The effect of social factors and exit signage on route choices and movement time in a virtual environment during a stressful event.

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Abstract

The lack of crowd safety during an evacuation is not only an engineering problem but also a psychological problem. Due to stress there is a reduction of cue utilization. People tend to follow others and ignore exit signage. This leads to a non-optimal use of evacuation routes during an evacuation, which could have detrimental effects. The amount of people using an exit influences the perceived utility of the exit route. In this study, we focused on two factors which influence people's behavior during a stressful event. The effect of social factors and exit signage on route choices and movement time were researched. We used a virtual environment to study human route decisions during a stressful event. In the virtual environment, we presented different Y-intersections with different presented (combinations) of the cues. We used two different gradations of a social factor; one virtual person and ten virtual people. Our findings suggest that participants tended to make route choices based upon exit signage more than upon social factors. We found no difference in the effect of one virtual person and ten virtual people. We found weak support that participants become aware of exit signage the more times they see them. Our findings may be useful for future research on real human route decisions during an evacuation or for developing more realistic virtual simulations.

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1. Introduction

During crowd evacuations, the death of many people led to crowd disasters (Kok, Lim & Chan, 2016). This lacking of crowd safety is not only an engineering problem but also a psychological problem. For example, people tend to prefer a familiar exit route (Kobes, Helsloot, De Vries, Post, Oberije & Groenewegen, 2010c; Kobes, Helsloot, De Vries & Post, 2010a; Gwynne, Galea, Lawrence & Filippidis, 2001) rather than an unfamiliar exit. This leads to the non-optimal use of emergency exits, which can be very inefficient in an evacuation situation (Sime, 1995). This non-optimal behavior of evacuees could also have an effect on the number of exits needed in a building. With the non-optimal use of these exits, more exits are needed, which increases construction costs. Therefore, it is important to research evacuation behavior and investigate different aspects of crowd evacuations. In this thesis, I focus on the effect of social factors and environmental factors on route choices people make during an evacuation event and the time it takes people to make these decisions.

1.1 Evacuation and stress reactions

During an evacuation the physical stress of people may rise because they are confronted with an unfamiliar situation and their information processing is exceeded (Kobes et al., 2010a; Kobes, Helsloot, De Vries & Post 2010b). We describe stress as perceiving the experience of an event as endangering the physical or psychological well-being of one's own (Nolen-Hoeksema, Frederickson, Loftus & Wagenaar, 2009). Hereby the possible physical or psychological threat due to the cause of the evacuation creates stress (Ozel, 2001). Such an emergency situation is an acute and time-limited stressor (Polst, 2016). A stress reaction has a major impact on cognitive processes because stress reduces the effectiveness of information processing. This can affect how people respond to a given situation (Kobes et al., 2010a, 2010b). Stress can affect decision-making performance (Pires, 2005). For example, the effect of stress on decision-making leads to making wrong judgments and evaluations based on the presented cues and neglecting important information (Zakay, 1993). Thereby stress can have a high impact on decision-making (Starcke & Brand, 2012). This impact can also be important during an evacuation where decisions about route and exit choices are being made (Bode, Kemloh Wagoum & Codling, 2015).

To understand the decision-making process of people during an evacuation it is important to understand the physical reaction of stress. Regardless of the cause of a stress reaction, the human body immediately prepares for an action. Physiological changes occur from the activation of two neuroendocrine systems controlled by the hypothalamus (figure 1), namely the automatic nervous system and the adrenal-cortical system. The automatic nervous system includes the sympathetic nervous system and the parasympathetic nervous system. The sympathetic nervous system acts directly to muscles and organs to produce an increased heart rate, blood pressure and dilated pupils. The adrenal cortical system activates the release of cortisol that regulates the blood levels of glucose (Nolen-Hoeksema et al., 2009). A stress reaction leads to an increase in heart rate (Dirkin, 1983). This physiological reaction of an increased heart rate is a good indicator for measuring stress (Jacobs et al., 1994). The increased heart rate returns to baseline approximately ten minutes after the cessation of the stressor (Starcke & Brand, 2012). The variability of the heart rate is sensitive to the recent experience of mental stress (Dishman et al., 2000) and associated with the amygdala, which is involved in the perception of threat and safety (Thayer, Åhs, Fredrikson, Sollers & Wager, 2012).

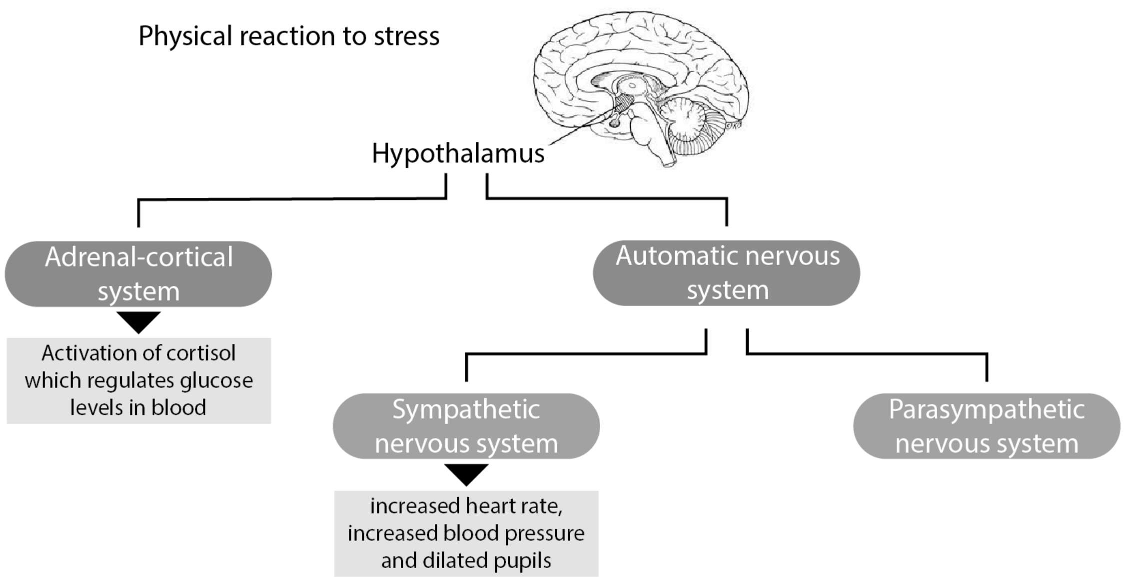


Figure 1: Overview of physical reaction to stress.

People who experience stress process superficial aspects and information faster in their working memory. As a result, there is a loss of working memory capacity for encoding information that is more complex and takes more time to process (Evans & Skorpanich, 1984). The capacity of a person to effectively process environmental information becomes limited due to stress (Ozel, 2001). This stress leads to forgetting important information. It also leads to a reduction of information search and processing during decision-making (Zakay, 1993). Every person reacts differently to stress because of a personal level of stress resistance (Kobes et al., 2010a). In addition, there is a difference between men and women in the reaction to stress and the effect of stress on decision-making (Van den Bos, Harteveld & Stoop, 2009).

Deadlines induce the feeling of time pressure (Maule, Hockey & Bdzola, 2000). Time pressure as a stressor makes people process information faster and lets people make decisions faster (Kerstholt, 1994; Zur & Breznitz, 1981). The most common reaction to stress is anxiety. Anxiety is a state of apprehension and worries about possible danger. Psychological arousal can be explained as tension, which can vary from calmness to anxiety. Physiological arousal can be defined as the level of alertness. A stress reaction is a reaction to the experience of a threat (Nolen-Hoeksema et al., 2009). Time pressure leads to an increase in arousal (Edland & Svenson, 1993) which for example reduces the range of cues that a person uses to make decisions (Ozel, 2001). This stressor reduces the chance of a replacement of the immediately available decision to a situation for another one. Therefore, overthinking of a decision is less likely to happen (Zur & Breznitz, 1981). People who are exposed to stress make premature closure about decisions, which means that these decisions are made before all of the alternatives are considered (Starcke & Brand, 2012; Keinan, 1987; Keinan, Friedland & Ben-Porath, 1987). These choices can be suboptimal because of the use of simple decision strategies (Zakay, 1993).

The reaction time during an evacuation process can be split up by three phases: interpretation, preparation and action. The movement time within the evacuation concerns the time taken to initiate movement, to take a decision for the appropriate action and to take the actual action and move towards an exit (Challenger, Clegg & Robinson, 2009).

Choo (1995) refers to Easterbrooks' research from 1959 as the best theory to describe the relation between stress and judgments. This relation can be explained by an inverted U-function. This function describes the influence of stress on judgments. A moderate stress level is best for making relevant judgments because due to stress irrelevant cues are being ignored. Experiencing no stress leads to an over evaluation of cues. A high-stress level leads to more emotion-oriented behaviors which dominate the judgment (Choo, 1995). Svenson, Edland and Slovic (1990) also refers to the Easterbrook's research and mentions that time pressure is likely to lead to high-stress reactions. As a result, less relevant cues are being ignored and more relevant cues are being used in decision making (Svenson et al., 1990). Choo (1995) argues that this could be an explanation why under high-stress levels people tend to rely more on other people's behavior when making a decision.

1.2 Social influence

Gwynne et al. (2001) stated that an evacuation is a social process where people are likely to form groups. Sime (1995) named this social behavior affiliative behavior, which implies that people refer their interpretation of an unclear situation by looking at other people's behavior.

The route choices of individuals are influenced by actions of other evacuees. People tend to move in the same direction as the main crowd during an evacuation situation (Sime, 1983). The (in)action of others can influence the understanding of the situation and the following behavior of individuals (Sime, 1995; Kinateder & Warren, 2016). Nilsson (2009) describes this behavior as an informational social influence. Another type of influence is the normative social influence, where there is a desire of individuals to conform to the expectations of others (Nilsson, 2009). During an evacuation situation, people tend to follow others, even if the route is more dangerous or subsequently more crowded than an alternative route (Challenger et al., 2009). This behavior may be beneficial but could also have detrimental effects (Kinateder et al., 2014).

1.2.1 Effect of difference in group size

By following the majority of people, individuals take the risk to end up in a built-up bottleneck. This amount of congestion by others is influential in route choice (Bode et al., 2015). The movement of large groups towards an unknown exit adds to the utility of that exit route. If the exit is known, the opposite effect is shown. Individuals interpret congested exits as a less great utility. Therefore, herd behavior is not always applicable to all evacuation situations (Haghani & Sarvi, 2017). When people are motivated to leave an environment as quickly as possible, crowded routes are less popular (Bode & Codling, 2013).

The definition of a crowd is a sizable gathering of people in a given location with a sufficient density distribution (Challenger et al., 2009). As mentioned, the size of a group, (i.e. the number of people in the group), could have an influence on the route choice and crowd's influence on this route choice. Kinateder et al. (2014) show that one virtual person has a major effect on route choice in a virtual evacuation situation. The risk of a congested exit is not relevant if only one person is using that exit. The effect of crowds on the perceived utility of an exit depends on the risk of congestion. Therefore, it is important to investigate if a relatively small crowd has a different effect on route choice than one person.

1.3 Exit signage

Besides the social influence on route choice, explicit information like exit signage also has a positive effect on wayfinding and evacuation time (Till & Babcock, 2011; Kobes et al., 2010b). Till and Babcock (2011) demonstrated that people in a new environment rely more on signage than people in a familiar environment. Stress can affect how people use and process these environmental cues for route selection during a time-pressured evacuation (Ozel, 2001). Kobes et al. (2010c) show that evacuees in an emergency situation are rarely aware of the presence of escape route signs at ceiling level, at least their route choices are not based upon them. An explanation could be that people ignore the exit signage because these peripheral cues are interpreted as less relevant and are therefore ignored. The location of exit signage in the visual field can play an important role in the effectiveness of these cues (Ozel, 2001). All signs should be located so that people see them in advance of a decision point at a route intersection (Corlett, Manenica & Bishop, 1972).

1.4 Exit signage versus social factors

Exit signage is mandatory in public buildings in the Netherlands. However, it is doubtful if the effect of signage on route choice is still observable when other cues are present in the environment. Due to stress, there is a reduction of cue utilization (Ozel, 2001) and people tend to follow others during an evacuation (Kinateder et al., 2014). It could be that exit signage becomes less useful because people are unaware of the exit signage due to the influence of other people in route choice during a stressful event. By examining social and environmental factors together, we can investigate which factor a greater influence has on route choice during a stressful event.

1.6 Hypotheses

The research question in this study is: What is the effect of social factors compared to the effect of exit signage on route choice and movement time during a stressful event?

Based on the literature study different hypotheses are described. These hypotheses focus on the dependent variables of route choice and movement time separately. First, we present the hypotheses concerning route choice. The third, fourth and fifth hypotheses are concerning movement time.

H1: During a stressful event, the presence of virtual people (#) has a greater effect on the route choice of participants than the presence of exit signage. With this first hypothesis, we compare which cues have a greater effect on route choice. We expect that virtual people (#) have a greater influence on route choice than exit signage, due to the described effect of stress on the awareness of exit signage (Ozel, 2001) and the tendency of people to follow others during an evacuation (Kinateder et al., 2014).

H2: During a stressful event, one virtual person has a greater effect on the route choice of participants than a group of ten virtual people. By comparing these two grades of the social factor, we can research if the threshold of the risk on a built-up bottleneck is shown between one and ten virtual people. We expect that one virtual person has a greater effect on route choice than ten virtual people because, when people are motivated to leave as quickly as possible, crowded routes are less popular (Bode & Codling, 2013).

H3: During a stressful event, participants will have a longer movement time to reach their evacuation goal in the presence of exit signage compared to in the presence of (a) virtual person(s). We expect that due to the possible lack of awareness of exit signage, participants will take longer in the presence of this signage compared to virtual people (#).

H4: During a stressful event, participants will have a longer movement time to reach their evacuation goal if they are presented with ten virtual people compared to one virtual person. We expect that participants will take longer in the presence of ten virtual people because participants can perceive the risk of a built-up bottleneck and therefore might take more time in the decision-making process.

H5: During a stressful event, participants will have a longer movement time to reach the evacuation goal if exit signage and the social factor provide incongruent route information compared to congruent. We expect that in the conditions with both cues presented in a congruent way, participants will have a shorter decision time and hereby a shorter movement time because the redundancy of the cues can enhance the decision-making.

2. Methods

For this study, a set of virtual indoor corridors was presented to the participants. Research showed that the behavior of participants in a virtual reality environment corresponds closely to the behavior in real life (Feng, Cui & Zhao, 2015). The response of the participants was collected by the outcome of a two-alternative forced-choice method. The participants' behavior in the simulated corridors, was quantified by measuring route choice and movement (reaction) time.

2.1 Experiment design

We tested the influence of three separate cues, social factors (one person and ten people) and exit signage, on route selection by participants during a limited time (Figure 2, column B). We also examined the effect of combining social and exit signage cues in congruent and incongruent ways, making four further conditions (Figure 2, column C). We used within-subject comparisons to investigate differences in the dependent variables between conditions. The dependent variables were the frequency of trials where each route was chosen and the movement time per corridor in seven different corridor intersections. All seven conditions were presented twice in a mirror image of each other. To avoid possible biases for the left or right direction. All conditions where the cues were presented separately (Figure 2, column B) were presented twice to see if there is a difference in route choice and movement time when participants were familiar with the situation.

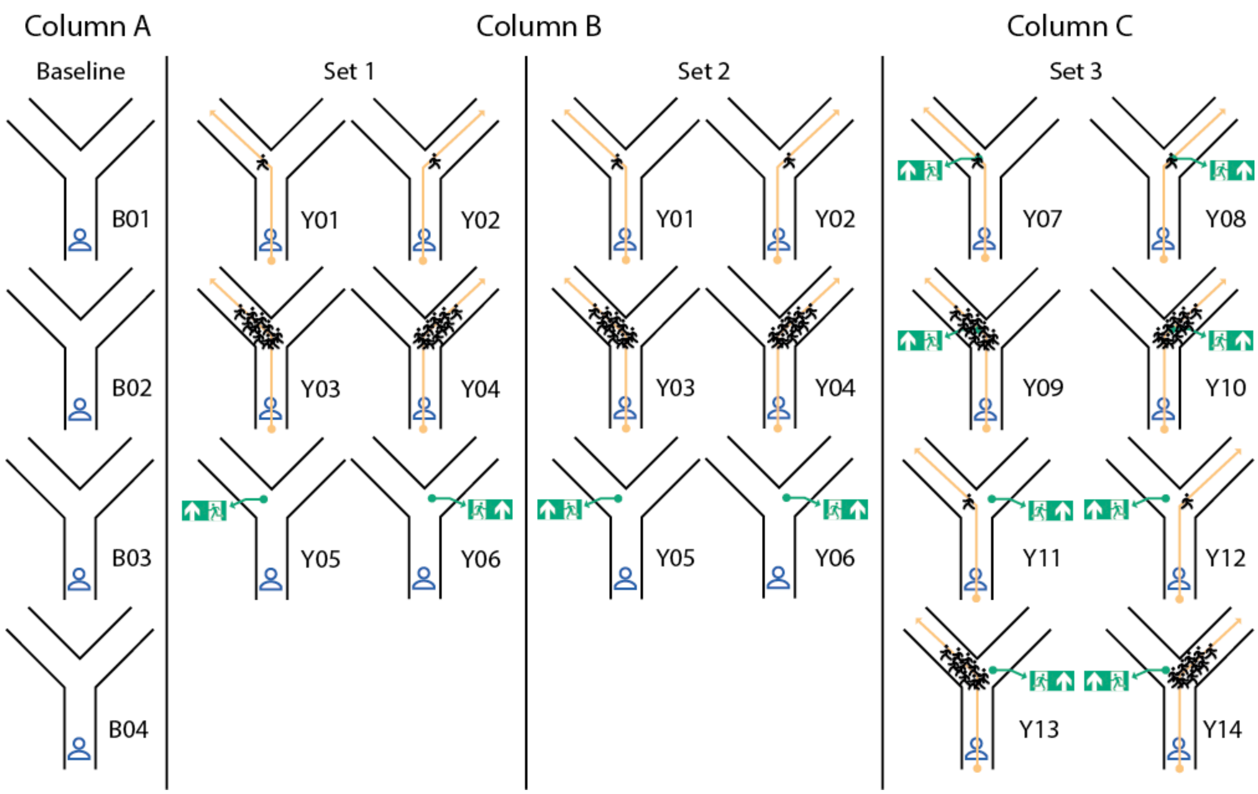


Figure 2: All conditions within this experiment. Four sets are used. The first column (A) is the baseline where no cues are presented. In the second column (B) cues are presented separately. The third column (C) cues are presented in a congruent and incongruent way. All conditions within the sets were randomly presented to the participants.

The experiment was divided into four parts, see figure 2. First, the baseline condition was tested, consisting of four identical corridors where no exit signage or social factor was presented. This was followed by the first set, which consisted of six corridors where all cues were presented separately in both the left and right direction. The second set was a repetition of the first set. The third set consisted of four corridors where both levels of the social factor were presented with congruent direction information of the exit signage in both the left and right direction and also four corridors where both levels of the social factor were presented with incongruent direction information of the exit signage in both the left and right direction. The sets mentioned were presented in the order shown in figure 2 during the experiment. Within these sets, the conditions were randomized. The order of the sets was not randomized to minimize the influence of learning effects on comparisons between the conditions within each set.

A time stressor was implemented in this experiment by using a time-limited deadline, which induced the feeling of time-pressure. By measuring the heart rate and heart rate variability, we quantified the effect of this time stressor. Besides this objective measurement of stress, we also gave participants a set of questionnaires before and after the experiment, where among other things, the subjective stress was being measured.

We used the State-Trait Anxiety Inventory (STAI), which focusses on the state anxiety, to measure subjective stress. This questionnaire focusses on how a person feels 'right at this moment'. Subjective feelings of tension, worry or arousal due to the activation of the autonomic nervous system are characterized by the different states mentioned in this questionnaire (Spielberger & Gorsuch, 1983). The study of Spielberger and Gorsuch (1983) explains that scores of the state anxiety can vary from 20 to 80. For relatively non-stressed working adults these mean scores are 35.72 (male) and 35.20 (female) and for relatively non-stressed college students 36.47 (male) and 38.76 (female). Military recruits scores were 44.05 (male) and 47.01 (female) after they began a highly stressful training (Spielberger & Gorsuch, 1983).

The experiment was conducted using virtual reality. To measure if participants experienced any discomfort due to the virtual environment, we measured motion sickness. We used the Motion Sickness Assessment Questionnaire (MSAQ) (Gianaros, Muth, Mordkoff, Levine & Stern, 2001). Any reported feeling of nausea was considered as susceptibility of motion sickness. According to Max Levine, a score between 30% and 40% or higher is generally considered as experiencing motion sickness. Although any self-report of motion sickness (on the scale of 1 to 9, any report higher than 1) should be taken into account (Max Levine, personal communication, May 18, 2017). We researched if participants experienced discomfort due to the virtual environment and the devices used to navigate through the environment. We evaluated this method of navigating through the virtual environment using this questionnaire.

To measure arousal and dominance of participants we used the Self-Assessment Manikin (SAM). The SAM was used to rate pleasure, arousal and dominance by using a 9 point Likert scale to indicate which visual representation of those states participants associated with most (Bradley & Lang, 1994). With this information we also researched if feelings of pleasure, arousal or dominance had an effect on route choices in general.

For this experiment, it is important to ensure that participants are experiencing stress during the navigation task. By measuring heart rate, heart rate variability and subjective feelings, we quantify this stress effect. Heart rate was expressed in beats per minute. Heart rate variability was expressed in RR interval, which is the time between two consecutive heartbeats. Heart rate and heart rate variability was measured using the Polar H7. This device is a valid tool for measuring heart rate variability (Giles, Draper & Neil, 2016).

2.2 Apparatus

The virtual environment used was designed for the following specific requirements:

- Existence of a point of decision-making related to route choice;

- The use of a Y-intersection makes sure that both routes have the same length and the same line of sight. This will prevent people from being influenced by these factors (Nishinari, Sugawara, Kazama, Schadschneider & Chowdhury, 2006)
- Maintaining of the decision point, the same distance from the starting point until the decision point for all conditions;
- Constant width of all corridors for all conditions;
- Constant lighting distribution and intensity in all corridors for all conditions;
- Avoidance of extra environmental cues, only use of solid color.

2.3 Experimental settings

The virtual environment was presented to the participants by using an HTC Vive. The HTC Vive is a virtual reality headset, which turns an area into 3D by using sensors. A SteelSeries Stratus XL was used as a navigation device. This gamepad is easy to use and rated as a good device to navigate through a virtual environment (Lindsey, 2017). The movement speed inside the virtual environment for the participant was limited to 10 km/h (2.78 m/s). The virtual people had a movement speed between 14 km/h and 8 km/h to assure a dispersion of people within the crowd. The density of the virtual crowd was circa four virtual agents per square meter. This is a recommend and safe crowd density if people are moving, which is the case for this experiment (Challenger et al., 2009). The virtual crowd/agents were programmed to not take detours.

2.4 Sample

Thirty-three participants, compensated with an incentive, were recruited for this experiment via post ads hanging on the High Tech Campus in Eindhoven and Eindhoven University of Technology. Two participants were excluded, as both participants reported after the experiment that they had a navigation strategy of going only one direction (only left/right). Data confirmed that both participants deviated with two standard deviations or more from the mean left/right choices of all participants and were considered as outliers and excluded from the data analysis. In total thirty-one participants remained in the sample, of which twelve female, nineteen male and one participant reported to be left-handed.

2.5 Procedure

Ethical clearance was granted by the ethics committee of Philips Lighting. This experiment was conducted within a virtual reality environment to make sure that participants do not physically harm themselves during navigation task with time limitation. See figure 3 for a visual image of the virtual environment used.

Figure 3: Photo of the virtual environment, in condition Y11. Here one virtual person and exit signage are presented incongruent from each other.

Before starting the experiment in virtual reality, all participants were asked to sign an informed consent form and were being told that at any time they could stop participating in the experiment. The average duration of each experimental session was about 60 minutes. This consisted of filling in a short socio-demographics questionnaire, a training session, experimental test, filling out questionnaires and a short interview. Before the training sessions and experimental test, participants were instructed to wear the heart rate measuring device Polar H7. After that, participants watched a calming aquatic video 'Coral Sea Dreaming, Small World Music, Inc.' (Piferi, Kline, Younger & Lawler, 2000) for 5 minutes to measure the baseline heart rate and heart rate variability. Directly after watching the video participants were asked to fill in the first part of the STAI questionnaire.

During the training session, participants were informed with instructions about the experiment and the handling of equipment involved. This procedure intended to ensure that all participants were able to navigate through the virtual environment using the HTC Vive in combination with the SteelSeries Stratus XL. After the training sessions, participants had to fill in the MSAQ. Any reported feeling of nausea was considered as susceptibility of motion sickness. All participants who reported any nausea were asked about their current state and reminded that if they felt queasy or sick they could stop the experiment. None of the participants stopped during the experiment.

Before the experimental test started participants were informed about the time limitation of the navigation task and about the goal of the virtual agents they would come across. Participants were told that they had a time limitation of two minutes to succeed in leaving the virtual maze. This was an unrealistic and not feasible time limitation. As a motivation, participants were told that if they succeeded in doing this, they would receive an incentive of 30 euros. If they did not succeed, the incentive would be halved. At the end, each participant received 30 euros anyway. Participants were told that the virtual agents represent the behavior of other participants in a previous similar experiment, so they had the same goal to leave the virtual maze. Finally, participants were being informed that there is a fire in the virtual maze, which is coming in their direction from behind. They could hear and see the fire in the virtual environment. After the baseline and first two sets of the experimental test, participants were informed about their current time taken, which was told to be 1 minute 25 seconds. This time was actually around two minutes and ten seconds but told to be less to motivate and remind participants of their time limitation to remain a stress effect.

During the experimental test, twenty-four corridors were presented to the participants. Heart rate and heart rate variability were measured during this part of the experiment. After the experimental test participants were asked to fill in the STAI questionnaire again and the SAM. Also, a short interview was held to ask participants if they had seen the virtual agents and the exit signage, what they thought the objective of the experiment was, if they experienced a real evacuation, their experience with virtual reality and some questions about factors that could affect their heart rate (drinking coffee and such). After the interview, participants were informed about the real experiments' objective and that all instructions regarding the test and time limitation were not real but used to motivate them. Finally, participants were asked to take off the Polar H7 and all received the incentive of 30 euros.

3. Results

Table 1 and table 2 summarizes the results obtained for all conditions. The corridors were presented randomly within each set. Sets were presented in the order shown in table 1 and figure 2. All statistical analyses were conducted using IBM SPSS v.23. The statistical significance level was set at 5%.

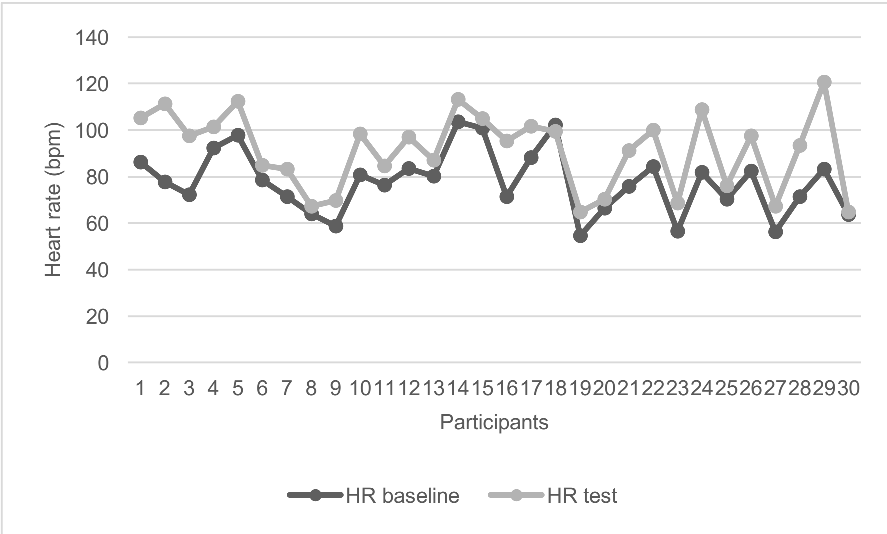
3.1 STAI

To answer the research question and hypotheses, it is first important to see if participants were experiencing stress during the experimental test. The mean value of the STAI, for self-reported state anxiety, for all participant in baseline was 53.74 (54.50 female, 53.26 male) and for test 55.61 (57.17 female, 54.63). With the Wilcoxon Signed-ranks test we compared these values per participant with a significant difference between both measurements, $Z = -2.362$, $p = 0.018$, $r = -0.42$. Both measures show a relatively high score compared to the mean values described by Spielberger and Gorsuch (1983).

3.2 Heart rate and heart rate variability

We recorded the heart rate and heart rate variability of 30 participants, for one participant we did not succeed in recording this data. We excluded this participant from the analyses for heart rate and heart rate variability. These objective measurements of heart rate and heart rate variability differ significantly between both measure moments. We used the last 2 minutes of the baseline measurement which correlated with the total 5-minute baseline recording, $r = 0.915$, $n = 30$, $p < 0.001$. A paired-samples t-test was conducted to compare the heart rate during baseline and during the test. There was a significant difference in heart rate between baseline (M: 77.76 bpm, SD: 13.51 bpm) and test (M: 91.30 bpm, 16.38 bpm), $t(29)= -7.995$, $p < 0.001$. The mean heart rate during baseline for females was 78.48 bpm and for males, it was 77.28 bpm. The mean heart rate during the test for females was 96.37 bpm and for males, it was 87.92 bpm.

The mean heart rate variability expressed in RR intervals for baseline was 789.86 ms (788.89 ms female, 805.51 ms male) and for test 685.06 ms (642.51 ms female, 713.42 ms male). With the Wilcoxon Signed-ranks test we compared these values for all participants between both measurements with a significant difference between both measurements, $Z = -4.741$, $p = 0.000$, $r = -0.85$. In figure 4, a visual representation of the different measure moments is shown.



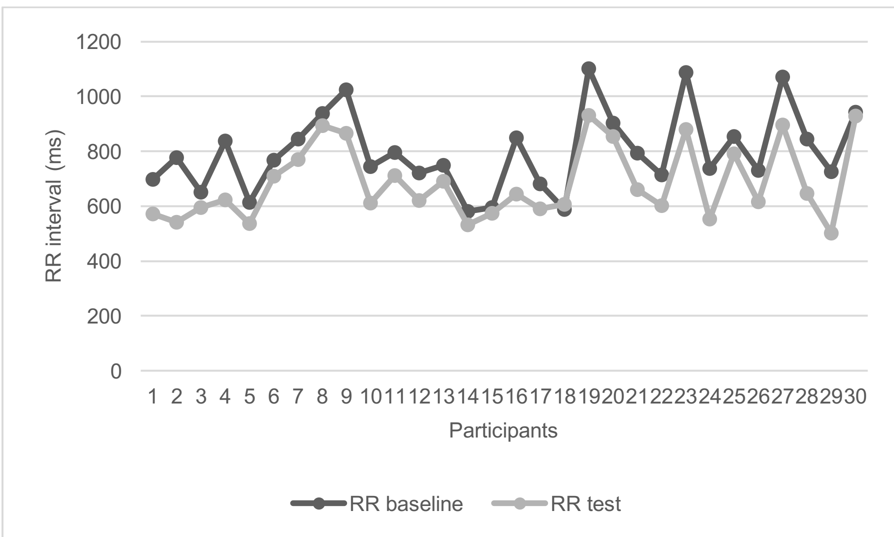


Figure 4: Heart rate (HR) and heart rate variability (expressed in RR interval) for the baseline and test measurements. We see an overall lower HR for the baseline and an overall higher HR for the test measurement. Also, we see a higher RR for the baseline and an overall lower RR for the test measurement.

3.3 Route choice

To answer the main research question of this study '*What is the effect of social factors compared to the effect of exit signage on route choice and movement time during a stressful event?*' we first want to see what the effect is of both cues separately on route choice. Route choices were coded as 'Following person', 'Not following person' for all conditions except conditions with only exit signage presented route choices were coded as 'Follow signage', 'Not follow signage'.

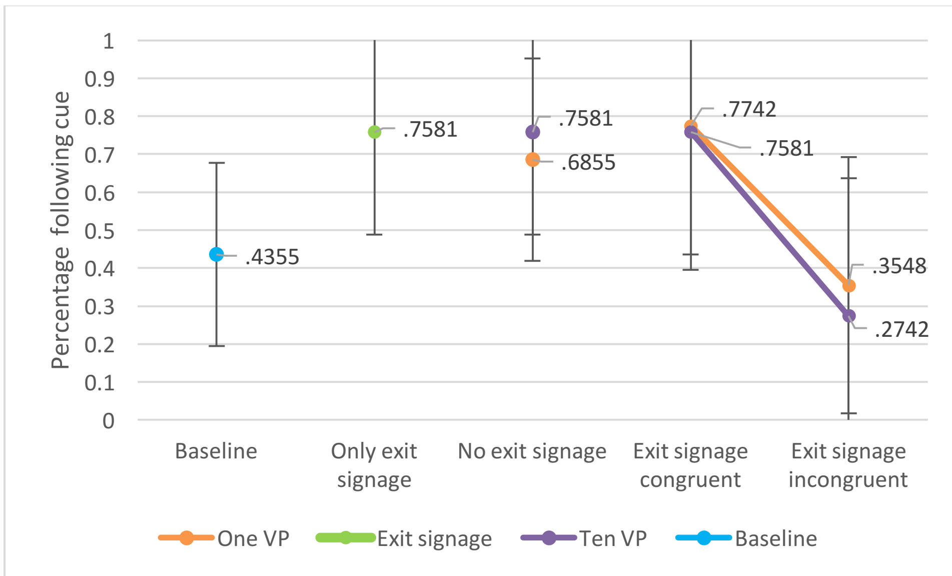


Figure 5: Mean percentages of participants following the cue for all conditions, one virtual person (VP), exit signage and ten virtual people. If cues are presented incongruent, the percentages show the participants following the social factor.

For conditions with the same cue(s) presented, we took the average percentage. Figure 5, shows all average percentages of route choice. No cues were presented in the four baseline conditions. The mean percentage of the baseline shows the direction participants chose. The mean of .4355 implies a small preference for going left. We took this mean outcome of the four baseline conditions and compared these to the value of 0.5, which is equal to complete random route choices. A Wilcoxon Signed-ranks test indicated that the baseline does not significantly differ from 0.5, $Z = -1.476$, $p = 0.140$.

We also compared the conditions with one cue presented solely to the value 0.5, which would indicate random behavior. The social factor was split into two gradations, one virtual person or ten virtual people. A Wilcoxon Signed-ranks test indicated that one virtual person has an effect on route choice, $Z = 3.116$, $p = 0.002$, $r = -0.56$. The conditions with one virtual person presented solely have a significantly higher percentage than 0.5. Effect sizes (r) of 0.5 or higher indicate a large effect. This effect of $r = -0.56$ indicates a large effect. For ten virtual people a Wilcoxon Signed-ranks test also indicated that ten virtual people have an effect on route choice, Z = -3.746, p = 0.000, r = -0.67. The conditions with ten virtual people presented solely have a significantly higher percentage than 0.5. We performed a Wilcoxon Signed-ranks test which indicated an effect of exit signage on route choice, Z = -3.916, p = 0.000, r = -0.70. Also, for the conditions with exit signage presented solely a significantly higher percentage than 0.5 is shown. There were no significant effects between the effect of the social factors and exit signage in the conditions where these cues were presented solely. In Table 1, mean percentages of all participants per corridor are presented.

To research if there is a significant difference in the effect of social factors and exit signage we compared the conditions where only one virtual person (M: 0.69, SD: 0.266) is presented with the conditions where both exit signage and one virtual person are presented in an incongruent way (M: 0.35, SD: 0.432). A Wilcoxon Signed-ranks test indicated a significant difference in the effect of one virtual person, Z = -2.906, p = 0.004, r = -0.52. We also compared the conditions where ten virtual people (M: 0.77, SD: 0.338) are presented with the conditions where both exit signage and ten virtual people are presented in an incongruent way (M: 0.27, SD: 0.384). A Wilcoxon Signed-rank test indicate a significant difference in the effect of ten virtual people, Z = -3.807, p = 0.000, r = -0.68.

We compared the route choices of participants between conditions with solely exit signage and both exit signage and one or ten virtual people presented in an incongruent way. We coded for this specific analysis the incongruent conditions as following exit signage. No significant differences in route choice were found between conditions with only exit signage (M: 0.76, SD: 0.270) presented solely compared to conditions with both exit signage and one virtual person presented in an incongruent way (M: 0.65, SD: 0.432), Z = -1.570, p = 0.116. Also no significant effects in route choice were shown between conditions with only exit signage presented solely compared to conditions with both exit signage and ten virtual people presented in an incongruent way (M: 0.73, SD: 0.384), Z = -0.651, p = 0.515.

No significant differences in route choice were found between conditions with only one virtual person presented solely compared to conditions with both exit signage and one virtual person presented in a congruent way, Z = -1.291, p = 0.197. No significant differences in route choice were found between conditions with only ten virtual people presented solely compared to conditions with both exit signage and ten virtual people presented in a congruent way, Z = -0.072, p = 0.942.

We did the same comparison between conditions where the social factor and exit signage were presented congruent and conditions where the social factor and exit signage were presented incongruent. For these conditions with the social factor of one virtual person presented congruent with exit signage (M: 0.77, SD: 0.338) compared to incongruent (M: 0.35, SD: 0.432) a Wilcoxon Signed-ranks test indicated a significant decrease in the effect of one virtual person on route choice, Z = -3.078, p = 0.002, r = -0.55. For the conditions with the social factor of ten virtual people presented congruent with exit signage (M: 0.76, SD: 0.362) compared to incongruent (M: 0.27, SD: 0.384) a Wilcoxon Signed-ranks test indicated a significant decrease in the effect of ten virtual people on route choice, Z = -3.528, p = 0.000, r = -0.63.

Besides the decrease in the mean percentages, we also saw an increase in the standard deviation (SD) in the conditions where cues were presented incongruent compared to conditions where cues were presented solely. For a better understanding of the behavior of participants, we took a closer look. The change in the SD between these conditions can be partially explained by the fact that the conditions with cues presented solely were consisting of four repeated measures and the conditions with incongruent cues were consisting of two repeated measures. We can estimate the SD between participants, for the different conditions with one virtual person presented, this increased from 0.14 (solely) to 0.27 (incongruent) with a Cohen's d of 1.6. Besides the change in the average probability of following one virtual person, also participants' behavior became more different from each other as well.

For conditions where cues are presented congruent compared to incongruent, both consisting of two repeated measures, we also estimated the SD between participants. This increased for one virtual person and exit signage from 0.16 (congruent) to 0.27 (incongruent) with a Cohen's d of 1.9. For ten virtual people and exit signage, this increased from 0.20 (congruent) to 0.21 (incongruent) with a Cohen's d of 2.4.

To see if there is a difference in the effect of the different gradations of the social factor, we compared the conditions with one virtual person versus the conditions with ten virtual people using a Wilcoxon Signed-ranks test. No significant differences were found. For conditions with the virtual people (#) presented solely, Z = -1.440, p = 0.150. For conditions with the virtual people (#) presented congruent, Z = -0.330, p = 0.741. For conditions with the virtual people (#) presented incongruent to exit signage, Z = -1.291, p = 0.197.

Set	Conditions	Corridor	Left	Right	% Left	% Right	% Follow social factor	% Not follow social factor	% Follow exit signage	% Not follow exit signage
	1 virtual person	Set 1 Y01	23	8	74.2	25.8	74.2	25.8		
		Set 1 Y02	10	21	32.3	67.7	67.7	32.3		
	10 virtual people	Set 1 Y03	26	5	83.9	16.1	83.9	16.1		
		Set 1 Y04	9	22	29.0	71.0	71.0	29.0		
	Exit signage	Set 1 Y05	20	11	64.5	35.5			64.5	35.5
Set 1		Set 1 Y06	5	26	16.1	83.9			83.9	16.1
	1 virtual person	Set 2 Y01	22	9	71.0	29.0	71.0	29.0		
		Set 2 Y02	12	19	38.7	61.3	61.3	38.7		
	10 virtual people	Set 2 Y03	22	9	71.0	29.0	71.0	29.0		
		Set 2 Y04	7	24	22.6	77.4	77.4	22.6		
	Exit signage	Set 2 Y05	26	5	83.9	16.1			83.9	16.1
Set 2		Set 2 Y06	9	22	29.0	71.0			71.0	29.0
							% Follow congruent	**% Not Follow congruent**		
	1 Virtual person & Exit signage congruent	Set 3 Y07	25	6	80.6	19.4	80.6	19.4		
		Set 3 Y08	8	23	25.8	74.2	74.2	25.8		
	10 virtual people & Exit signage incongruent	Set 3 Y09	24	7	77.4	22.6	77.4	22.6		
		Set 3 Y10	8	23	25.8	74.2	74.2	25.8		
							% Follow Social factor incongruent		**% Follow Exit signage incongruent**	
	1 Virtual person & Exit signage congruent	Set 3 Y11	8	23	25.8	74.2	25.8		74.2	
		Set 3 Y12	17	14	54.8	45.2	45.2		54.8	
	10 virtual people & Exit signage incongruent	Set 3 Y13	10	21	32.3	67.7	32.3		67.7	
Set 3		Set 3 Y14	24	7	77.4	22.6	22.6		77.4	

Table 1: All mean outcomes of route choice.

3.4 Movement time

To research the difference in movement time we first looked at the mean outcome of the four baseline conditions and compared these to the mean outcome of the conditions where cues were presented solely using a Wilcoxon Signed-ranks test. We found no significant difference between the different conditions and baseline. Also between the conditions where cues were presented solely, no significant difference were found. See Table 2, for the mean movement time of all participants per corridor.

We also compared the corresponding conditions with one virtual person presented to the conditions with ten virtual people presented, using a Wilcoxon Signed-ranks test, no significant differences were found.

To research if presenting cues congruent compared to incongruent has an effect on movement time, we used a Wilcoxon Signed-ranks test to compare the mean movement times. No significant differences were found.

To research if there is a difference between the four presentations of the same conditions in set 1 and set 2 a non-parametric Friedman test was conducted. There were no significant differences found between the presentations of the condition with one virtual person. Also, there were no significant differences found between the presentations of the conditions with 10 virtual people. For the condition with exit signage only the Friedman test of differences among repeated measures showed a Chi-square of 10.626 which was significant ($p = 0.014$). Post hoc analyses were conducted between the two presentations of conditions with exit signage only for set 1 and set 2 (figure 6). A Wilcoxon Signed-ranks test indicated a significant difference between the conditions where exit signage was presented solely in set 1 (M: 7.11, SD: 0.397) and set 2 (M: 6.97, SD: 0.241), $Z = -2.273$, $p = 0.023$, $r = -0.41$. This means that there was a significant decrease in movement time between set 1 and set 2 for these conditions. Where set 1 takes significantly longer than set 2. Effect sizes (r) between 0.3 and 0.5 indicate a medium effect. This effect of $r = -0.41$ indicated a medium effect. We also see a difference between baseline and both conditions in set 1 and 2. For set 1 a Wilcoxon Signed-ranks test indicated no significant difference between baseline (M: 7.30, SD: 0.708) and exit signage (M: 7.11, SD: 0.397), $Z = -0.764$, $p = 0.445$. For set 2 a Wilcoxon Signed-ranks test indicated a difference between baseline (M: 7.30, SD: 0.708) and exit signage (M: 6.98, SD: 0.241), $Z = -2.116$, $p = 0.034$, $r = -0.38$. This means that for these conditions there was a significant decrease in movement time compared to the baseline.

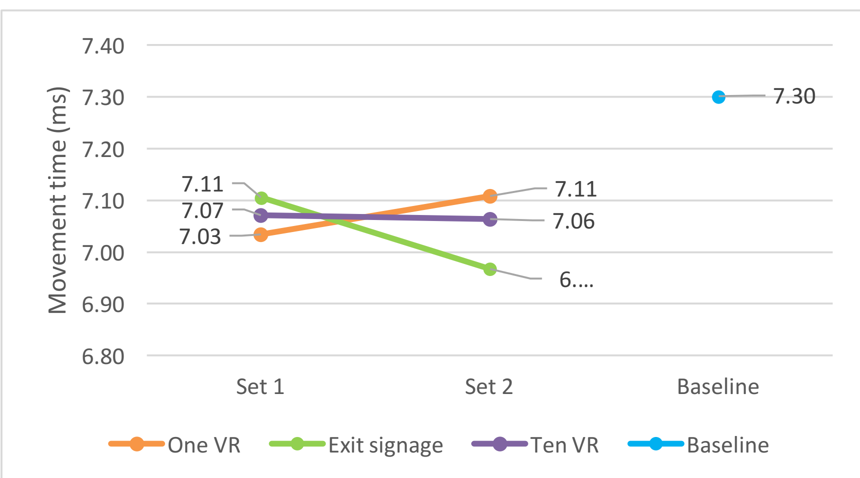


Figure 6: Movement time (in seconds) for the conditions in the baseline, set 1 and set 2 (separately).

Set	Conditions	Corridor	Movement time
Set 1	**1 virtual person**	Set 1 Y01	7.08
		Set 1 Y02	6.99
	10 virtual people	Set 1 Y03	7.07
		Set 1 Y04	7.07
	Exit signage	Set 1 Y05	7.04
		Set 1 Y06	7.17
Set 2	**1 virtual person**	Set 2 Y01	7.10
		Set 2 Y02	7.11
	10 virtual people	Set 2 Y03	6.99
		Set 2 Y04	7.14
	Exit signage	Set 2 Y05	6.93
		Set 2 Y06	7.00
Set 3	**1 Virtual person & Exit signage congruent**	Set 3 Y07	6.93
		Set 3 Y08	6.97
	10 virtual people & Exit signage incongruent	Set 3 Y09	6.96
		Set 3 Y10	7.00
	1 Virtual person & Exit signage congruent	Set 3 Y11	6.93
		Set 3 Y12	7.00
	10 virtual people & Exit signage incongruent	Set 3 Y13	6.96
		Set 3 Y14	6.98

Table 2: All mean outcomes of movement time.

3.5 No exit signage seen

Six participants (19.4%) reported they did not saw the exit signage during the experimental test. For all participants (N = 31) a Wilcoxon Signed-ranks test indicated that more participants followed exit signage in corridor Y05 (M: 0.65, SD: 0.486) in set 2 compared to Y05 (M: 0.84, SD: 0.374) in set 1, Z = -2.121, p = 0.034, r = -0.38.

3.6 Self-assessment manikin

A simple linear regression analysis was conducted to predict the behavior of route choice in different conditions using the outcome of the SAM questionnaire, focusing on the SAM3 regarding dominance. For conditions with only one virtual person presented, a significant regression equation was found ($F(1, 29) = 17.363$, $p < 0.001$), with an R^2 of 0.375. Participants' predicted behavior is equal to 0.144 + 0.105 (SAM3) when behavior is measured in percentages. Percentage of route choice increased 0.144 for each increase on the 9-point scale of 0.105 of SAM3. The SAM3 regarding dominance made a significant contribution to the prediction, $p < 0.001$.

For the conditions with only ten virtual people presented, a significant regression equation was found ($F(1, 29) = 6.775$, $p = 0.015$), with an R^2 of 0.189. Participants' predicted behavior is equal to 0.368 + 0.076 (SAM3) when behavior is measured in percentages. Percentage of route choice increase 0.368 for each increase on the 9-point scale of 0.076 of SAM3. The SAM3 regarding dominance made a significant contribution to the prediction, $p = 0.015$.

For the conditions with only exit signage presented, a significant regression equation was found ($F(1, 29) = 7.553$, $p = 0.010$), with an R^2 of 0.207. Participants' predicted behavior is equal to 0.350 + 0.079 (SAM3) when behavior is measured in percentages. Percentage of route choice increase 0.350 for each increase on the 9-point scale of 0.079 of SAM3. The SAM3 regarding dominance made a significant contribution to the prediction, $p = 0.010$.

3.7 Motion sickness

The outcome of the MSAQ for all participants was a mean of 20.80%, SD: 9.56. This indicated that participants overall experience a slight feeling of motion sickness according to Max Levine (personal communication, May 18, 2017). After the training session and after the experimental test all participants were asked if they experienced nausea or any discomfort due to the virtual reality, none of them reported a real feeling of nausea or discomfort.

4. Conclusion

The main objective of this study is to investigate and compare the effects of social factors and exit signage on route choice and movement time during a stressful event. For this, an experimental setting was designed using different conditions. Different cues are presented solely, in a congruent manner or incongruent manner. A two-alternative forced-choice method was used to measure participant's behavior of route choices. Five main hypotheses are formulated regarding route choice and movement time.

The increase in heart rate is in line with an effect of acute stress on heart rate (Schubert et al., 2009). The decrease in heart rate variability shows the effect of a mental task performance (Vandeput, Taelman, Spaepen & Van Huffel, 2009). The subjective measurements show an increase in state anxiety between baseline and test measurements. Based on these outcomes of the subjective and objective data we can conclude that participants experienced stress during the experimental test. The baseline measurement of the STAI questionnaire was higher than literature describes. This implies that participants also experienced anxiety at the start of the experiment.

Participants' route choice is influenced by exit signage and the two gradations of the social factor. We see no significant differences between the effect and effect sizes of these cues on route choice when presented solely. There is a decrease of the effect of the social factor when presented incongruent to exit signage. The effect of the social factors is higher when presented solely. Hereby we can reject the first hypothesis for this study; virtual people do not have a greater effect on route choices than exit signage. Striking is that the effect of exit signage in the incongruent conditions is more or less the reverse of the effect of social factors presented solely. No significant differences are found between the effect of exit signage presented solely compared to the effect of exit signage presented incongruent to the social factor. Also, no differences are found between exit signage or social factors compared to the congruent conditions. In other words, this study shows that presenting exit signage incongruent from social factors will influence route choice by decreasing the effect of social factors. When presenting exit signage congruent with social factors we see no increase in the influence of the social factor, or exit signage.

We see that the standard deviations of the overall behavior of participants become larger when one virtual person and exit signage are presented incongruent compared to one virtual person presented solely. This increase shows that there is a greater variance of route choices among participants when these cues are presented incongruent. This effect also holds when conditions with one and ten virtual people presented congruent is compared with these cues presented incongruent. We can conclude that in incongruent situations participants show less corresponding behavior.

The second hypothesis states that one virtual person a greater effect has on route choice than ten virtual people. In this study, we see no differences of route choice percentages between conditions with one virtual person compared to ten virtual people; hereby we can reject the second hypothesis.

For movement time we compared at the same conditions. The fourth hypothesis states that participants would have a smaller movement time in the conditions with one virtual person compared to the movement time in the conditions with ten virtual people. We see no effect between conditions with one virtual person compared to ten virtual people; hereby we can reject the fourth hypothesis.

For movement time we did not find an effect of the cues in this study. There is no difference in movement time between conditions where exit signage is presented solely to conditions with one or ten virtual people. Thereby we can reject the third hypothesis. Finally, the fifth hypothesis states that movement time of participants would be shorter in conditions where the cues are presented congruent compared to incongruent. We did not find differences in movement time between these conditions. No effect is shown between these average times per condition. Hereby we can reject the fifth hypothesis.

To evaluate the methods we see that overall participants did not experience discomfort due to using the SteelSeries Stratus CL and HTC Vive to navigate through a virtual environment at a fast pace. Hereby we can conclude that this method is suitable for similar studies in virtual reality, concerning nausea and motion sickness.

5. Discussion

We see that this study's outcome is not completely in line with presented literature. We see that exit signage has a bigger effect on route choices than the social factor. Literature shows a reduction of the use of explicit information during a stressful event (Ozel, 2001). We could explain this with the limitations of this study. A limitation of this experiment is that we used very clean virtual corridors to test the effect of different cues. We could argue that cues become less outstanding and notable if you add more distracting information to the setting. For example doors, cabinets, art or other distracting objects, which are likely to be present in a realistic environment. This lack of distractive objects might have resulted in the greater effect of exit signage on route choices compared to the social factors. Hereby it could be relevant for further research to implement more non-related cues in the virtual environment so that the exit signage does not stand out as much as it did in this experiment.

We did not see an increased effect size of the social factor compared to exit signage. The social factor was presented as virtual people. The study of Kinateder and Warren (2016) shows that effect sizes of virtual people could be smaller than those in the real world. Therefore, we could argue that the visualization of the virtual people used in this experiment might not be realistic to the real world. This realistic visualization could be improved for further research, which could affect the effect size of the social factor.

We did not see any effect between the two different gradations of the social factor, one or ten virtual people. An explanation for this could be that the threshold for the risk to end up in a bottleneck (Bode et al., 2015) will be shown with a bigger crowd than ten people. Crowded routes are according to Bode and Codling (2013) less popular when people are motivated to leave a situation as quickly as possible. This study did not confirm these findings. Therefore, it is interesting and relevant to conduct a study where a bigger crowd is used compared to one virtual person and compare these results to our results. This increase in crowd size could also have an effect on the amount of visual information seen and processed. When you are surrounded by other people your visual scope may be reduced which could have an influence on the route choices people make. This influence could be explained by the more visible the exit signage and routes are, the more attractive they are to people and the more likely it is that people will follow the route (Challenger et al., 2009).

In this study, 6 out of 31 participants (19.4%) mentioned to not have seen exit signage. This is in line with the publication of Kobes et al. (2010c), who states that people tend to not be aware of exit signage during a stressful event. Among these participants, social factors have a significantly higher effect on route choice than exit signage, for obvious reasons.

Among the other participants, it could be interesting to research if at a certain point participants become aware of the presence of exit signage. Therefore, we analyzed route choices of all participants between set 1 and set 2, to see if there is a difference in behavior when exit signage is presented for the first and second time compared to for the third and fourth time. We see an increase in the percentage of participants following the exit signage in corridor Y05 in set 2 compared to Y05 set 1. Also, movement time decreases in the conditions with exit signage presented solely between set 1 compared to set 2. This could be an indication that participants become aware of exit signage the more times they see them, which is in line with the publication of Tang, Wu and Lin (2009). For further research, it is relevant to focus on the moment people see exit signage and if this is in line with the moment that people adapt their behavior complaint with the exit signage.

Vilar, Rebelo, Noriega, Duarte and Mayhorn (2014) argue that explicit information, like exit signage, is not sufficient to guarantee good wayfinding. Implicit information like lighting can inform and attract people to choose that route. Even during a stressful event like an evacuation, implicit information has a stronger influential effect on exit route choice than signage (Vilar et al., 2014). Therefore, it could be relevant to add implicit information to the explicit directional exit information. This could improve the effect of exit signage. The number of people who are not aware of the exit signage could be reduced by this addition. By implementing lighting conform to the explicit directional exit information the route decisions could be improved because people actually see the important information. The eye is drawn to luminous parts, this could make the cues utilization more native (Ozel, 2001) which could improve both route decisions and decision time. This could lead to a more effective use of emergency exits, which could save evacuation time and therefore lives.

Dominance seems to be a significant predictor of route choice when cues are presented solely. For further research, it could be interesting to research more intensively what the effect of dominance is on route choice and on the amount of influence cues have on behavior. Kobes et al. (2010a) mention that in a fire evacuation most people take the role of a follower instead of a leader. These people wait for others to respond before they take action themselves (Kobes et al., 2010a). Therefore, it is relevant to research what the behavior of leader-type people is during stressful events.

In this study, we see that participants used social factors and exit signage to make route choices during a stressful event. Participants were more likely to follow exit signage. This is not in line with other studies on this topic. Due to the limitation of this study, we cannot reflect our outcomes on evacuation behavior in real crowd evacuations. Therefore, improvements of the virtual environment should lead to a better fit to people's behavior in the real world.

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Appendices

Appendix I: State-Trait Anxiety Inventory questionnaire

Subject ID ______________ Session ____________ Study _________ Date____/____/____

STAI FORM X-1

DIRECTIONS: A Number of statements which people have used to describe themselves are given below. Read each statement and then circle the response option to the right to indicate how you feel *right* now, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement, but give the answer which seems to describe your present feelings best.

	Not at all	Somewhat	Moderately so	Very much so
1. I feel calm	1	2	3	4
2. I feel secure	1	2	3	4
3. I am tense	1	2	3	4
4. I am regretful	1	2	3	4
5. I feel at ease	1	2	3	4
6. I feel upset	1	2	3	4
7. I am presently worrying about possible misfortunes	1	2	3	4
8. I feel rested	1	2	3	4
9. I feel anxious	1	2	3	4
10. I feel comfortable	1	2	3	4
11. I feel self-confident	1	2	3	4
12. I feel nervous	1	2	3	4
13. I am jittery	1	2	3	4
14. I feel "high strung"	1	2	3	4
15. I am relaxed	1	2	3	4
16. I feel content	1	2	3	4
17. I am worried	1	2	3	4
18. I feel over-excited and rattled	1	2	3	4
19. I feel joyful	1	2	3	4
20. I feel pleasant	1	2	3	4

Appendix II: Self-Assessment Manikin questionnaire

SAM Self Assessment Manikin

Study

____

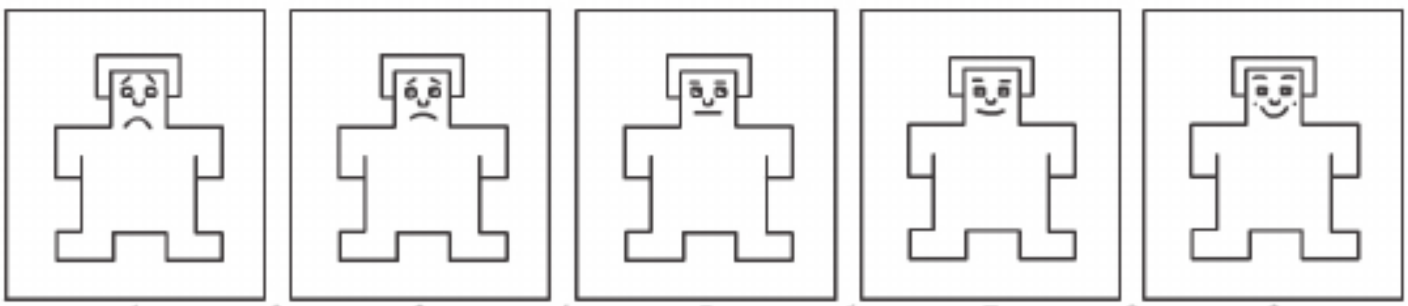
Date

____/____/_____

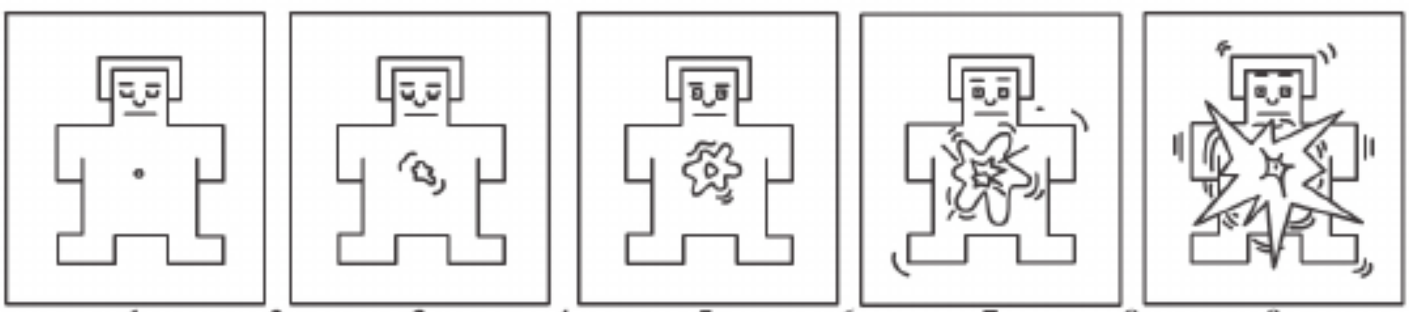
Subject ID

____

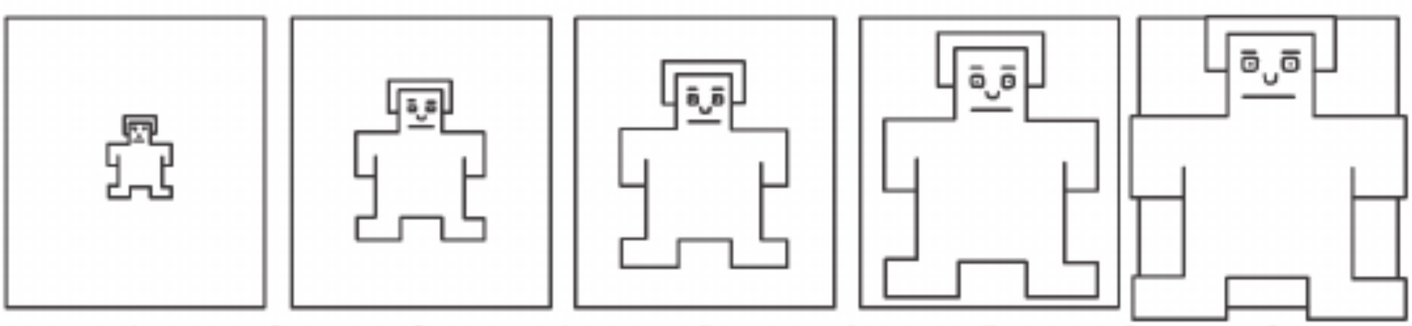
Please rate how accurately the following statements describe how you feel right now, at this moment. There are no right or wrong answers.



1 2 3 4 5 6 7 8 9



1 2 3 4 5 6 7 8 9



1 2 3 4 5 6 7 8 9

Appendix III: Demographic questionnaire

General information

Study

____

Date

_____/____/______

Subject ID

____

Gender

Instructions: Please strikethrough the item that does not apply

__Male / Female__

Dominant hand

Instructions: Please strikethrough the item that does not apply

___Left / Right____

Age range

Instructions: Please select the item that applies

O 18 – 25

O 26 – 35

O 36 – 45

O 46 – 55

O 56 – 67

Appendix IV: Motion Sickness Assessment Questionnaire

Motion Sickness Assessment Questionnaire

Study

____

Date

____/____/_____

Subject ID

____

Instructions: Using the scale below, please rate how accurately the following statements describe your experience

Not at all Severely

1 ---------- 2 ---------- 3 ---------- 4 ---------- 5 ---------- 6 ---------- 7 ---------- 8 ---------- 9

1. I felt sick to my stomach	1	2	3	4	5	6	7	8	9
2. I felt faint-like	1	2	3	4	5	6	7	8	9
3. I felt annoyed/irritated	1	2	3	4	5	6	7	8	9
4. I felt sweaty	1	2	3	4	5	6	7	8	9
5. I felt queasy	1	2	3	4	5	6	7	8	9
6. I felt lightheaded	1	2	3	4	5	6	7	8	9
7. I felt drowsy	1	2	3	4	5	6	7	8	9
8. I felt clammy/cold sweat	1	2	3	4	5	6	7	8	9
9. I felt disoriented	1	2	3	4	5	6	7	8	9
10. I felt tired/fatigued	1	2	3	4	5	6	7	8	9
11. I felt nauseated	1	2	3	4	5	6	7	8	9
12. I felt hot/warm	1	2	3	4	5	6	7	8	9
13. I felt dizzy	1	2	3	4	5	6	7	8	9
14. I felt like I was spinning	1	2	3	4	5	6	7	8	9
15. I felt as if I may vomit	1	2	3	4	5	6	7	8	9
16. I felt uneasy	1	2	3	4	5	6	7	8	9