agents in a complex virtual environment.

1. Introduction

Terrorist attacks on supermarkets, such as those in Buffalo in 2022 (New York, USA), Auckland in 2021 (New Zealand), and Trèbes in 2018 (France), which resulted in the death of 18 people and the loss of several hundred lives, have clearly demonstrated the importance of effective and rapid evacuation. Indeed, during an attack on a supermarket, orientation to an emergency exit plays an important role in saving customers [1–7]. However, an important finding was that people do not necessarily evacuate through emergency exits. For example, in the Trèbes (France) supermarket attack, none of the 87 customers and employees used emergency exits.

One explanation proposed in the literature is that the tendency of individuals not to choose to evacuate via emergency exits is the result of affiliation theory [8–10]. In other words, individuals are attracted to the exits they use regularly (i.e., the main entrance) and would naturally head toward them during an evacuation [8]. However, the work of [8–10] is specific to fire evacuation problems (i.e., the presence of smoke and sound alarms) and in simple environments (i.e., office buildings). On this point, we argue that in an emergency situation, and more specifically in a terrorist attack, the threat is more difficult to identify and locate than in a fire, and even more so in more complex environments (e.g., supermarkets, train stations, libraries).

Another possible explanation for the tendency of individuals not to evacuate via emergency exits is that complex environments can disorientate individuals in the event of an evacuation. For example, a supermarket is a complex geometric space saturated with visual and auditory information, which probably contributes to the fact that individuals are not always aware of the emergency exits during an emergency evacuation. It seems, therefore, that there are behavioral constraints that need to be taken into account to ensure that as many people as possible use an emergency exit to reach safety.

The novelty of this work lies in its approach to understanding human behavior in a complex environment (i.e., a supermarket) during a complex emergency (i.e., an attack).

To do this, we studied how to facilitate the orientation and path of people in an emergency evacuation situation during an attack in the specific environment of the supermarket. Thus, while the design of emergency exits meets current safety standards as defined in the fire codes (i.e., the number of exits, their spacing, the door dimensions, signage), we hypothesized that other features of emergency exit design could be considered to facilitate orientation and rapid decision-making during an emergency evacuation in a supermarket.

* Corresponding author at: EA 4556 EPSYLON, Univ Paul Valéry Montpellier 3, EPSYLON EA 4556, F34000, Montpellier, France
E-mail address: lancel.ed60@gmail.com (S. Lancel).

https://doi.org/10.1016/j.jnlssr.2022.10.006
Received 19 August 2022; Received in revised form 23 October 2022; Accepted 26 October 2022

To understand how to ensure that supermarket customers use an exit in an emergency, it is important to know how people perceive the environment [2].

1.1. Applications in emergency situations in supermarkets

A series of evacuation experiments in an IKEA store [11] found that customers rarely used emergency exits. As the author rightly points out, this may have consequences in the event of a fire; a longer evacuation in terms of time and distance would, for example, increase the risk of exposure to toxic fumes. Similar results were found in a study of a Marks & Spencer shop: only 17.6% of participants reported noticing one or more signs indicating an emergency exit inside the shop [1]. In another study conducted in two supermarkets and a large shopping mall in northern Italy showed that 80% of participants were unable to remember the location of emergency exits [2]. The underuse of emergency exits was also found in a study of four supermarkets involving 2,073 customers during unannounced evacuations [6]. These studies suggest that conventional emergency exit signage is not sufficiently effective in the specific supermarket environment [1,2,6,11]. As [2] points out, supermarkets are complex environments that tend to confuse customers [2,12]. The visual information-saturated environment (i.e., shelves, notice boards, lights) of the supermarket can make it difficult to identify relevant cues for evacuation through emergency exits in an emergency situation [6]. In this context, it seems essential to consider the specificities of the complex environment of the supermarket so that the majority of customers evacuate through an emergency exit [1,2,6].

1.2. The concept of affordance applied to emergency exits

To move around, find one's bearings quickly, and even survive, the perception of the environment plays a central role as a provider of warning signals, but also of orientation toward safe areas [13–15]. These offered (afforded) signals are all more essential for survival when the individual is in a situation of urgent decision-making and when his or her life is at stake. According to Gibsonian theory, the relationship between a human being's perception of his/her environment and movements in his/her environment generates possibilities for individual–environment interactions that are essential for choosing actions in a situation [15,16]. Thus, the individual does not perceive the properties of objects but constructs the possibilities of action offered by the objects [17,18].

The concept of "affordance," which occupies a central place in psychology, is of particular interest in this study. The term was proposed by Gibson [15], according to whom "the affordances of the environment are what it offers to the animal, what it provides or procures for it, for good or ill" ([18], p. 127). By transforming the verb "to afford" (as in "offer, allow, provide") into a noun, Gibson [18] sought to account for the ability of humans, and animals in general, to guide their behaviors by perceiving what the environment offers in terms of opportunities for action [13,16] According to Gibson [19], affordances are not properties of the environment; they are the opportunities for action offered to individuals by the environment in relation to the individuals' capacities for action [17,20–22]. As Martin et al. [20] show, a tool is not defined by a function; it is the result of the emergence between the needs of the individual and the possibilities offered by the environment at a given moment. For example, a chair can be used for sitting but also as a stepladder to change a light bulb. Affordance theory has been used in a number of different areas, such as the design of human–computer interactions [21] and the perception of climbing routes such as stairways [23,24]. In this theory, researchers systematically render affordances as an action verb followed by the suffix "ability" [16]. Thus, many affordances have been the subject of experimental work, such as the "passability" of openings [25,26], the "catchability" of objects [27–29], the "climbability" of stairs [30–32], or the "usability" of a door [33].

Closer to our problem, affordance theory has also been applied to the design of emergency exits to understand why some designs perform poorly [3,23,35,36,]. Indeed, [21] argues that the affordance between the user and an object—an escape route—can be split and combined into several types of affordances. Thus, Hartson's [23] work approaches the concept from a more complex angle by dividing it into four categories of affordances: sensory, physical, cognitive, and functional affordances.

1 Sensory affordance is "a design feature that helps, supports, facilitates, or enables the user to feel (i.e., see, hear, smell) something" ([23], p. 322). As a simple example, an illuminated sign with an ideogram of a man running through an emergency exit acts as visual support for identifying the door as an emergency exit (cognitive action) and using it in an emergency (physical action).
2 A physical affordance is "a design feature that helps, assists, supports, facilitates, or enables something to be done physically" ([23], p. 319). A push bar is a good example, highlighted by Hartson [23], which allows individuals to open a door simply by pushing (like a swinging door).
3 A cognitive affordance is "a design feature that helps, assists, supports, facilitates, or enables one to think and/or know something" ([23], p. 319). Explained simply by Hartson [23], the text under a button could help users understand the functionality of the button and the consequences of clicking on it. Or applied to the topic of doors, this could be a sign with the text "Emergency Exit" to help people understand the functionality of the door and the consequences of opening it (getting out in an emergency).
4 Finally, functional affordance is defined by Hartson ([23], p. 321) as "a design feature that helps or assists the user to do something." According to Hartson [23], functional affordance is a combination of sensory, cognitive, and physical affordances.

An interesting point in the evolution of the concept of affordances is Hartson's [23] proposal to bring cognitive and physical affordance together as a design combination. For example, the text "Pull" or "Push" associated with a door handle tells individuals which direction the door opens. According to Hartson [23], the text "Pull" above a door handle could constitute a cognitive affordance in support of physical affordance by providing a physical means of action (to pull the door), as well as a visual cue to help individuals understand the opening functionality. In this sense, physical affordance not only means the handle can be grasped and turned, but that the manual grasping action can enable the individual to operate the door-opening mechanism. In turn, the door provides access to the passage functionality (functional affordance). In the case of a door with a safety function, it must be sufficiently visible, physically usable, and open; it must be a simple operation. Thus, the design of an emergency exit must be adapted such that users can link sensory affordances with cognitive and physical affordances so that the door can be used in an emergency [21]. In other words, the design of products and objects, whether in the context of everyday life or safety and health, should be guided by the type of interactions that the product or object enables, not the product or object itself.

Thus, objects are an extension of the mind and not a replacement. Integrating the issue of affordances into the design of objects would make it possible to blame objects rather than users for non-use or error. In reality, errors often result from poor interaction design [20,36,37].

1.3. Elements of application in case of fire

In this study, it is essential to consider the specifics of the complex supermarket environment so that most customers evacuate through emergency exits during an attack [1,2,6]. In this context, extensive work on security suggests that the effectiveness of signage can be improved if its detectability is enhanced [1,3–5,34,35,38,39]. Recent research has shown that only 38% of individuals "see" a sign in an emergency situation in a non-residential building, even if the sign is directly in front of them [38]. These results suggest that current signage (i.e., passive signage) is not as effective as orientation and decision aid [2,4,38,39].

On this point, work on fire safety shows that the combination of conventional (i.e., passive) and active signage (i.e., flashing arrows, illuminated floor markings, flashing lights) is a way to influence choice in order to compensate for long distances to emergency exits [1,5,35,38]. For example, Galéa et al. [4] proposed and tested a new dynamic signage design (flashing green or red arrows in the emergency exit sign) to solve the problem of under-detection found with conventional signage. The results suggest that the use of dynamic exit signs would allow more people to identify the correct exit route during an emergency evacuation compared with the use of conventional exit signs [4].

In another study [1], the effectiveness of an alternative design that combines flashing lights (i.e., active signage) with backlit signs above the emergency exit (i.e., passive signage) was demonstrated. In this study, participants were asked to compare the alternative design (i.e., flashing lights) with five other designs, using a questionnaire. The results revealed that flashing lights had the greatest ability to capture attention and were preferred by participants [1].

As already mentioned, the effectiveness of active signaling with flashing lights seems to be an interesting avenue for increasing the use of emergency exits [1,4]. However, in addition to flashing, the color of flashing lights is also important. Green is associated with “safety” or “go,”“ red with “danger” or “stop,” yellow and orange with warning, and blue with emergency services [1,7,35]. Künzer et al. [7] observed the effect of the sensory affordance of traffic lights, according to their red or green color, on route choice in metro stations with a population of adults and children. The results showed that the use of green lights influenced route choice for both groups and led 84% of participants to choose to follow the direction indicated by the green lights. Furthermore, the study suggests that green lights prompted participants to change their route: participants chose to take the left-hand direction instead of the usual route via the stairs to the right [7]. This result is particularly relevant to our problem: the green color not only guides but also changes the route decision. The results of these experiments suggest the use of “active evacuation systems to encourage people to escape via emergency exits” [12,35].

In a series of studies, Nilsson[36] compared the effectiveness of a standard evacuation device with that of a dynamic device (flashing green lights). The situation was a building or road tunnel. In one experiment, participants were placed in the middle of a corridor. The instructions were as follows:

Try to imagine the following scenario: You are alone in a long corridor, and you know there is fire in the building, but you do not know where. You want to get out of here because you want to go somewhere safe. Do it, please. [35]

In the experiment, the left exit (Exit 1) was equipped with a sign with flashing (green or orange) or strobe lights (active signaling), and the right exit (Exit 2) was equipped with a sign with a backlit emergency exit indication (passive signaling). The results revealed that the participants were significantly more likely to head for an exit equipped with flashing or strobe lights. When green flashing lights were used and the participant was placed in the middle of the corridor (starting position 1), 75% of participants used the left door with green flashing lights, compared to 50% in the control condition where nothing was flashing, an increase of 25% [35]. As an extension of this study, unannounced evacuations were conducted in an office building and movie theater. The aim was to determine whether flashing green lights could influence the choice to exit in other environmental contexts. The results again confirmed that green flashing lights encourage people to use doors equipped with them [35]. The work of [35] is inspired by the fact that it provides an answer to our problem of how to increase the chances that an individual will use an emergency exit. However, the work in [35] is specific to fire evacuation problems (i.e., presence of smoke, audible alarm) and less complex environments (i.e., office buildings, movie theaters, road tunnels). In addition, fire is an identifiable and easily locatable threat, unlike a terrorist or armed attack (e.g., hostage-taking, robbery). To determine whether the flashing light device of [35] is appropriate to address our problem, the possibility of actively guiding the behavior of individuals in an emergency evacuation situation in a supermarket via green flashing lights at emergency exits was tested in a series of behavioral experiments and computer simulations.

1.4. Hypothesis and problem

Drawing on recent studies [4,5,7,35] and affordance theory [15,16,21,36,40], we conducted two behavioral experiments (Sections 2.1,2.2) and computer simulations (Section 3). In this study, our main objective was to test the hypothesis that affordances between the subject and its environment modify its choices. In addition, we wanted to show that environmental modification can aid decision-making in emergency evacuation situations. According to our hypothesis, an individual’s decision-making could benefit from the resources embedded in the environment, which would likely increase the cognitive capacities facilitating the action.

In two behavioral experiments conducted in HYPER U supermarket (Experiments 1 and 2), we tested our hypothesis that sensory affordances between the subject and the environment modify decision-making. To this end, we modified the signage of the emergency exits to explore whether the implementation of dynamic signage would influence the action possibilities of individuals in an emergency evacuation situation in the complex environment of the supermarket.

The main objective was to observe whether an active guidance system could influence evacuation behavior compared to the standard design (i.e., a passive device) in a particular attack situation. It should be remembered that, in the case of an attack, unlike a fire, there is no smell or smoke that individuals can use to help them make a choice. The series of behavioral experiments also aimed to explore the feasibility of installing a guidance system *in situ*, taking into account the real constraints of a supermarket (the height of the emergency exits, the height of shelves, and brightness). To perform these two experiments, we used a device similar to that of [35] in the complex environment of the supermarket.

Experiment 1 aimed to test the feasibility of the active device, its functionality in the supermarket, its acceptability, and its influence on the binary choice that participants had to make according to their position in relation to the device (left or right door). The aim of Experiment 2 was to test the impact of the device on participants’ choice, given that no constraints were formulated. The participants had to evacuate through their preferred doors. Experiment 2 also allowed us to test the device in a less-controlled environment with many sources of confounding variables.

The novelty of this research is that it builds on the results of the behavioral experiments conducted (Section 2.1, Section 2.2) and then uses a multi-agent system (MAS) modeling and simulation approach. In the context of modeling the virtual supermarket environment and modeling the characteristics and probabilistic behavior of individuals, our aim was to test our hypothesis that affordances between the subject and its environment modify its possibilities of action. A series of computer simulations, derived from artificial intelligence based on MAS, were conducted to model, develop, and visualize the individual movements of customers during an emergency evacuation in a supermarket.

2. Behavioral experiments

2.1. Experiment 1

In the first behavioral experiment (Experiment 1), our objective was to observe whether the dynamic device tested by Nilsson [35] could provide answers to our problem. That is, whether emergency exit signaling with a green flashing light device (i.e., active guidance) could influence evacuation behavior compared to standard signaling without green flashing lights (i.e., passive guidance) in a complex environment (i.e., supermarket) and in a complex emergency situation (i.e., attack). Thus,

A B

Fig. 1. Illustration of the experimental set-up (A. passive state and B. active state)

Experiment 1 aimed to determine whether the device (i.e., green flashing lights) that Nilsson's studies had achieved in low-complexity environments (i.e., office buildings, movie theaters, road tunnels) was adaptable to a complex geometry environment (e.g., supermarkets) that may have traffic obstacles and high population density (i.e., supermarkets). As previously mentioned, supermarkets are complex environments in which 1) they tend to disorientate customers and 2) are saturated with visual information (i.e., shelving, billboards, lights), which makes it difficult to identify relevant cues to evacuate to emergency exits during an emergency. Experiment 1 aimed to determine whether the device (i.e., green flashing lights) that Nilsson's studies had proven in a fire situation was suitable for a terrorist attack. Indeed, fire has the particularity of being an identifiable and easily locatable danger, unlike threats such as terrorist attacks.

For this purpose, we equipped two emergency exits with the green flashing light device of [35] in the self-service bakery department of the HYPER U supermarket in Mende (France). Each participant was given the opportunity to choose between two doors, knowing that one door was flashing and the other was not, and knowing that the participant could be facing, in the middle of, or opposite the flashing door. We hypothesized that the number of exit choices would be greater when the door was flashing than when it was not.

2.1.1. Participants

A total of 144 French-speaking customers of the HYPER U supermarket participated individually in the "sandwich loaf experiment." Companions and minors were excluded from this study. The mean age of the participants was 39.67 years (SD: 18.58), with a minimum and maximum of 18 to 84 years, respectively. Sex was controlled, with 70 females and 74 males participating in the experiment. The experiment was conducted on Wednesdays and Fridays, between 10 am and 6 pm. Participants were recruited directly from customers in the supermarket, as they passed through the experimenter's stand. The participants were given very little information during recruitment before the experiment. The experimenter stated that this was a scientific study of customer behavior in the shop. They were also informed that the experiment was safe and that they could stop the experiment at any time. Participation in the experiment was voluntary, and written consent was obtained from each participant.

2.1.2. Materials and methods

The guidance system. The guidance system used in our experiment was as close as possible to the device described by Nilsson [35]. The flashing lights of DINFU model E3-L consisted of green bulbs. All bulbs in the flashing lights flashed simultaneously at a frequency of 1 Hz. Flashing lights were installed on each side of the backlit emergency exit panel above the two emergency exits (Fig. 1).

The following figure shows the experimental setup with flashing lights on both sides of the backlit traffic sign in passive (A) and active (B) states.

Configuration of the experimental area. The "sandwich loaf experiment" was carried out in the self-service bakery and pastry department of the HYPER U supermarket in Mende (France). The department used was 15.5 m long, 6 m wide, and had a floor to ceiling distance of 11 m. In the middle of the area there was a central shelf 6.30 m long, 0.77 m wide and 1.80 m high (Fig. 2). The crosses indicate the three different positions of the participants (inter-individual variable): either the position was to the left (blue cross), middle (black cross), or right (orange cross) of the central shelf (Fig. 2).

Fig. 2. The area used in the "sandwich loaf experiment" of the HYPER U supermarket in Mende (France)

Table 1
Experimental conditions

Starting position	Guidance system Emergency exit (left)	Emergency exit (right)
1. left	active	passive
2. middle	active	passive
3. right	active	passive
4. left	passive	active
5. middle	passive	active
6. right	passive	active
7. left	passive	passive
8. middle	passive	passive
9. right	passive	passive
Total number of participants	16 * 9	

Experimental conditions. The guidance system could be active on the left door, inactive on both doors, or active on the right door. This set of manipulations led to nine experimental conditions (Table 1).

2.1.3. Procedure

After receiving prior information, the experimenter gave the following instructions to the participant:

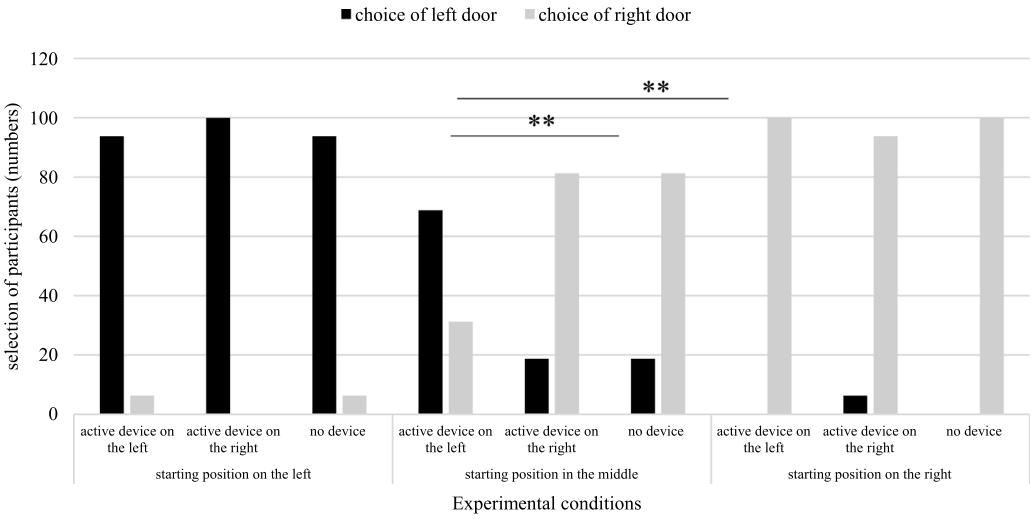

Fig. 3. Choice of exit for participants depending on the starting position and the state of the device

Try to imagine the following scenario. You are shopping. You realize that there is a serious incident in the shop behind you (the area was indicated by the experimenter). You want to get out of here because you want to get to a safe place. Tell me the direction of your exit (the area of the emergency exit was indicated by the experimenter).

The experimenter ensured that the participant understood the instructions. If not, the instruction was explained again but not repeated in its entirety. Once the participant understood the instruction, the experimenter instructed the participant to follow him/her by looking down until he/she was placed in one of the three starting positions. When the participant was placed in the indicated starting position, a countdown from three. At the end of the countdown, the participant was free to choose an exit in the area indicated by the experimenter. To indicate their choice, the participants had to move to the emergency exit as quickly as possible. The participant's choice was noted by an observer who remained in the same place throughout the experiment.

2.1.4. Results

Fig. 3 illustrates the exit choice of participants who chose the right or left door depending on the starting position and state of the device.

In Experiment 1, each participant could choose between two doors (one flashing and one not), and the participant could be facing, in the center, or on the opposite side of the flashing door. The participant could be placed on the left (i.e., left of the central shelf), center (i.e., facing the central shelf), or right (i.e., right of the central shelf).

When the individual was placed on the left

Each participant was positioned to the left of the central shelf and could choose between two doors, knowing that one of the two doors was either flashing to the left or to the right, or neither door was flashing. Fig. 3 shows the participants' exit choices according to the starting position (left) and the state of the device (active on the left, passive, and active on the right).

Participants almost exclusively used the left door to evacuate in all situations studied. We compared participants' decisions in each of the experimental modalities (flashing left [A] and right [C]] to the control modality (no flashing [B]): ***Active left versus passive device (A versus B)***: the presence or absence of flashing did not influence participants' decisions. Participants, when placed on the left, chose the left door whether it was flashing (n = 15, 93.75%) or not (n = 15, 93.75%) [X^2 (1, N = 32) = 0, p = .1]. ***Active right versus passive device (C versus B)***: The presence or absence of flashing did not influence the participants' decisions. Participants, when placed on the left, always chose the left door, whether the right door was flashing (n = 16, 100%) or not (n = 15, 93.75%) [X^2 (1, N = 32) = 0, p = .1]. In summary, when participants were placed to the left of the shelves, the device was ineffective. This did not influence participants' decisions. Indeed, participants chose to evacuate through the left emergency exit, whether active (on the left or right) or inactive. The following results show the participants' choice of exit when they were placed in front of the central shelf and could choose between two doors that flashed either to the left, right, or neither.

When the individual was placed in the center (behind the shelf)

The participants used emergency exits differently, depending on the experimental situation. Fig. 3 shows the participants' exit choices according to the starting position (center) and the state of the device (active on the left, passive, and active on the right).

Statistically, participants moved predominantly to the left when the device was active on the left (n = 11, 68.75%); and conversely, participants moved predominantly to the right when the device was active on the right (n = 13, 81.25%) [X^2 (1, N = 32) = 6.22, p = .01]. The measure of the strength of the relationship between the two variables was considered strong given the value of Cramer's V > .30. Thus, in accordance with our hypothesis, we can see that the state of the device influences the choice of participants. Second, we compared the participants' decisions in each of the experimental modalities (flashing left [A] and right [C]] to the control modality (no flashing [B]]. ***Active left versus passive device (A versus B)***: the presence of flashing on the left led participants to preferentially choose the left door (n = 11, 68.75%) compared to the classic passive device (n = 3, 18.75%) [X^2 (1, N = 32) = 6.22, p = .01]. Furthermore, the measure of the relationship between the two variables was considered strong, given the value of Cramer's V > .30. ***Active right versus passive device (C versus B)***: The presence or absence of flashing did not influence the participants' decisions. Participants, when placed in the center, chose the right-hand door in the majority of cases, whether the right door was flashing (n = 13, 81.25%) or not (n = 13, 81.25%) [X^2 (1, N = 32) = 0, p = .1]. In summary, when the participants were placed in the center (facing the shelf), the device was effective. This influenced participants' decisions to evacuate through the flashing door, regardless of whether the door was active on the left or right.

When the individual was placed on the right

Participants almost exclusively used the right-hand door to evacuate in all the situations studied. Fig. 3 shows the participants' exit choices according to the starting position (right) and the state of the device (active on the left, passive, and active on the right).

We compared participants' decisions in each of the experimental modalities (flashing left [A] and right [C]] to the control modality (no flashing [B]]. ***Active left versus passive device (A versus B)***: the pres-

ence or absence of flashing did not influence participants' decisions. Participants, when placed on the right side of the shelves, chose the right door, whether it was flashing ($n = 16$; 100%) or not ($n = 15$; 93.75%) [X^2 (1, $N = 32$) = 0, $p = .1$]. ***Active right versus passive device (C versus B)***: The presence or absence of flashing did not influence the participants' decisions. Participants, when placed on the right side of the aisle, always chose the right door, whether the right door was flashing ($n = 16$; 100%) or not ($n = 15$; 93.75%) [X^2 (1, $N = 32$) = 0, $p = .1$]. In summary, when participants were placed to the right of the shelves, the device was ineffective. This did not influence participants' decisions. Indeed, participants chose to evacuate through the right emergency exit, whether it was active (on the left or right).

2.1.5. Conclusion

The results of the first experiment show that when the participant was placed between two doors, their behavior was influenced by the state of the emergency exit signage device. Specifically, the participant moved toward the emergency exit that was equipped with the active signage device rather than toward the door equipped with the passive signage device. However, when the participant was in front of a door, he/she mostly went toward an exit, regardless of whether the device was active or passive. A simple interpretation is that the bread shelf hinders the transmission of visual information in the space contralateral to the individual. These data, not particularly explored in the first instance, are important in view of future recommendations to consiswe the presence or absence of high shelves when choosing the layout of emergency exits. Conversely, to take into account the position of the exits when deciding the height of the shelves in the vicinity.

2.2. Experiment 2

In Experiment 1, we tested the feasibility of an active signage device in a controlled supermarket environment. The objective of Experiment 2 was to test the influence of the device in an uncontrolled and complex environment (i.e., with confounding variables). As in the first experiment, we equipped emergency exits in another department of the HYPER U supermarket in Mende (France)with a green flashing light device. Each participant was given the opportunity to choose between two doors, of which, as in the previous experiment, one flashed, and the other did not. Our hypothesis was that the number of exit choices would be greater for flashing doors than for non-flashing doors.

2.2.1. Participants

Seventy-two French-speaking customers of the supermarket participated individually in the "fruit and vegetables" experiment. Companions and minors were excluded from this study. The average age of the participants was 43.82 years (SD: 16.27), with a minimum and maximum of 18 to 78 years, respectively. Sex was controlled, with 36 females and 36 males taking part in the experiment. The experiment was conducted on Wednesdays and Fridays, between 10 am and 6 pm. Participants were recruited directly from customers in the supermarket, as they passed by the experimenter's stand. The participants were given very little information during recruitment before the experiment. The experimenter stated that this was a scientific study of customer behavior in the shop. They were also informed that the experiment was safe and that they could stop the experiment at any time. Participation in the experiment was voluntary, and written consent was obtained from each participant.

2.2.2. Materials and methods

The guidance system. The guidance system was identical to that used in Experiment 1 (Section 2.1.2).

Configuration of the experimental area. Experiment 2 was conducted between the butchery/seafood/fruit and vegetable departments of the HYPER U supermarket in Mende (France). The area used was 46.5 m long, 19.30 m wide, and had a floor-to-ceiling distance of 11 m. The shelves were located at an average distance of 77.5 m from the main entrance. In the "fruit and vegetables" experiment, there was a single participant at the beginning of the experiment. The participant's position was located in front of the two emergency exit doors in the area at an equal distance between the emergency exit door on the left of the participant and the emergency exit door on the right of the participant (15.5 m). The white cross indicates the positions of the participants. Following Experiment 1, we made sure in this configuration that no shelfs obstructed the visibility of the exits.

Experimental conditions. The guidance system could be active on the left door, inactive, or active on the right door. These manipulations led to three experimental conditions.

For a better understanding, Fig. 4 illustrates the area of the supermarket that was used.

2.2.3. Procedure

After receiving prior information, the experimenter gave the participant the following instructions:

Try to imagine the following scenario. You are shopping. You realize that there is a serious incident in the shop behind you (the area is indicated by the observer). What do you do?

The experimenter checked if the participant understood the instructions. If so, the participant was asked to follow the examiner back to the starting position while looking downwards. If not, the instructions were explained but not fully repeated. Once the participant understood the instructions, the experimenter instructed the participant to follow him or her by looking down until he or she reached the starting position. When the participant was placed in the indicated starting position, a countdown from three. At the end of the countdown, the participant was free to choose an exit. The participant had to simply show the exit of his choice to the examiner. The participant's choice was noted by an observer who remained in the same location throughout the experiment.

2.2.4. Results

The following figure (Fig. 5) illustrates the choice of participants (left door, right door, checkout) according to the state of the device (active left, passive, and active right).

The participants used emergency exits differently, depending on the experimental situation. Statistically, participants moved predominantly to the left when the device was active on the left (n = 17, 70.83%); and conversely, participants moved predominantly to the right when the device was active on the right (n = 18, 18.75%) [X^2 (1, N = 48) = 6.91, p = .0085]. The measure of the strength of the relationship between the two variables was considered strong given the value of Cramer's V > .30.

Second, we compared the participants' decisions in each of the experimental modalities (flashing left [A] and right [C]] to the control modality (no flashing [B]]. ***Active on the left versus passive device (A versus B)***; the presence or absence of flashing did not influence the participants' decisions. The majority of participants chose the left door, whether the door was flashing (n = 17, 70.83%) or not (n = 16, 66.66%) [X^2 (1, N = 48) = 0.55, p = .46]. ***Active on the right versus passive device (C vs. B)***: the presence of flashing on the right led participants to preferentially choose the right door (n = 18, 75 %) over the classic passive device (n = 8, 33.33 %) [X^2 (1, N = 48) = 6.79, p = .009].

2.2.5. Conclusion

In Experiment 2, we found that, in a complex, uncontrolled environment with many sources of interference, participants' behavior was significantly influenced by the state of the emergency exit signaling device. Specifically, when participants were placed equidistant from two unfamiliar exits and were free to choose the direction in which they wanted to evacuate, they overwhelmingly chose to head toward the flashing door. In summary, Experiment 2 yielded encouraging results regarding the effectiveness of the device. There is an influence of the participants'

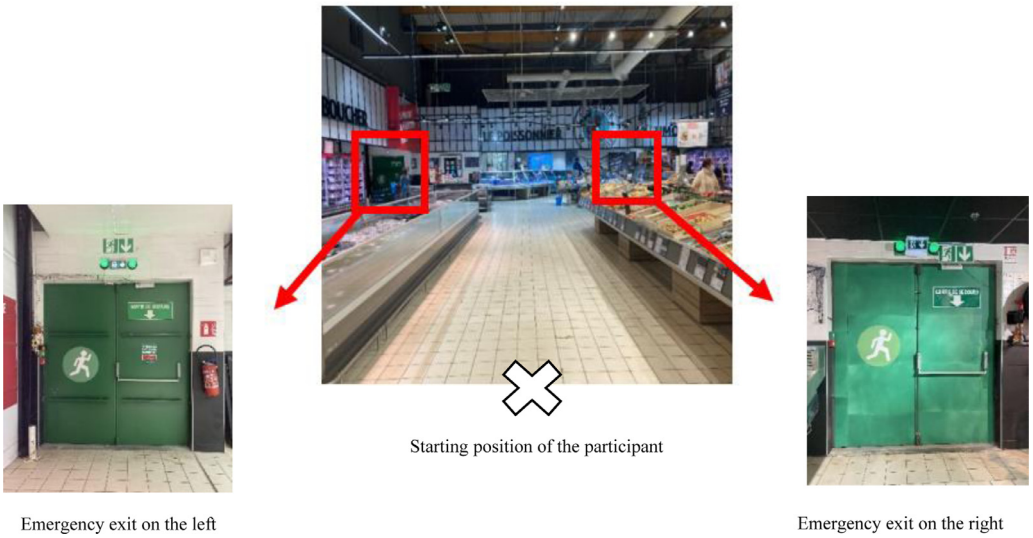

Fig. 4. The area used in the "fruit and vegetables" experiment of the HYPER U supermarket in Mende (France)

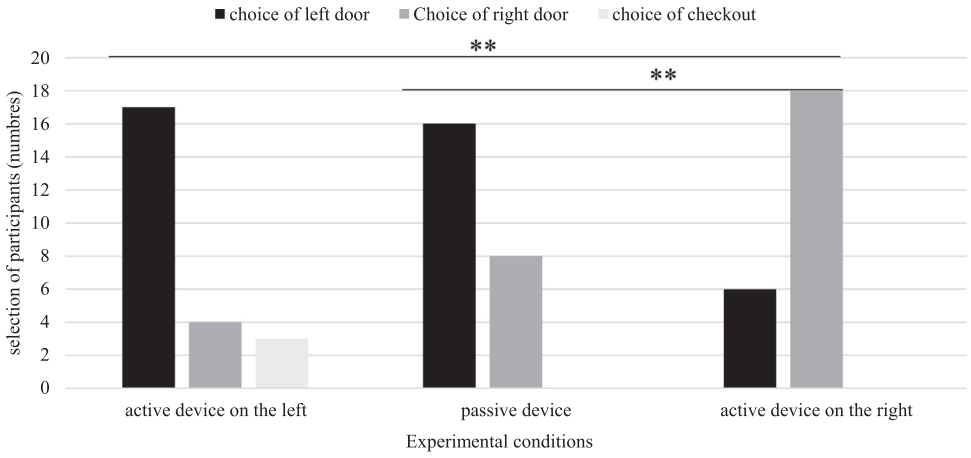

Fig. 5. Choice of participant exit depending on the state of the door device

decision to evacuate through the flashing door, whether the door was active on the left or on the right.

Based on the behavioral experiments (Experiments 1 and 2), it seems possible that the experimental device (i.e., active guidance) provides sufficient sensory support to generate useful and relevant actions in a given context [21,35]. As highlighted in the literature [3,5,34,35], this result suggests that the design of supermarket exits should evolve toward equipping emergency exits with green flashing lights to direct customers to the desired exits and avoid the threat. These results are consistent with Norman's theory [40]: affordances (i.e., physical affordances) specify the range of possible activities, but affordances are of little use if they are not visible to the individual in a sensory (detectable) and cognitive (understandable) sense [40,41].

In the next section (simulation experiments), we propose to test our hypothesis that affordances between the subject and its environment modify its action options in the context of modeling the virtual supermarket environment, modeling the probabilistic features and behavior of individuals, and modeling–environment interactions. To this end, we present a series of computer simulations derived from artificial intelligence based on MAS, the results of behavioral experiments (Experiments 1 and 2), and previous studies [1–7]. In particular, computer simulation experiments will compare the results of the influence of dynamic guidance (i.e., flashing lights) on exit selection during an emergency evacuation with a larger population (350 agents) in a virtual supermarket environment (10 emergency and three main exits).

3. Simulation experiments

3.1. Implementation

The multi-agent environment chosen for modeling and simulation was the open-source GAMA platform.[1] For this study, GAMA version 1.8.2 was used on a PC running Windows 7 Professional. The data collection for the simulations was controlled elsewhere. GAMA was not specifically designed to simulate an evacuation process. However, many studies have used GAMA to model pedestrian movement [38], amphitheater evacuation [42], emergency building evacuation [43–45], and crowd evacuation [11]. GAMA has been chosen here as a modeling and simulation tool to study behaviors observable in real evacuation situations, such as flight behaviors, competitive behaviors, the queuing in front of exits, and even the occurrence of gregarious behaviors [42,46].

3.2. Modeling the environment i.e., the supermarket

The evacuation modeling used was agent-based to explore the potential impact of emergency exit signage on evacuation efficiency in a complex geometry. The geometry chosen consisted of a real supermarket : 10 emergency exits, three main entrances/exits, and all the facilities specific to the HYPER U supermarket in Mende, France (Fig. 6).

[1] See www.gama.org .

Fig. 6. The virtual environment of the supermarket used in the multi-agent simulation including the lower (light blue) and upper (dark blue) facilities, the emergency exits and the main entrance.

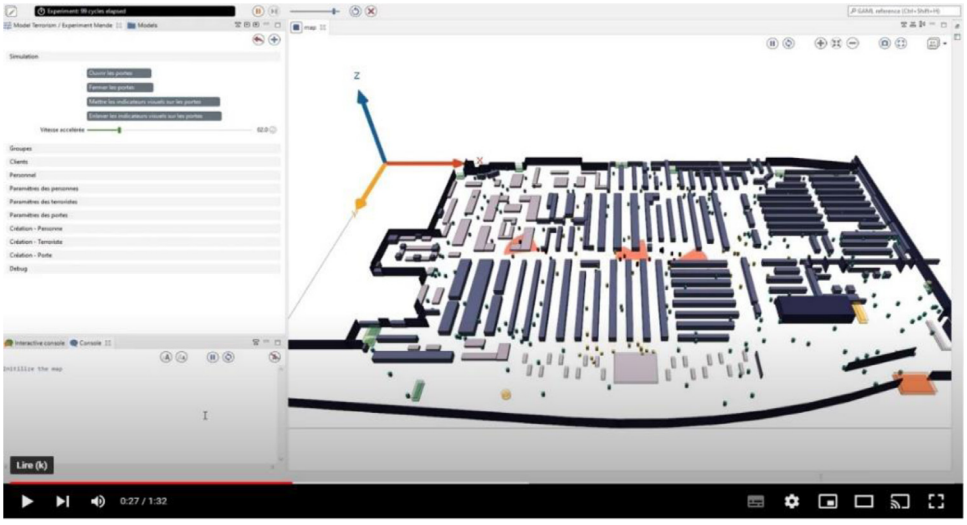

Fig. 7. Video demonstration of the virtual environment
https://www.youtube.com/watch?v=P_j1lqqbfQY

The modeling of the supermarket environment consisted of specifying various areas (shelves, checkouts, storerooms, etc.), their dimensions, the location of doors, possible obstacles, customers at the initial time of the simulation, and possible routes for the movement of all people (Fig. 7).

3.3. Modeling the characteristics and probabilistic behavior of individuals as customers and terrorists

The modeling of human behavior allows the integration of certain physical, psychological, and cognitive properties. Agent behavior has been defined as independent, with different characteristics such as age and sex, pre-movement time [47], movement speed [47], viewing distance [46], different types of relationships between agents [48–54], and interaction with the environment [7,18,35,55,56]. Thus, the multi-agent approach allows the decision-making process to be simulated while considering environmental factors.

The formalization of agent behavior rules is based on 1) modeling the human behavior and human/human behavior and 2) modeling the behavior of objects in the environment and human/environment interaction behavior. The following video illustrates some of the actions considered in this study (Fig. 8).

3.4. Setting up the simulation

The initial settings can be modified according to the requirements of the simulation. These modifications can be performed on the GAMA platform via a specific interface. This interface allowed the number of agents to be set for each experiment. The interface also allows the behavior of customers and terrorists to be parameterized for each experiment. It should be noted that, for all agents, the agents' vision was a cone of 10 m × 60°, and the communication distance between agents was 1 m. In terms of modeling, we retained two types of human actors, and each human actor was modeled by an agent type. The proposed modeling does not include staff members. In this work, we have retained the terms "customer" agents and "terrorist" agents.

"Customer" agents. The "customer" agents were defined by their walking speed (normal distribution | average:1.41 m/s | standard deviation:0.37 m/s). "Customer" agents had several behaviors such as walking in the shop, fleeing to look for the exit, running, and bending down when they were close to a low unit (e.g., a checkout line), communicating with other agents (i.e., warning other agents of the threat, informing them of the location of nearby exits). Regarding the action of fleeing to the exit, if they did not know the exit, movement was free as long as the agent did not encounter an obstacle. During the escape movement, the agent bent down to hide, take shelter, or crawl to lower units. These behaviors, in interaction with the environment, decreased the speed of movement and increased the exit time.

"Terrorist" agents. The "terrorist" agent moves randomly. The selection and number of "victim" agents that could be injured by the "terrorist" agents were random. The maximum number of victims was set at seven; this number is fixed to the terrorism reference data, which determined a threshold of five victims ([57], p. 7), and to limit the actions of

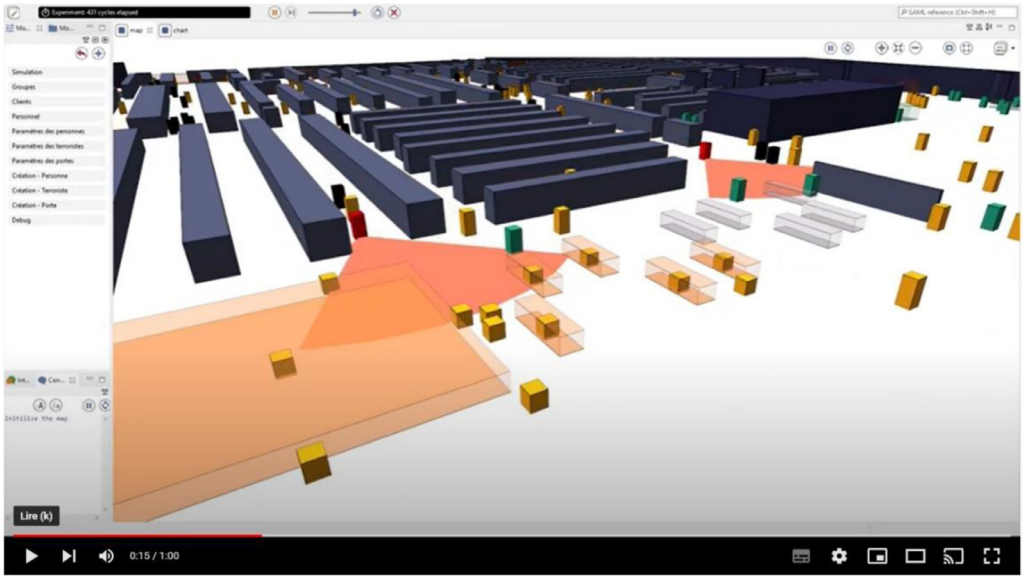

Fig. 8. Demonstration of agents represented with human–environmental interactions with high and low environment elements
https://www.youtube.com/watch?v=9iO78yoZ6Lw

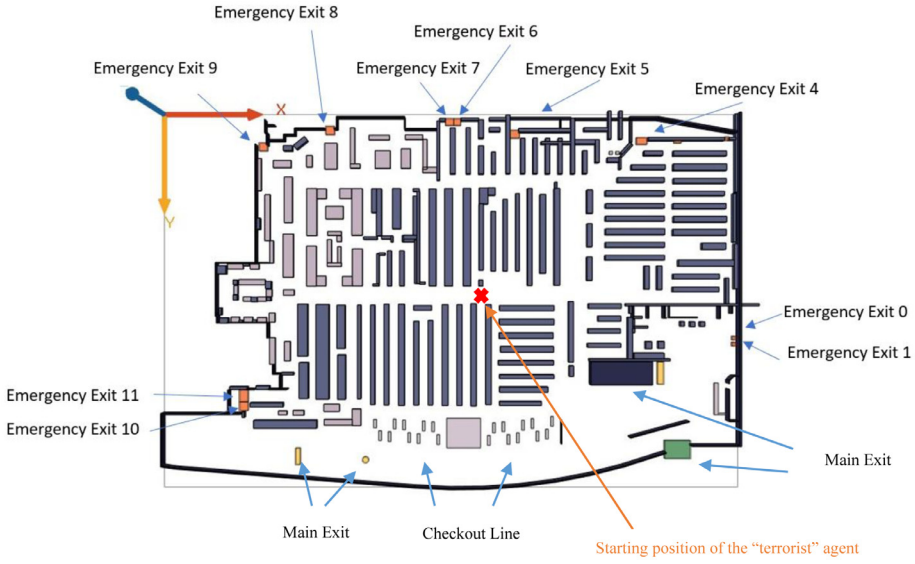

Fig. 9. Starting position of the "terrorist" agent in the virtual supermarket

the "terrorist" agent on the "client" agents. The "terrorist" agent had a 20% chance of missing each attempt to injure an agent. Agents who hid or ducked behind a low unit were not visible to the "terrorist" agent.

4. Simulations and results

4.1. Procedure for starting a simulation

At the beginning of the simulation, the agents were randomly generated in the supermarket. The simulation was then run for 100 cycles. This time of 100 cycles is necessary for the "customer" agents to have a stable behavior of normal activity in the shop. After running the simulation environment for 100 cycles, a "terrorist" agent was introduced. To limit its random trajectory, the "terrorist" agent is introduced in the middle of supermarket activity (i.e., in the middle aisle). The introduction of the "terrorist" agent is determined by the position $x = 7060$; $y = 3911$ and this for each simulation of each of the three scenarios studied (Fig. 9).

Upon perception of danger or receipt of information about danger, the agents started to evacuate toward the exits of the supermarket. The simulation was stopped until all employees had left. The time required for evacuation was a decisive factor in our study. To identify the evacuation behavior of the individuals, we measured the evacuation time. This was measured based on the time recorded for the agents' evacuation, which included the selection of the evacuation route and exit used. Therefore, different simulations were set up and run to observe the influence of flashing light on exit selection. The results were studied in relation to the main factors, namely the time factor and the factor of exit used to evacuate the supermarket. Considering the stochastic behavior of the agents when making the decision about exit choice, the simulation consisted of simulation three parameterization scenarios. The "base" scenario had no signage, and the "customer" agents only knew about the main exits and used them during the evacuation. The "nearest exit" scenario was an ideal scenario in which all "customer" agents knew all the exits: main and emergency exits, and therefore used the nearest exit during the evacuation. The "dynamic signage" scenario was

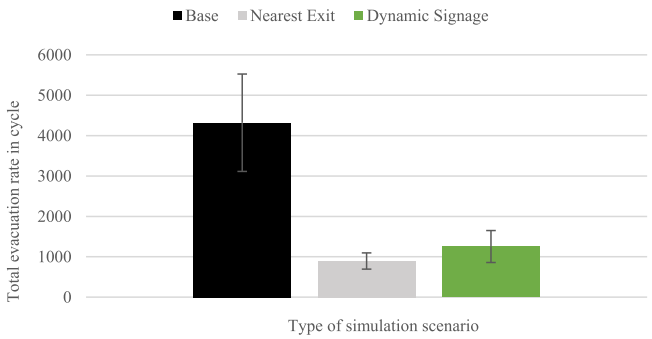

Fig. 10. Average total evacuation performance of agents by scenario type (in cycles)

one where initially the agents only knew the main exits, but during the evacuation, if they detected flashing lights above an emergency exit, they could choose to use that exit. Each scenario was run 20 times to assess exit choice and total exit time [58].

For each simulation, the population and terrorists were generated at the same location in the supermarket. The customer population corresponds to the demographic profile recorded over a given period. The evacuation behavior was particularly sensitive to the movement of the agents, the interactions between the customer agents, the interactions between the agents and the terrorist agent, the agent–environment interaction (base scenario, nearest exit scenario, dynamic signage scenario), and interactions with the signage (dynamic signage scenario).

To reduce the stochastic variation within each simulation, each scenario was run 20 times [58].

4.2. Results

In this study, 20 simulations were performed for three scenarios (base, nearest exit, and dynamic signage). The average simulation evacuation times were 4,319 cycles, 896 cycles, and 1,254 cycles. Fig. 10 illustrates the average evacuation performance of the agents according to the type of scenario (base, nearest exit, or dynamic signage).

Results of the "base" scenario: The "base" scenario was a scenario without the use of signs. The average simulation evacuation time was 4,319 cycles. The "customer" agents only knew the main exits and used them for evacuation (N=300). This scenario does not include the "staff" agent population. The results show that the average number of "evacuated" people was 275. Regarding the use of exits, 100% of the agents used the main exit, with an average exit time of 703 cycles. The modeling proposed above yields some interesting results. In particular, this simulation shows that 34 people were more psychologically impacted than others (i.e., scared) and that 25 people were injured or killed.

Results of the "nearest exit" scenario: The "nearest exit" scenario was an ideal scenario in which all customer "agents" knew all the exits (main exits and emergency exits) and used the nearest exit for evacuation (N=300). The average simulated evacuation time was 896. This scenario does not include the "staff" agent population. The results show that the average number of "evacuated" was 292. Regarding the use of exits, 63% of customer agents used the emergency exit with an average exit time of 321 cycles, and 37% of customer agents used the main exit with an average exit time of 312 cycles. The modeling proposed earlier shows highly relevant results. In fact, this simulation revealed that 22 people were more psychologically impacted, and eight people were injured or killed.

Results of the "dynamic signage" scenario: The "dynamic signage" scenario was one in which initially the "customer" agents were only aware of the main exits (N=300), but during the evacuation if they detected flashing lights above an emergency exit, they could choose to use that exit. The average simulation evacuation time was 1254 cycles. The results show that the average number of "evacuated people" was 288. Regarding the use of the exits, out of an average of 51% of agents who used the emergency exit with an average exit time of 316 cycles, 41.5% of agents used an emergency exit with dynamic guidance with an average time of 253 cycles, 10% used a conventional emergency exit with an average time of 379 cycles, and 48.5% of agents used the main exit with an average exit time of 253 cycles. The modeling previously described allows us to highlight two elements that are relevant to our study. First, the simulation showed that 21 people were more afraid, that is, there was a stronger psychological impact, and 12 people were killed or injured.

4.3. Conclusion

The results of the execution of the three scenarios are presented according to the number of agents evacuated and the total evacuation time (in cycles) for a comparative descriptive analysis of the "base," "nearest exit," and "dynamic signage" scenarios.

Fig. 11 illustrates the performance of the number of agents evacuated according to the type of scenario (base, nearest exit, or dynamic signage) and evacuation time.

In the "base" scenario: Per the studies noted in Section 1.1, this scenario was configured as close as possible to real-life situations. The "base" scenario was set up according to the theory that individuals tend to use the door through which they entered. That is, they use the same path to enter and exit [1,2,7,12]. The results showed that the "base" scenario produced a longer time for the total evacuation of agents compared to the "nearest exit" and "dynamic signage" scenarios.

In the "nearest exit" scenario: In this "ideal" scenario, the setup allowed all customer agents to know all exits (the three main exits and the 10 emergency exits) and to use the nearest exit during the evacuation. The results showed that compared to the "baseline" scenario, the total evacuation time decreased by 79.24%. This result suggests that a better distribution of agents to the nearest exit influences their evacuation performance. This suggests that the improvement in evacuation efficiency was the result of better distribution of agents to the available exits and a reduction in travel time to the exits.

In the "dynamic signage" scenario: A scenario that included dynamic signage of five of the 10 emergency exits in the virtual supermarket. In the initial setup, the customer agents were only aware of the main exits, but during the evacuation, they could choose to use that exit if they detected flashing lights above the emergency exit. The results showed a 70.09% reduction in the total evacuation time of the customer agents when comparing the "dynamic signage" scenario with the "base" scenario. In addition, the results show a 39.9% difference in agent evacuation time compared to the "nearest exit" scenario. However, it is important to note that the "nearest exit" scenario is not a realistic configuration, and that this scenario requires customer training in evacuation procedures.

Comparison of the "nearest exit" and "dynamic signage" scenarios: The results of the "nearest exit" and "dynamic signage" scenarios are presented according to the number of agents evacuated and the type of exit used for a comparative descriptive analysis of the two scenarios (Fig. 12).

The analysis of the distribution of the use of the emergency exits revealed that the "nearest exit" scenario (ideal scenario) had a 39.92% lower total evacuation time than the "dynamic signage" scenario. However, a comparative analysis of the results showed a difference in the use of emergency exits and the distribution of personnel. Indeed, the "nearest exit" scenario produced an unbalanced use of emergency exits, with a higher use of emergency exits (5 and 8) compared to under-use of emergency exits (0, 4, 1, 10, 11, 4, 7, and 9). In the "dynamic signage" scenario, the results showed a higher rate of use of equipped emergency exits compared to conventional emergency exits. This resulted in better distribution of emergency exits in the virtual supermarket.

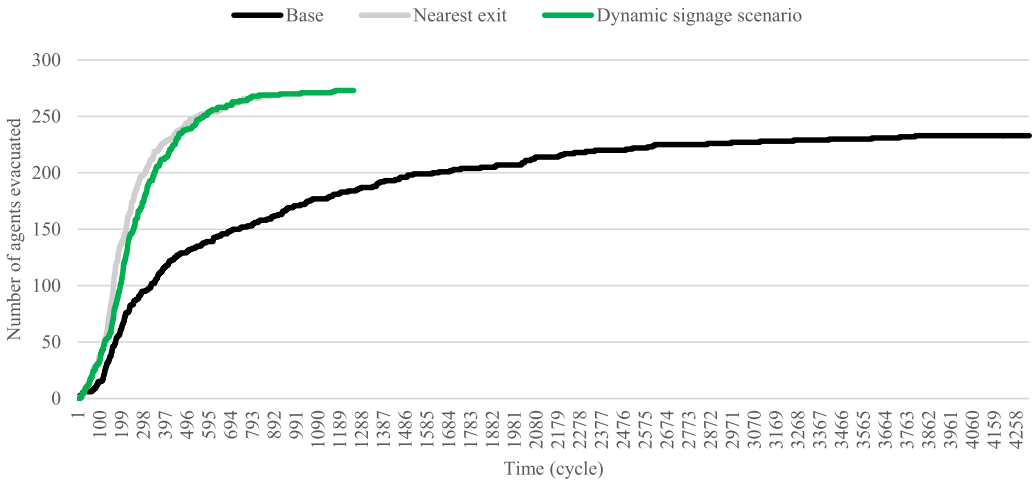

Fig. 11. Evacuation performance of the number of agents evacuated according to scenarios and time (in cycles)

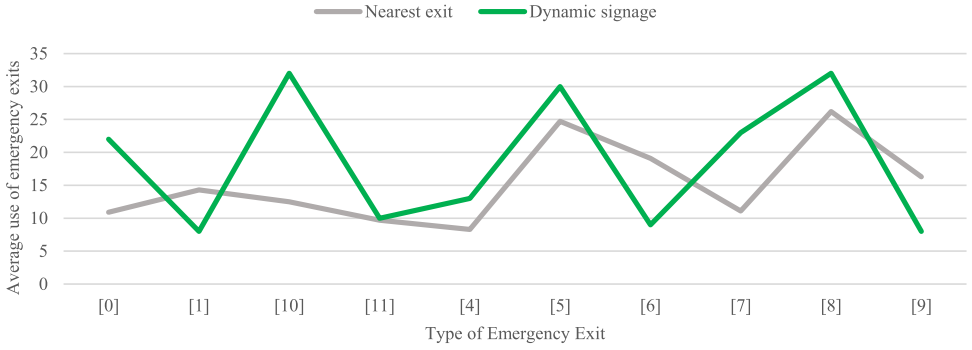

Fig. 12. Distribution of the use of emergency exits by according to the "nearest exit" and "dynamic signage" scenarios (in numbers)

5. Discussions and perspectives

Our embodied and situated approach to cognition views an individual's decision-making in the context of emergency evacuation as a consequence of a functional change in the way the subject interacts with the environment. In this context, our work has focused on understanding the relationship between cognition and environment in the development of cognitive flexibility and the ability to safeguard physical and psychological integrity—i.e., the factors at work in the interactions between cognition, resources, and sensoriality. To this end, we conducted behavioral and computer simulation experiments to explore the links between cognition and the dynamics of human capabilities in a complex environment.

Drawing on affordance theory [16,21,37] and recent studies [1,3,5,6,12,35,58], we explored the links between sensory and cognitive affordances in a series of emergency evacuation experiments in a specific environment of the supermarket. The aim of this series of experiments was to test our hypothesis that altering environmental (sensory) affordances alters participants' decision-making (i.e., exit choice). In line with our hypothesis, an individual's decision-making could benefit from the resources embedded in the environment and would likely increase the cognitive abilities that facilitate action. However, we believe it is essential to replicate this study by considering the participants' decision-making time. The results of this new study would allow us to confirm or refute the hypothesis that modification of the environment would influence decision-making in an emergency situation in a supermarket.

Despite the limitations of our study, the analyses of the behavioral experiments and the simulation experiments provide some insights into the possible links between environmental (sensory) affordances and human behavior during an emergency evacuation in the specific environment of a supermarket. In particular, the results of the behavioral experiments allow us to consider the feasibility of the device (i.e., the green flashing lights), its functionality in the supermarket, its acceptability, and its influence on the participants' evacuation choice in both controlled and uncontrolled environments with many sources of variations. In comparison, the data from the simulation experiments provide promising insights into the influence of dynamic versus conventional signaling in a virtual supermarket environment. This could support the possibility of a possible modeling of the influence of affordances on the evacuation behavior of agents in a complex virtual environment [5].

In conclusion, our study opens research perspectives on the understanding of the evacuation behavior of individuals in response to different types of attacks (e.g., armed robberies, hostage-taking scenarios, bombings) and in different types of public establishments (e.g., nightclubs, train stations, museums, and supermarkets).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jnlssr.2022.10.006.

References

[1] T.J. McClintock, A.H. Reinhardt-Rutland, & J.C. Leslie, A behavioural solution to the learned irrelevance of emergency exit signage. (2001).
[2] E. Carattin, Wayfinding architectural criteria for the design of complex environmentsin emergency scenarios. (2011).

[3] E. Carattin, C. Meneghetti, V. Tatano, F. Pazzaglia, Human navigation inside complex buildings: using instructions and maps to reach an area of refuge, International Journal of Design Creativity and Innovation 4 (2) (2016) 105–118, doi:10.1080/21650349.2015.1135760.

[4] E.R. Galéa, H. Xie, S. Deere, D. Cooney, L. Filippidis, Evaluating the effectiveness of an improved active dynamic signage system using full scale evacuation trials, Fire Safety Journal 91 (2017) 908–917, doi:10.1016/j.firesaf.2017.03.022.

[5] L. Filippidis, H. Xie, E.R. Galea, P.J. Lawrence, Exploring the potential effectiveness of dynamic and static emergency exit signage in complex spaces through simulation, Fire Safety Journal 125 (2021) 103404, doi:10.1016/j.firesaf.2021.103404.

[6] T.J. Shields, K.E. Boyce, A study of evacuation from large retail stores, Fire safety journal 35 (1) (2000) 25–49, doi:10.1016/S0379-7112(00)00013-8.

[7] L. Künzer, G. Hofinger, R. Zinke, The Influence of Colored Running Lights on Route Choice-Dynamic Guidance and Affordance, in: Proceedings of the 8th International Conference on Pedestrian and Evacuation Dynamics: PED 2016, 2016, pp. 167–172. https://team-hf.de/wp-content/uploads/2021/05/kuenzer-2016-ped-2016-influence-of-colored-run.pdf.

[8] J.D. Sime, Movement toward the familiar: Person and place affiliation in a fire entrapment setting, Environment and Behavior 17 (6) (1985) 697–724, doi:10.1177/0013916585176003.

[9] J.L. Bryan, in: Behavioral Response to Fire and Smoke, FPE Handbook of Fire Protection Engineering, 2nd ed., National Fire Protection Association, Quincy, MA, 1995, pp. 315–341.

[10] G. Proulx, in: Movement of People: the Evacuation Timing, SFPE Handbook of Fire Protection Engineering, 3rd ed., National Fire Protection Association, Quincy, MA, 2002, pp. 342–366.

[11] H. Frantzich, Occupant behaviour and response time, in: 2nd International Symposium on Human Behaviour in Fire, Interscience Communications Ltd., 2001, pp. 159–165. https://lup.lub.lu.se/record/781730.

[12] D. Norman, (2004). Affordances and design. Unpublished article, available online at: https://jnd.org/affordances_and_design/

[13] A.H. Morice, G.J. Diaz, B.R. Fajen, N. Basilio, G. Montagne, An affordance-based approach to visually guided overtaking, Ecological Psychology 27 (1) (2015) 1–25, doi:10.1080/10407413.2015.991641.

[14] L. Dutriaux, & V. Gyselinck, Learning is better with the hands free: The role of posture in the memory of manipulable objects, PLoS One 11 (7) (2016) e0159108, doi:10.1371/journal.pone.0159108.

[15] J.J. Gibson, The theory of affordances, Hilldale, USA 1 (2) (1979) 67–82.

[16] M. Luyat, & T. Regia-Corte, Affordances: from James Jerome Gibson to recent formalisations of the concept, L'Année psychologique 109 (2) (2009) 297–332, doi:10.3917/anpsy.092.0297.

[17] R. Versace, D. Brouillet, G. Vallet, Embodied cognition: A situated cognition and projected, Mardaga (2018).

[18] J.J. Gibson, The theory of affordances, Hilldale, USA 1 (2) (1977) 67–82.

[19] J.J. Gibson, Affordances and behavior, Reasons for realism: Selected essays of James J. Gibson (1975) 410–411.

[20] S. Martin, K. Moinier, S. Lancel, et al., The Importance of Body and Action in the Design of Technological Devices: For an Embodied Shift as an Alternative Conceptual and Methodological Framework in Gerontechnology, Adv Complement Alt Med 7 (2) (2022) ACAM.000656.2022, doi:10.31031/ACAM.2022.07.000656.

[21] F.Da Silva, T. Camus, D. Brouillet, M. Jimenez, E. Viglieno, L. Brunel, Is a letterbox always a letterbox? The role of affordances in guiding perceptual categorization, Psychological research 85 (4) (2021) 1673–1684, doi:10.1007/s00426-020-01328-x.

[22] F. Osiurak, C. Jarry, D.Le Gall, Grasping the affordances, understanding the reasoning: toward a dialectical theory of human tool use, Psychological review 117 (2) (2010) 517, doi:10.1037/a0019004.

[23] R. Hartson, Cognitive, physical, sensory, and functional affordances in interaction design, Behaviour & information technology 22 (5) (2003) 315–338, doi:10.1080/01449290310001592587.

[24] L. Seifert, M. Dicks, F. Wittmann, P. Wolf, The perception of nested affordances: An examination of expert climbers, Psychology of Sport and Exercise 52 (2021) 101843, doi:10.1016/j.psychsport.2020.101843.

[25] M.S. Boschker, F.C. Bakker, C.F. Michaels, Memory for the functional characteristics of climbing walls: perceiving affordances, Journal of Motor Behavior 34 (1) (2002) 25–36, doi:10.1080/00222890209601928.

[26] W.H. Warren Jr, S. Whang, Visual guidance of walking through apertures: body-scaled information for affordances, Journal of experimental psychology: human perception and performance 13 (3) (1987) 371, doi:10.1037/0096-1523.13.3.371.

[27] A. Bhargava, H. Solini, K. Lucaites, J.W. Bertrand, A. Robb, C.C. Pagano, S.V. Babu, Comparative evaluation of viewing and self-representation on passability affordances to a realistic sliding doorway in real and immersive virtual environments, in: 2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), IEEE, 2020, pp. 519–528. March.

[28] S.P. Tipper, M.A. Paul, A.E. Hayes, Vision-for-action: The effects of object property discrimination and action state on affordance compatibility effects, Psychonomic bulletin & review 13 (3) (2006) 493–498, doi:10.3758/BF03193875.

[29] D.T. Cho, R.W. Proctor, The object-based Simon effect: Grasping affordance or relative location of the graspable part? Journal of Experimental Psychology: Human Perception and Performance 36 (4) (2010) 853, doi:10.1037/a0019328.

[30] M. Tucker, & R. Ellis, The potentiation of grasp types during visual object categorization, Visual cognition 8 (6) (2001) 769–800, doi:10.1080/13506280042000144.

[31] W.H. Warren, Perceiving affordances: visual guidance of stair climbing, Journal Of experimental psychology: Human perception and performance 10 (5) (1984) 683, doi:10.1037/0096-1523.10.5.683.

[32] L.S. Mark, Eyeheight-scaled information about affordances: a study of sitting and stair climbing, Journal of experimental psychology: human perception and performance 13 (3) (1987) 361, doi:10.1037/0096-1523.13.3.361.

[33] B.K. Maraj, & J.A. Domingue, Standing distance in climbability of stairs, Perceptual and motor skills 88 (2) (1999) 682–684, doi:10.2466/pms.1999.88.2.682.

[34] E. Economidou, & B. Hengeveld, No Door Handle, No Entry! Expressing Cues through a Shape-Changing Door, Interactive Surfaces and Spaces (2021) 1–7, doi:10.1145/3447932.3492326.

[35] J. Olander, E. Ronchi, R. Lovreglio, D. Nilsson, Dissuasive exit signage for building fire evacuation, Applied ergonomics 59 (2017) 84–93, doi:10.1016/j.apergo.2016.08.029.

[36] D. Nilsson, (2009). Exit choice in fire emergencies-Influencing choice of exit with flashing lights. https://portal.research.lu.se/en/publications/exit-choice-in-fire-emergencies-influencing-choice-of-exit-with-fr

[37] D. Norman, (1986). The psychology of everyday things.

[38] D.A. Norman, Affordance, conventions, and design, interactions 6 (3) (1999) 38–43, doi:10.1145/301153.301168.

[39] E.R. Galéa, H. Xie, P.J. Lawrence, Experimental and survey studies on the effectiveness of dynamic signage systems, Fire Safety Science 11 (2014) 1129–1143, doi:10.3801/IAFSS.FSS.11-1129.

[40] J.C. Craveur, E.R. Galea, L. Filippidis, L.M. ISMANS, Velocity measurements for the movement of people and evacuation simulations. Days of the Fire Research Group, Cadarche (2016) http://docs.gdrfeux.univ-lorraine.fr/Cadarache/ISMANS1.pdf.

[41] D. Norman, A The psychology of everyday things. (1986)

[42] J. Procházka, R. Cimler, K. Olševičová, Pedestrian modelling in netlogo, in: Emergent Trends in Robotics and Intelligent Systems, Springer, Cham, 2015, pp. 303–312, doi:10.1007/978-3-319-10783-7_33.

[43] X. Zhang, G. Coates,& X. Ni, Agent-based modelling and simulation for theatre emergency evacuation. IMT Mines Albi-Carmaux (École Mines-Télécom). (2017) https://dro.dur.ac.uk/21880/1/21880.pdf

[44] E.G. Macatulad, & A.C. Blanco, A 3DGIS multi-agent geo-simulation model for assessment of building evacuation scenarios considering urgency and knowledge of exits, International Journal of Urban Sciences 23 (3) (2019) 318–334, doi:10.1080/12265934.2018.1549505.

[45] S. Manalili, H. Rafols, J. Ramos, S. Shah, L.E. Garciano, Enhanced safe 137 Conduct and preparation for effective evacuation (escapee) using gama, GEOMATE Journal 18 (68) (2020) 194–199 https://geomatejournal.com/geomate/article/view/562.

[46] X. Pan, C.S. Han, K. Dauber, K.H. Law, A multi-agent based framework for the simulation of human and social behaviors during emergency evacuations, Ai & Society 22 (2) (2007) 113–132, doi:10.1007/s00146-007-0126-1.

[47] H. Abdelhak, Modelling panic phenomena in the context of the management of crisis, University of Le Havre, 2013 Doctoral dissertationtel-01356721.

[48] N. Ding, Y. Ma, D. Dong, Y. Wang, Experiment and simulation study of emergency evacuation during violent attack in classrooms, Journal of Safety Science and Resilience 2 (4) (2021) 208–221, doi:10.1016/j.jnlssr.2021.09.002.

[49] S. Hassanpour, & A.A. Rassafi, Agent-Based Simulation for Pedestrian Evacuation, Behaviour Using the Affordance Concept. KSCE Journal of Civil Engineering 25 (4) (2021) 1433–1445, doi:10.1007/s12205-021-0206-7.

[50] D. Helbing, & P. Molnar, Social force model for pedestrian dynamics, Physical review E 51 (5) (1995) 4282, doi:10.1103/PhysRevE.51.4282.

[51] D. Helbing, L. Buzna, A. Johansson, T. Werner, Self-organized pedestrian crowd dynamics: Experiments, simulations, and design solutions, Transportation science 39 (1) (2005) 1–24, doi:10.1287/trsc.1040.0108.

[52] F. Huo, W. Song, L. Chen, C. Liu, K.M. Liew, Experimental study on characteristics of pedestrian evacuation on stairs in a high-rise building, Safety science 86 (2016) 165–173, doi:10.1016/j.ssci.2016.02.025.

[53] H. Jones, J. Saunier, D. Lourdeaux, Towards an integration of factors physiological, personality and emotion in cognitive agents, Rencontres Jeunes Chercheurs en Intelligence Artificielle (2009) https://pagesperso.litislab.fr/~jsaunier/publi/rjcia09.pdf.

[54] J. Lin, R. Zhu, N. Li, B. Becerik-Gerber, Do people follow the crowd in building emergency evacuation? A cross-cultural immersive virtual reality-based study, Advanced Engineering Informatics 43 (2020) 101040, doi:10.1016/j.aei.2020.101040.

[55] L. Ma, B. Chen, S. Qiu, Z. Li, X. Qiu, Agent-based modeling of emergency evacuation in a railway station square under sarin terrorist attack, International Journal of Modeling, Simulation, and Scientific Computing 8 (02) (2017) 1750022, doi:10.1142/S1793962317500222.

[56] M. Kinateder, W.H. Warren, K.B. Schloss, What color are emergency exit signs? Egress behavior differs from verbal report, Applied ergonomics 75 (2019) 155–160, doi:10.1016/j.apergo.2018.08.010.

[57] Global Terrorism Database, National Consortium for the Study of Terrorism (START), Université du MarylandCodebook: Inclusion Criteria and Variables, juillet, 2017 https://www.start.umd.edu/sites/default/files/publications/local_attachments/START_GTD_TerrorismIn2018_Oct2018.pdf.

[58] A. Edrisi, B. Lahoorpoor, R. Lovreglio, Simulating metro station evacuation using three agent-based exit choice models, Case studies on transport policy 9 (3) (2021) 1261–1272, doi:10.1016/j.cstp.2021.06.011.