A survey based study concerning public comprehension of two-component EXIT/NO-EXIT signage concepts

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Abstract

Emergency signage conveys exit route information enabling occupants to identify and utilise emergency exits during evacuation. However, it has been frequently demonstrated that static signs are insufficient to attract people's attention. Previous incidents also demonstrate that if exit routes and exits become compromised by the incident, static signs are unable to adapt as required. A goal of the signage industry is to address these limitations while maintaining the clear and unambiguous information conveyed. A signage concept addressing these limitations incorporating a pair of linked adjacent signs, a standard EXIT sign and a text based 'NO EXIT' sign, is proposed. At any one time, only one sign is activated, displaying either EXIT or NO EXIT. The active sign can also flash to improve detectability. To assess whether this concept was acceptable, an on-line international survey, based on the ANSI Z535.3 comprehension test methodology was conducted. The results demonstrate that this novel concept fails to meet the acceptance criteria for safety signs, and as a result, the concept was abandoned by the manufacturer. This study also highlights the importance of conducting comprehension tests for any new safety signage design and the need for composing guidelines for design and application of dynamic signs.

Keywords: Egress, Human Factors, Dynamic Signage, Wayfinding, Comprehension Test

1 Introduction

In public buildings multiple evacuation routes and associated emergency exits are required to enable efficient evacuation of building occupants in the event of an emergency [1][2]. The availability of multiple alternative emergency exits is especially important for large buildings with complex layout. In many cases, the means of escape are not utilised as part of normal circulation system, e.g. office buildings, rail stations, etc., while in other situations new or occasional users of the building may be unfamiliar with the layout, e.g. airport terminals, hospitals, etc. To facilitate the use of the means of escape, escape route signage systems are required to identify evacuation routes and emergency exits [3]-[6]. The implicit assumption associated with emergency exit signs is that in the event of an emergency, building occupants will readily identify, correctly interpret and follow the guidance provided by the signs and thereby enabling them to locate their nearest viable emergency exit. However, studies of past fire disasters and evacuation drills have revealed that during emergency evacuation, most people tend to use familiar routes and exits, usually the entrance they used to gain access to the building in order to evacuate, bypassing or ignoring the designated emergency exits, despite the presence of regulatory compliant emergency exit signs [7]-[11].

In situations involving rapidly deteriorating conditions, such as may result from a fire or a terror incident, some designated evacuation routes and exits may become compromised and hence no longer viable [12]-[14]. In these situations, the signage system points not to a place of relative safety but could lead occupants to potential danger. Thus, it is necessary to redirect occupants to an alternative

route/exit. Currently, the only way of achieving this is through the use of a public address system or staff intervention.

The potential for emergency signage systems to fail to reliably and consistently fulfil their intended purpose, as evidenced by a number of tragedies [7], [10]-[15], is due in part, to their potential to be overlooked by many people and their inability to adapt to a rapidly changing environment. Thus, there is a clear need to improve conventional emergency signage so that they can attract attention when they need to be conspicuous, to redirect people in an evolving emergency, and to identify, not just an exit route, but a viable exit route. This has driven the pursuit for a new generation of advanced emergency signage system to improve public safety in buildings for a number of years [16]-[27], with several new dynamic signage concepts already appearing in the market, e.g. [28]-[31].

In emergency evacuation situations time is critical and so in addition to improved detectability, it is also important that the intended message conveyed by the sign can be clearly comprehended by the public. It is thus essential to establish whether these new concept dynamic emergency signs introduce potential confusion among occupants who have not been trained to use the signs or have not previously seen them in active mode. Currently, there is a lack of explicit guidance or standards for the design and assessment of dynamic emergency signage. Thus, it is currently possible for signage manufacturers to propose, manufacture and bring to the market novel emergency signage concepts, which while appearing to be intuitive, have not been rigorously evaluated to ensure that they perform as expected without unintended consequences.

In this paper we describe a study to assess the level of public comprehension of a novel signage concept involving linked adjacent emergency exit signage pairs as defined by the concept presented in Figure 1 [29]. While this design includes the familiar green running man pictogram, it also incorporates three novel signage concepts, a flashing backlight to improve conspicuity, a linked adjacent pair of signs and the red coloured text based 'NO-EXIT' sign enabling the sign to adapt when the exit route is no longer viable. The design used in [29] can be operated in both static and flashing activation options. It is noted that the green running man sign in [29] does not include a directional arrow as required by the ISO standard [6] which is also adopted in Europe [3]. This approach is typically used in Australia, Japan and New Zealand for final exit signs.

Figure 1. Linked pair of adjacent signs intended to indicate that an exit is viable (a) and not viable (b).

The active nature of the selected design is indicated either through the backlight of the sign being activated in a continuous static lit 'on' state (activation option 1 (AO1)) or through a flashing backlight (activation option 2 (AO2)). Only one of the pair of signs is ever activated at any one time, the second sign is deactivated and so the backlight is in the unlit 'off' state. Thus, this particular design has four possible display configurations, two to indicate that the emergency exit is considered viable (i.e. State 1 (S1)), in which the backlight of the green running man sign is either continuously illuminated or flashing, while the NO-EXIT sign remains unlit. The other two configurations indicate that the emergency exit is considered not viable (i.e. State 2 (S2)). This involves the backlight of the NO-EXIT sign either being continuously illuminated or flashing in red while the green running man sign remains unlit (see Table 1).

Table 1: Four signage options and corresponding EXIT status.

In order to determine how intuitive these four signage configurations are to the general public and hence their appropriateness for use in public buildings, the Fire Safety Engineering Group (FSEG) at the University of Greenwich undertook an on-line international survey. The specific purpose of the survey was to determine:

- How intuitive is the design in conveying the message that the associated exit is considered viable or not viable?
- Is there a difference in the level of public understanding between the static lit and flashing backlit options?

The implemented survey methodology was previously developed and successfully used by Galea *et al.* [26] in testing the negated Active Dynamic Signage System (ADSS) concepts. The specific survey methodology and questions used in the current study were approved by the independent University Research Ethics Committee of the University of Greenwich. The international survey was made available on the FSEG website and the data presented in this paper was collected over a 6-week period from 5th August 2016 to 15th September 2016 with a total of 425 replies received from 33 countries. The survey mainly considered replies from two sub-populations, one consisting of members of the general public and the other consisting of those whose profession is related to fire safety.

This paper presents a detailed review of dynamic signage concepts and their evaluation (Section 2), details of the survey methodology proposed for this study (Section 3), the analysis of the data collected (Section 4), the implication of the findings (Section 5) and study limitations (Section 6) prior to drawing final conclusions (Section 7).

2 Dynamic signage technology and their evaluation

One of the earliest studies into enhanced signage systems was undertaken by Jin *et al.* [16], where the conspicuousness of self-flashing EXIT signs and ordinary illuminated signs were measured and compared using an experimental method. They found that signs with a flashing (on and off) internal backlight were more conspicuous than standard illuminated signs of the same size to observers viewing the signs at the same distance. Jin further argued that the noticeability of signs particularly benefits from the flashing light in an environment with distractions from other light sources.

In an attempt to establish the psychological cause of the under-use of emergency exits in building evacuation [8], McClintock *et al.* [17] surveyed 500 supermarket shoppers and found that people readily recognise and associate conventional emergency exit signs with safety in an emergency. However, they also found that only 18% of those surveyed could recall seeing an emergency exit and only 25% could mark the location of at least one emergency exit on a store diagram. McClintock explained this phenomenon by the concept of acquired 'learned irrelevance'; as people repeatedly encounter emergency exit signs but without ever needing to make use of them under everyday conditions, they tend not to notice or recall their location, resulting in the under-use of emergency exits during an actual evacuation. Findings by Xie *et al.* [18] from laboratory trials involving the usage of standard exit signs during evacuation scenarios, in which only 38% of the participants perceived and made use of emergency exit signs with unobscured visual access support this concept.

McClintock *et al.* [17] argued that in order to break the learned irrelevance to signage and improve signage conspicuity it is necessary to introduce stimulus in the form of additional lighting that only come into play during an emergency. To explore this concept they tested a number of approaches including using a flashing backlight and introducing an additional external flashing blue light to the standard illuminated exit sign. They simultaneously showed each participant (of which there were 361) six signage options placed above six doors and asked them to score the signage options in terms of conspicuousness. The sign with the external flashing blue light was considered the most conspicuous option while the flashing backlight was considered the second best option. In addition, 73% of the participants stated that they would use the door indicated by the blue flashing light in the event of an

emergency. It is noted that in this experiment each door was clearly marked with the text 'emergency exit' written across its face and the participants were told that the door was intended to represent an emergency exit and so the methodology could not reliably measure the association of each signage concept with an emergency exit.

Furthermore, Nilsson *et al.* [19] questioned the single option of the blue flashing strobe light in the study and the association of the blue colour with emergency EXIT signs. They argued that certain colours have known established meaning and in particular, green normally signals *go* or *safety*. Nilsson *et al.* [19] then compared several options of emergency EXIT signs augmented with different coloured flashing lights and confirmed that people are more likely to associate the emergency exit with green lights. In further studies, the signs and exits augmented with green flashing lights were found to stand out and attract more people during evacuation trials [20][21] as well as in virtual reality environments [22][23]. However, the difficulty with these experiments is that none of them have attempted to directly measure the inherent understanding of the intended message provided by the modified signs.

The studies described above explored the methods of drawing people's attention to exit signage during an emergency through flashing backlight or the addition of external lights, but the appearance of the signs remains largely the same as they are in a normal state. Galea *et al.* [24]-[27] proposed a unique signage design concept that changes the appearance of the signs when activated. This design integrates a set of LEDs into the arrow symbol of the standard 'green running man' emergency EXIT sign [6]. When activated during an emergency, the LEDs flash in sequence and create an animation of a running arrow, effectively incorporating two types of dynamism, flashing (temporal changes) and animation (spatial changes), into the sign. This design reinforces not only the conspicuity of the sign, but also the indicated direction of travel. This design concept was demonstrated to be significantly more effective than standard EXIT signs in laboratory trials [24] and full-scale evacuation trials [25]-[27]. These trials also measured the inherent public understanding of the dynamic concept in several ways, the most important being, measuring the decision time required to commit to a particular course of action [24], through post-trial questionnaires [24]-[27] and indirectly through the improved number of people following the dynamic sign instruction [26][27].

In summary, efforts to address the issue of low detectability of standard EXIT signs have led to the concept of introducing flashing lights, which transform the static sign into a new form of dynamic sign. Several approaches have been adopted to create dynamic signs, including flashing backlights, external flashing lights and flashing animation. The first two approaches introduce temporal changes to draw attention to the sign. The third approach introduces an animation effect created by the use of a dynamic sequence of flashing or running lights within a physical sign, essentially using both temporal and spatial changes to draw attention to the sign. A fourth approach, not considered in this paper, involves a moving animation created by a projected virtual sign [32]-[34]. These two animation approaches utilise spatial changes to enhance both the signage conspicuity and the conveyed signage message. The introduction of flashing lights, by whichever method, is an effective means of improving the detectability of signs as they improve signage conspicuity and consequently, may also improve the sensory affordance of the signs [20][35][36]. Based on Gibson's theory of affordances [36], affordance is what an object offers the user in relation to the fulfilment of its goal. Here the sensory affordance is provided by the features of the sign that support people in detecting it while cognitive affordance is provided by features that enable it to be recognised as an emergency sign; for example, the green colour of the sign assists people in distinguishing the 'emergency' sign from other signage. The flashing lights may increase the sensory affordance of the sign by making it more noticeable. It may also potentially enhance the cognitive affordance of the emergency nature of the message conveyed by the sign. However, it is also possible that the flashing nature of the sign may decrease its cognitive

affordance, creating confusion or uncertainty. It is essential that improving the detectability of the sign is not achieved at the expense of the inherent understanding of the message conveyed by the sign.

These various approaches to improving the detectability of emergency exit signs have been adopted by several signage manufacturers, for example, the flashing arrow concept has been adopted by [28], the flashing backlight concept has been adopted by [29], while the concept of flashing and animated LEDs in the arrow of the exit sign has been adopted by [30][31].

In addition to enhancing the conspicuity of emergency exit signs and thereby encouraging occupants to use the indicated escape routes and exits, there are occasions in which some exit routes or exits may become unavailable or unsafe to use; for example, if compromised by the nature of the developing incident. In these circumstances, the signs would ideally be able to adapt to the changing situation and indicate that an exit route or exit is no longer viable. One way of achieving this is to negate the original signage information to discourage occupants from using the exit route or exit.

To address this situation, Galea *et al.* [24] proposed four potential design concepts that could be used to negate the original signage information to indicate that a normally viable exit route was no longer considered safe. These concepts were tested using an international survey to gauge inherent understanding of the various proposed concepts [26]. The design with a large red cross through the entire sign achieved the best interpretation and recognition rates – with 92% of the participants correctly interpreting the meaning of the sign [26] and achieving a critical confusion rate (see Supporting Information Part A) of only 0.5% (see Supporting Information Part F). This concept was then developed into a prototype negated flashing sign (see Figure 2) and successfully tested in a series of full-scale evacuation experiments [25]-[27]. As with the concept for the dynamic EXIT sign, this approach has now been adopted by several signage manufacturers such as [30][31]. Olander *et al.* [37] tested a similar design concept involving a red cross placed across the entire EXIT sign, accompanying external red flashing lights and red background colour in a questionnaire study, and also found the design is very effective in conveying a dissuasive message of not using the associated exit door.

Figure 2. The prototype of the negated sign in operation depicting a single operation cycle [24].

An alternative approach to negate an exit involves making use of a linked pair of adjacent signs. The alternate design incorporates one sign displaying the green running man graphic (indicating exit) and the other sign conveying the text message ‘NO EXIT’ with red backlight [29] (see Figure 1). At any one time, only one of the signs is activated, depending on the viability of the exit. This concept, while not involving a flashing component is another form of dynamic sign, as it can adapt the conveyed message to the evolving situation. However, variations of the concept can include flashing red backlight when the ‘no exit’ option is required and the backlight of the green running man sign can flash when the ‘exit’ option is required [29].

In practice, it is not uncommon to have a combination sign consisting of several graphical symbols or even multiple signs (see Figure 3). However, it is relatively rare to have a combination of two signs with opposite meaning, even though both signs are not intended to be in effect or activated at the same time. In the case of the sign proposed by [29], this involves having the green running man graphic sign and NO EXIT sign side by side. An issue that must be addressed is whether this type of signage concept may cause potential confusion among occupants who have not been trained to use the signs or have not previously seen them in active mode.

(a) (b)

Figure 3. (a) Combination of three graphical symbols to form an escape route sign [5] and (b) multiple safety signs applied together [6].

It is suggested that all novel dynamic emergency exit signage concepts should undergo individual testing to ensure that they have both improved detectability and that the intended message can be clearly and unambiguously understood by the public. The design options proposed by Galea *et al.* [24]-[27] have successfully demonstrated both aspects through a combination of laboratory and full-scale trials, with associated questionnaires and international surveys. While the enhanced detectability of the flashing backlit design (as used in [29]) has been successfully demonstrated in [16], the degree to which the public unambiguously understands the intended meaning of this signage concept has not been rigorously assessed. While it could be argued that the flashing arrow, as used in [28], would have similar enhanced detectability to that of the flashing backlit design, the degree to which the public understands the meaning of the flashing arrow sign [28] has also not been demonstrated. Similarly, the degree to which the public understands the meaning of the linked adjacent pair of signs to negate an exit [29] has not been reported in the academic literature. In the next section we present the methodology used to test the comprehensibility of the proposed dynamic two component sign [29].

3 The survey methodology

The core part of the FSEG survey methodology used in this study is similar to the comprehension test for designing and evaluating new graphical symbols developed by ISO [38] and ANSI [39] (see Supporting Information Part A). The FSEG survey methodology includes some adaptations and additional test questions to suit the purpose of this study.

The survey attempts to identify the level of public understanding for each signage option. Since an international audience may interact with these signs, an international web-based survey was considered appropriate using an internet presentation of the signage options. The presentation of each signage option, created by the signage manufacturer, was via videos of the actual signs in operation above the intended closed EXIT for a short period of signage activation (20 s) (see Table 1). Invitation to participate in the survey was placed on FSEG's website (http://bit.ly/sign-survey) and advertised through social media outlets (e.g. Linkedin, Facebook), as well as circulated through emails and social networks. Anyone over the age of 18 from all over the world could take part. However, they needed to be able to read and write in English. In total, 425 replies were received from 33 countries over a period of 6 weeks. It is important to note that the participants were naïve in that the trial was the first time they would have seen the dynamic signs and the nature of the signs was not explained to them in the comprehension test.

The survey consisted of two parts, four questions relating to personal demographics and ten questions relating to signage interpretation. It required around 5 to 10 minutes to complete all 14 questions. Details of the survey questions can be found in Supporting Information Part B, here we outline the content of each section.

The four personal demographics questions concerned participants' age, gender, country/region of residence and more importantly, whether their profession or work is related to fire safety. This was to identify participants who worked in the fire engineering or safety so that their replies could be assessed separately in case of professional bias.

The second part of the survey included three sections. The first section is a comprehension test as in [38] and [39], in which the participants were shown each of the signage options along with the context through the recorded video footage, and then they were asked to explain in their own words what they

thought the sign indicated. This section of the survey was intended to measure how intuitive the proposed signage options were to the members of the public with or without a fire safety background.

In the second section, the participants were given the correct interpretation for each of the signage options, and they were asked to indicate their level of agreement with the interpretation using a five-point Likert Scale (i.e. strongly disagree, disagree, neither disagree or agree, agree and strongly agree). This section was intended to measure the level of agreement that the public had with the intended interpretation of the signs.

In the final section, the participants were shown the two signage configurations with the same meaning side by side for the two EXIT activation options and two NO-EXIT activation options respectively. The participants were then asked to select which of the two configurations most clearly indicated the stated intention of the sign. This section was intended to examine participants' preference between two signage options (i.e. the static lit sign and the flashing sign) that convey the same message.

The collected data was analysed using several statistical methods (see Section 4). In Section 4.1, as the paired samples of participants' interpretation was transformed into nominal data, the proportion of correct interpretation of the four signage configurations was examined using McNemar's test. Also, as multiple pairwise comparisons were conducted for the four signage configurations, a Bonferroni correction was applied accordingly and participants in the repeated measures for the six comparisons were treated as one cluster. In Section 4.3, Pearson's chi-square test for goodness of fit was used to compare the measured preference of AO1 and AO2 in both states S1 and S2, with the hypothesis of equal preference between AO1 and AO2. Furthermore, in Supporting Information Part C, the chi-square test of independence and the Fisher's exact test (where the measured values in any cells of contingency table are below 5) were used to rule out the likely influence of gender and profession on the interpretation of the signage options. In all the cases, a significant level of 0.05 was chosen as the critical value, except in the first case in which the Bonferroni correction was applied.

4 Results

In total there were 425 replies from 33 countries, with 257 (60.5%) replies from the UK, 66 (15.5%) replies from Australia, 30 (7.1%) replies from the USA and the remainder (72 or 16.9%) from 30 other countries. It was originally intended to undertake a comparative study of the results from different national groups. However, the sample size for the various countries was too small to allow a statistically meaningful comparison and so here we present a global analysis. Of all the replies, 168 (39.5%) were from females while 255 (60.0%) were from males (two preferred not to state their gender). Furthermore, of the 425 replies, 195 (45.9%) were from the fire safety professions while 230 (54.1%) were not related to these professions. The analysis first considers whether there is a gender (female/male) or profession (fire/non-fire professions) difference in signage interpretation before undertaking a detailed analysis. The detailed results from this analysis can be found in Supporting Information Part C. The results show that there is no statistically significant difference in the interpretation of the signage options for gender or profession, and thus these variables are excluded from the detailed analysis of global results.

It is noted that for an activation option of the linked pair of adjacent signs to satisfy the ANSI acceptance criteria, both states must satisfy both criterion, i.e. at least 85% correct responses and less than 5% critical confusions (see Supporting Information Part A).

4.1 Signage interpretation

The numbers of correct and incorrect interpretation of each signage configuration from the entire sample are presented in Table 2. Examples of participant statements that are considered correct, incorrect and displaying critical confusion can be found in Table 3. Further examples are provided in Supporting Information Part D.

Table 2. Replies to signage interpretation question from the entire sample[†].

The vast majority of the sample (98%) provided a correct interpretation of AO1S1 (**Static EXIT, deactivated NO-EXIT**) and there were no incorrect interpretations with critical confusion. Thus AO1S1 satisfies both ANSI acceptance criteria. This strongly suggests that this linked pair of adjacent signs, when operated in static mode and indicating a viable exit, is likely to be clearly understood by virtually everyone. This is not surprising as the illuminated green running man **Static EXIT** is a standard signage concept that is easily recognisable by people around the world. Furthermore, when only the **Static EXIT** component is illuminated, it is relatively difficult to detect the text on the adjacent **NO-EXIT** component, limiting the chance for potential confusion (see Table 1). As already noted, the sign does not contain an arrow as is required within the UK and Europe to indicate an exit direction. Nevertheless, over 60% of the test subjects who were from the UK correctly interpreted the meaning of the sign. See Table 3 and Supporting Information Part D1 for examples of correct interpretation. Of the nine incorrect interpretations for this configuration, five were due to the lack of an arrow (see Table 3 and Supporting Information Part D2).

Table 3. Examples of participant statements relating to each signage state and their interpretation.

The rates of correct interpretation of the other three signage configurations (i.e. AO1S2, AO2S1 and AO2S2) are broadly similar, i.e. 81%, 74% and 75% respectively, and clearly lower than that of AO1S1 (98%). The difference in the proportion of correct interpretation between AO1S1 and each of the other three configurations is statistically significant at a significance level of 0.0083 (tested using McNemar's test with the Bonferroni correction (i.e. $0.05/6 \approx 0.0083$), see Supporting Information Part E). However the difference in the proportion of correct interpretation between each pair of the three configurations (i.e. AO1S2, AO2S1 and AO2S2) is not statistically significant. Thus, all three of these signage configurations fail to satisfy the ANSI acceptance criterion of achieving at least 85% correct responses and so indicates a poor level of understanding. Furthermore, AO1S2 and AO2S2 also fail to satisfy the ANSI acceptance criterion related to the proportion of critical confusions as in both cases these are greater than 5%.

One problem with AO1S2 (**Static NO-EXIT, deactivated EXIT**) is that the adjacent **EXIT** sign, even though unlit, is still visible to some extent (see Table 1). Thus, there are two contradicting pieces of information being provided to an observer which are inherently confusing. It is thus not surprising that it achieved such a low comprehension score. See Table 3 and Supporting Information Part D3 for examples of the incorrect interpretation. Of greater concern is the high percentage (9.9%) of participants that displayed critical confusion. This represents a little more than a half of the incorrect category, i.e. at least half of the participants who incorrectly interpreted the meaning of this sign had an opposite interpretation to what is intended by the sign. They thought that the sign indicated that one should use this exit in the event of an emergency. See Table 3 and Supporting Information Part D4 for examples of incorrect interpretation with critical confusion.

Both AO2S1 (**Flashing EXIT, deactivated NO-EXIT**) and AO2S2 (**Flashing NO-EXIT, deactivated EXIT**) achieved the lowest levels of comprehension among the four configurations. A number of participants (73 or 17.2%) thought that AO2S1 was malfunctioning and as a result, some

of these did not know what the sign meant (see Table 3 and Supporting Information Part D5). Similar to AO2S1, some participants (40 or 9.4%) misinterpreted the flashing component of AO2S2 as possibly a fault in the hardware or got confused (see Table 3 and Supporting Information Part D6). AO2S2 also achieved a higher occurrence of critical confusion (5.2%) and so failed to satisfy the ANSI acceptance criterion. The interpretations of these critical confusions suggested that this signage combination indicated that one could use the exit during an emergency (see Table 3 and Supporting Information Part D7).

In summary, only AO1S1 passed the comprehension test with 98% correct responses and zero critical confusion, while the other three configurations failed on one or both of the ANSI acceptance criteria for safety signs. However, as both states associated with an activation option must pass the ANSI acceptance criteria, both the static and flashing options of the tested pair of adjacent signs are considered inappropriate for general use due to the poor levels of comprehensibility achieved. It is noted that many participants thought that the flashing backlight of the EXIT sign component in both AO2S1 and AO2S2 could indicate that the sign was malfunctioning and as a result, some did not know what it meant. However, of greater concern is that a number of the participants who misinterpreted the meaning of AO1S2 and AO2S2 (the NO-EXIT options) thought that the sign meant exactly the opposite to its intended meaning. Thus, instead of preventing people from using the exit, these two signage configurations would potentially encourage some people to use the exit. Several members of the fire professional community also expressed concerns at the contradictory and confusing nature of having both EXIT and NO-EXIT signs visible (see Supporting Information Part D8).

4.2 Level of agreement to intended meaning

The participants' level of agreement with the correct interpretation for each signage configuration measured by a five point Likert scale is presented in Table 4. Among the four configurations, AO1S1 achieves the highest level of strong agreement with the intended meaning (68%), while AO1S2 is the only other signage option to achieve greater than 50% strong agreement. The poorest level of strong agreement is achieved by AO2S1 and AO2S2 which only manage 40% strong agreement with the intended meaning.

Table 4. Level of agreement with provided signage meaning for the fire professionals.

If the categories of Strongly Agree and Agree are collapsed and the categories of Strongly Disagree and Disagree are collapsed, the differences between the levels of agreement for the signs become a little clearer. Even after the meaning of the various signs is explained to the participant population, only AO1S1 achieves 90% agreement with the intended interpretation. AO1S2 achieves 82% agreement while AO2S1 and AO2S2 achieve less than 80% agreement. The reluctance to accept the intended meanings for the signs is greatest for the two flashing signage options.

4.3 Preferred options

The participants' preferred signage options when shown the static (AO1) and flashing (AO2) design options side by side for the activated EXIT, deactivated NO-EXIT combination (S1) and the activated NO-EXIT, deactivated EXIT combination (S2) are presented in Table 5. The majority of the population prefer the static signage design (AO1) to the flashing signage design (AO2) for both activation states. Although slightly fewer prefer AO1S2 (static NO-EXIT, deactivated EXIT) to AO1S1 (static EXIT, deactivated NO-EXIT), compared with the hypothesis that AO1 and AO2 are equally preferred, the difference in the preference for static (AO1) compared to flashing (AO2) activation option for both states S1 and S2 is statistically significant at a significance level of 0.05 (Pearson's chi-square test, $P<0.0001$). Clearly, the static signage options (AO1) are strongly preferred to the flashing signage options (AO2), irrespective of the state.

Table 5. Preferred signage options.

5 Discussion

When interpreting these results it is important to recall that the participants were naïve, in that the nature of the dynamic signage was not explained to them. In essence, the survey was the first time the participants had seen these dynamic signs along with the context and their intended meaning had not been explained to them. This is considered important as the signage system, if effective, must be intuitive, i.e. the first time you see the sign in operation it must be clear what it means.

The dynamic signage concept (i.e. [29]) examined in this study attempts to overcome the two fundamental weaknesses of standard static emergency exit signage – their inability to adapt to an evolving emergency situation in which an exit becomes non-viable and their fundamentally low conspicuity. However, in addressing these weaknesses, it is equally important that any proposed modification to the standard signage appearance should not cause significant confusion or misinterpretation among potential users.

The concept of indicating an exit is either viable or not through the use of a linked pair of adjacent signs is simple in principle: one sign indicates that the exit is viable (graphic green running man) and the other indicating that the exit is not viable (text based NO-EXIT). The signage system thus has two states of operation, one indicating that the exit is viable, in which the standard green running man sign is active and the adjacent NO-EXIT sign is deactivated, and the other state indicating that the exit is not viable, in which the standard green running man sign is deactivated and the NO-EXIT sign is activated. Two activation options are available for each state, one involving static signs and the other involving dynamic (flashing) signs. As each individual sign in the pair conveys opposite meaning, inherently contradictory and confusing information would be conveyed if the message on both signs could be perceived simultaneously. Thus, the concept is only viable if one sign is active at any one time and the message conveyed by the deactivated sign is not perceivable.

For the static options (AO1), the signage system tested failed to pass the comprehension test for one of the two activation states. When indicating that the exit is viable (S1), the activated static graphical green exit sign was clearly visible while the text on the deactivated NO-EXIT sign was barely perceivable. Furthermore, the green running man graphic is widely recognised as indicating an emergency exit, this coupled with the fact that the adjacent NO-EXIT sign was barely perceptible resulted in this combination achieving an almost perfect comprehension score, achieving 98% (414 participants) correct interpretation with none of the incorrect comprehensions displaying critical confusion. The high degree of success of this combination is due to the information conveyed by the deactivated text sign being essentially invisible.

However, for the other static activation state, when indicating that the exit is not viable (S2), there was poor comprehension as to the meaning of the sign. In this state, the activated static text based NO-EXIT sign with red backlight was clearly visible and the graphical green running man exit sign was deactivated. However, even in deactivated mode, the luminaire showing the green running man was still clearly perceivable. As a result, only 81% (345 participants) achieved a correct interpretation of the intended meaning of the sign, thus failing to satisfy the ANSI comprehension requirement. Of greater concern is the high number of critical confusions achieved by this signage combination. Almost 10% (42 participants) believed that the signage was indicating the opposite of the intended meaning, i.e. that the exit was to be used in the event of an emergency. Thus, the linked pair of adjacent

signs in the static activation option also failed the ANSI critical confusion criterion when indicating the exit is not viable (S2). As a result, the linked pair of adjacent signs in static activation mode is considered inappropriate to indicate the status of an exit.

For the dynamic options (AO2), the signage system tested failed to satisfy the comprehension requirement for both of the two activation states. With a flashing green backlight, graphic green running man exit signs are known to have improved detectability, allowing the signs to be more noticeable; however, enhanced noticeability does not necessarily also mean increased comprehension of the message conveyed by the sign. With a flashing green backlight, the graphic green running man exit sign with deactivated adjacent NO-EXIT sign (S1), intended to represent a viable exit, only achieved a 74% (313 participants) correct comprehension, and thus fails the ANSI comprehension criterion. It is noted that in this option, as in the case of the static green backlight option, the deactivated NO-EXIT sign is barely perceivable and so did not contribute to the poor comprehension of this sign. This observation is supported by the replies provided by the participants which did not mention the NO-EXIT sign as an issue. Many participants were confused as to the meaning of the flashing EXIT sign, thinking that the sign was malfunctioning. In a real emergency situation, this confusion could manifest itself in hesitation to commitment to utilise the exit. While the critical confusion associated with this sign was low (1% or 4 participants), the low comprehension score means that the configuration consisting of flashing graphic green running man sign and deactivated NO-EXIT sign (S1) is considered inappropriate to indicate the viable status of an exit.

With a flashing red backlight, the text based NO-EXIT sign with deactivated graphic green running man sign (S2), intended to represent a non-viable exit, not only achieved a poor comprehension rate of 75% (316 participants) but also achieved a high critical confusion rate of 5.2% (22 participants). Thus this combination failed both ANSI acceptance criteria and so is considered inappropriate to indicate the non-viable status of an exit. This configuration is considered inappropriate not only because the flashing nature of the sign caused confusion, suggesting to many that the sign may be malfunctioning which in turn may result in undesirable hesitation, but the high level of critical confusion suggested to a significant number that the sign may have the opposite meaning to that intended, i.e. that the exit is considered viable. As a result, linked pair of adjacent signs in flashing activation mode is considered inappropriate to indicate the status of an exit.

Thus the signage configuration of a pair of linked adjacent signs as evaluated in this study, one incorporating a graphical green exit sign and the other a red text based NO-EXIT sign are considered NOT to be sufficiently intuitive to justify their general use as a means of indicating whether an exit was considered viable or non-viable. The poor levels of comprehension as to the meaning of the signs may be addressed by educating the target population. However this would mean that the signs could only be reliably used in situations where the entire user population have been appropriately trained.

On the basis of these findings, the manufacturer of the specific pair of linked adjacent signs investigated in this study abandoned the concept and adopted the embedded flashing and animated green LEDs within the arrow of the graphic exit sign and the dynamic red-cross to indicate an exit route or final exit was no longer viable.

While a specific dynamic signage concept was examined in this study, based on the findings of this comprehension study, it is possible to suggest potential issues associated with other dynamic signage concepts that share some of the key features of the tested configuration.

Based on the poor performance (74.3% correct comprehension) of the combined flashing backlight green running man sign with deactivated NO-EXIT sign (i.e. AO2S1), it is possible that a standard

standalone graphic green running man sign enhanced with flashing backlight will also achieve a relatively low level of comprehension. This is based on the observation that the deactivated NO-EXIT sign was barely perceivable and so is unlikely to have impacted the interpretation of the active exit sign. Furthermore, it is clear from the responses of the participants, that their confused interpretation was due to the flashing nature of the sign, not the neighbouring deactivated NO-EXIT sign. Of particular concern, 73 (or 17.2%) of the AO2S1 participants associated the flashing component of the dynamic sign with a malfunction in the signage hardware. Thus the flashing backlight, while improving the conspicuity of the green running man sign, as intended, may also result in unintended confusion. To reduce the likelihood of introducing potential confusion through the introduction of flashing lights, the flashing component should ideally have a deliberate and unambiguous function such as in the running dynamic arrow used in [24]. It is however promising that very few participants (1%, or 4) displayed critical confusion and so did not mistakenly think that the exit should NOT be used. However, as this specific configuration was not tested, it is recommended that the comprehension achieved by this and similar signage concepts should be evaluated in a similar comprehension study.

However, the importance of these findings go beyond determining whether or not the signage concept investigated in this study is fit for purpose, perhaps more importantly, they highlight the need for a set of national and international standards for dynamic signage systems, in particular emergency exit signs. Currently, there are no such explicit standards or guidance for emergency exit signage and so it is possible for signage manufacturers to propose, manufacture and bring to market novel signage concepts, which may appear to be intuitive, without any way of ensuring that they are fit for purpose. This study has suggested that while a novel concept may improve one perceived deficiency of emergency signage, e.g. poor detectability, or inability to adapt to changing circumstances, it may also result in unintended and undesirable consequences, such as compromising comprehension and possibly even leading to critical confusion. It is noted that, at the time of writing, ISO (TC 159/SC 5) is working on two standards documents concerning dynamic signs excluding those intended for indicating emergency exit routes [40][41]. While the detailed content of these documents is not known, as described in this paper, ISO also consider two types of dynamism in signage, temporal, involving flashing sequences and spatial, involving moving images. It is understood that these documents set out ergonomic requirements for dynamic signs in order to improve visibility and conspicuity. Furthermore, while comprehension is acknowledged as an important issue for dynamic signs, it is not clear if these documents address, if or how, comprehension of dynamic signs should be assessed. Finally, as these proposed standards exclude emergency signage, there is also a clear need for specific standards relating to dynamic emergency signage.

It is also noted that the graphic green running man exit sign without arrow was clearly understood by almost everyone in the study – achieving 98% (414 participants) correct interpretation, with no critical confusions. As already noted, this signage option does not comply with the ISO standard sign typically used in the UK and Europe, which includes an arrow to indicate a final exit point. As the survey population consisted of 61% (257) from the UK (with additional participants from Europe), assuming that all 9 participants who had an incorrect interpretation of the sign are from the UK, this would suggest that at most 3.5% (9) had an incorrect interpretation of the sign, with no critical confusions. Based on the ANSI comprehension test, this would suggest that this signage option is understandable by the UK population.

Finally, it is noted that ISO 9186-1 [38] and ANSI Z535.3 [39] provide simple pass/fail criteria based on achieving or exceeding the required proportion of correct interpretations and ensuring that the proportion of critical confusions is less than the maximum specified proportion (see Supporting Information Part A). While this approach is simple to use, involving comparing the measured

frequencies against the stated criteria, it fails to consider uncertainty due to sampling error or the variable nature of the samples, in particular given the relatively small minimum sample size required (50 participants). It is suggested that a test of statistical significance should be introduced to determine the reliability of the conclusions derived from comparing the measured results against the criteria for acceptance.

6 Limitations

As with any survey study, there are limitations associated with this work which should be considered when reviewing the results. The limitations of the current study are identified as follows:

- It is acknowledged that a survey is not a controlled experiment and so the responses may be different from their behaviour when faced with the real situation. However, this study was concerned with determining understanding of information conveyed by signage along with the context and so a survey analysis was considered appropriate. Furthermore, the technique is a standard technique adopted by ISO and ANSI for testing comprehension of graphical and text based signage.
- The order in which the signs were presented to the participants was not varied. There may therefore be a sampling bias, associated with the order in which the signs were presented. However, the consistency of the written explanation within the replies provided suggests that sample order was not an issue. Furthermore, the preferences for the first sign were so marked that this is unlikely to have been an issue.
- There was no control over the nature of the device that participants could use to complete the survey. Devices could vary from a mobile phone to a desktop computer. As a result, the appearance of the animation was an uncontrolled variable and may not have been sufficiently clear on very small devices. However, participants could repeat the animation as many times as desired in order to derive a better understanding of the animation. Furthermore, given the nature of the written responses, it is clear that reading the text of the sign or clearly seeing the graphical symbol was not an issue.
- It is difficult to determine if the appearance of the various signage combinations in the video accurately represented how the signage combinations appeared in reality, in particular the contrast of the deactivated signs. However, the manufacturer of the signs produced the video and acknowledged that the quality of the video was an accurate representation of the appearance of the signs.

7 Conclusions

Emergency exit signs are only effective if they can be easily perceived and their message clearly and unambiguously understood. Therefore, while it is important to improve signage detectability through enhanced design, it is essential that any proposed alteration to signage appearance should not degrade the level of comprehension achieved by standard emergency exit signs, or even worse, result in critical confusion amongst potential users.

This study considered the level of comprehension achieved by a novel dynamic two-sign combination intended to improve detectability of final exits and provide an ability for the exit sign to indicate whether the exit was viable or not. The study involved an online survey of 425 participants and was based on the ANSI Z535.3 signage comprehension test methodology to determine if the signage combination was easily understood by participants. The linked pair of adjacent signs had two activation options, one involving static signs (AO1) and the other involving flashing backlights (AO2) and for each option there were two states, one indicating that the exit was viable (S1) and the other indicating that the exit was not viable (S2). The resulting four configurations of the new signage concept were

investigated with only AO1S1 satisfying the two ANSI acceptance criteria, achieving 98% comprehension rate with no critical confusions. The other three configurations, AO1S2, AO2S1 and AO2S2, failed to satisfy either one or two of the acceptance criteria. As both signage states must be understood for the signage combination to be viable, both the static (AO1) and dynamic (AO2) versions of the sign were considered unacceptable.

Despite its relatively simple concept, the primary concern with this dynamic signage design is the possibility of having contradictory and hence confusing messages perceived at the same time. While not intended, in some activation states both signs are visible to some extent; resulting in critical confusion among the participants. Thus, the concept is only viable if one sign is active at any one time and the message conveyed by the deactivated sign is completely unperceivable. Also of particular concern, 73 (or 17.2%) of the AO2S1 participants associated the flashing green running man sign component of the dynamic sign with a malfunction in the signage hardware. Thus the flashing backlight, while improving the conspicuity of the sign, as intended, may also result in unintended confusion. To reduce the likelihood of introducing potential confusion, the flashing component of emergency signs should ideally have a deliberate and unambiguous function such as in the running dynamic arrow used in several dynamic signage designs.

The significance of this work goes beyond determining whether or not the signage concept investigated in this study is fit for purpose, perhaps more importantly, it highlights the need for a set of national and international standards for dynamic emergency signage systems. Currently, there are no such explicit standards or guidance and so it is possible for signage manufacturers to propose, manufacture and bring to market novel emergency signage concepts, which while appearing to be intuitive, have not been rigorously evaluated to ensure that they perform as expected without unintended consequences. This study has demonstrated that while a novel concept may improve one perceived deficiency of emergency signage, e.g. poor conspicuity, it may also result in unintended and undesirable consequences, such as compromising comprehension and possibly even leading to critical confusion. Standards and guidance for dynamic emergency signage systems should be developed as a matter of priority and these should include objective measures of comprehension.

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Table 1: Four signage options and corresponding EXIT status.

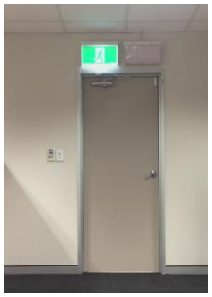
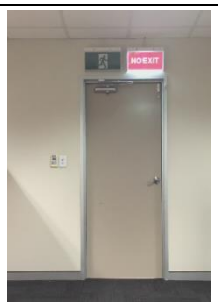
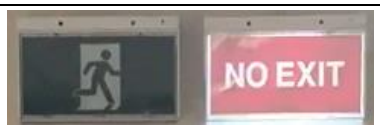
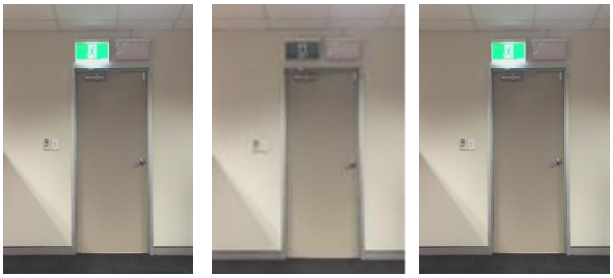
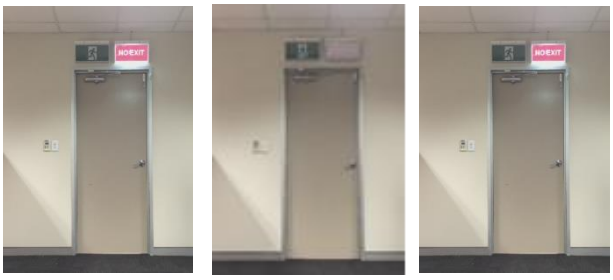
Signage activation option and state	Status of the linked adjacent pair of signs	Status of the exit
Activation option 1, state 1: (AO1S1) Static illuminated EXIT sign (The backlight of the NO-EXIT sign is switched off).	  (Zoomed in picture of the signs above door. The NO-EXIT sign to the right is barely visible)	The exit is available for use.
Activation option 1, state 2: (AO1S2) Static illuminated NO-EXIT sign (The backlight of the EXIT sign is switched off).	  (Zoomed in picture of the signs above door. The EXIT sign to the left is somewhat visible.)	The exit is no longer available for use.
Activation option 2, state 1: (AO2S1) Flashing EXIT sign (The backlight of the NO-EXIT sign is switched off).		The exit is available for use.
Activation option 2, state 2: (AO2S2) Flashing NO-EXIT sign (The backlight of the EXIT sign is switched off).		The exit is no longer available for use.

Table 2. Replies to signage interpretation question from the entire sample †.

Category	AO1S1	AO1S2	AO2S1	AO2S2
Correct	414 (97.9%)	345 (81.4%)	313 (74.3%)	316 (74.9%)
Incorrect	9 (2.1%)	79 (18.6%)	108 (25.7%)	106 (25.1%)
Incorrect with critical confusion	0 (0%)	42 (9.9%)	4 (1.0%)	22 (5.2%)
Total	423	424	421	422
Meet both ANSI acceptance criteria?	Yes	No	No	No

† A few flippant replies are excluded.

Table 3. Examples of participant statements relating to each signage state and their interpretation.

Sign	Interpretation	Example statement	Supporting information section
AO1S1	Correct	*'Go out of this door in an emergency.' (a non-fire professional)*	D1
AO1S1	Incorrect	*'Fire EXIT to the right.' (a non-fire professional)*	D2
AO1S2	Incorrect	*As we have two indicating different things, I am unsure.' (a non-fire professional)*	D3
AO1S2	Critical confusion	*Fire EXIT only, NO-EXIT at other times.' (a non-fire professional*	D4
AO2S1	Incorrect	*'I am confused as to what the blinking means (and annoyed by it)... perhaps the EXIT is not going to be usable for much longer? or it's indicating this is the EXIT we should use Right Now, but the confusion makes me hesitate, not good in emergencies.' (a non-fire professional)*	D5
AO2S2	Incorrect	*'faulty sign.' (a non-fire professional)*	D6
AO2S2	Critical confusion	*'That it is normally not an exit but is an emergency exit.' (a non-fire professional)*	D7

Table 4. Level of agreement with provided signage meaning for the fire professionals.

Signage option	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
AO1S1	289 (68.0%)	94 (22.1%)	7 (1.6%)	11 (2.6%)	24 (5.6%)
AO1S2	232 (54.6%)	117 (27.5%)	22 (5.2%)	34 (8.0%)	20 (4.7%)
AO2S1	182 (42.8%)	141 (33.2%)	50 (11.8%)	34 (8.0%)	18 (4.2%)
AO2S2	170 (40.0%)	141 (33.2%)	49 (11.5%)	47 (11.1%)	18 (4.2%)

Table 5. Preferred signage options.

	State 1 Activated EXIT, deactivated NO-EXIT signage combination	State 2 Deactivated EXIT, activated NO-EXIT signage combination
Activation option 1, Static sign	289 (68.0%)	262 (61.6%)
Activation option 2, Flashing sign	136 (32.0%)	163 (38.4%)

(a) Exit **(b) No Exit**

Figure 1. Linked pair of adjacent signs intended to indicate that an exit is viable (a) and not viable (b).

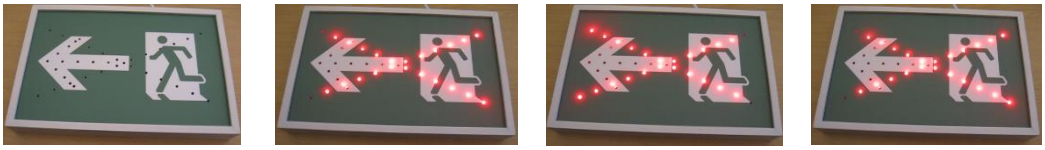


Figure 2. The prototype of the negated sign in operation depicting a single operation cycle [24].

(a)

(b)

Figure 3. (a) Combination of three graphical symbols to form an escape route sign [5] and (b) multiple safety signs applied together [6].