VR BASED ASSESSMENT OF EFFECTS OF GENDER AND STRESS ON INDOOR WAYFINDING DURING BUILDING EMERGENCIES

Jing Lin, Nan Li, & Dongping Fang

Department of Construction Management, Tsinghua University, Beijing 100084, China

ABSTRACT:

Prior studies have found significant gender effect on people's wayfinding strategies in indoor environments. It is unclear, however, whether the gender effect is significant on people's actual wayfinding performance, especially when the wayfinding task is performed under stress, such as in a building fire evacuation situation. To address this gap, wayfinding behavioral experiments were conducted in this study. The experiments were carried out in immersive virtual environments (IVEs), and involved two independent variables, including gender (male or female) and environmental condition (normal or fire emergency). The participants were asked to complete a treasure hunting task which allowed the participants to freely explore a virtual indoor space. Upon completion of this task, the participants were immediately asked to perform an egress task to exit the indoor space. The wayfinding performance of the participants during these two tasks were measured, and their physiological and emotional responses, as well as sense of direction, wayfinding anxiety, and simulator sickness were collected. Analysis of the experiment results revealed significant or marginal significant gender effect on the wayfinding performance of participants during the treasure hunting task and egress task, as male participants spent less time and traveled shorter distance. The results also revealed that the virtual fire emergency made participants feel stressful and hence adversely impacted their wayfinding performance during the egress task. No significant interaction effect between gender and environmental condition was found during the egress task.

KEYWORDS: *Wayfinding; Virtual Reality; Gender; Fire Emergency; Spatial Ability.*

1. INTRODUCTION

Cognitive research has found that gender can affect people's wayfinding abilities (De Goede and Postma, 2015) and wayfinding behavior (Lawton, 1996). For instance, it was reported in prior research that males generally outperformed females in forming and manipulating spatial knowledge in cognitive map when they were exposed to unfamiliar space (De Goede and Postma, 2015). Males and females may also differ with respect to their preferred wayfinding strategies (Lawton, 1996). Females usually choose landmark-based strategy (route strategy) whereas males usually choose global reference directions (orientational strategy). However, such gender effect has not been thoroughly examined under building fire emergency scenario, where wayfinding is complicated by the stress to quickly egress from hazardous environment. Whether the gender effect on wayfinding abilities and wayfinding strategies can be translated to effect on actual wayfinding performance, which is usually measured by travel time and travel distance, also largely remains unclear.

Laboratory experiments are usually used to analyze the causal relationships with the power of controlling variables. To study building fire evacuation behavior by conducting fire evacuation experiment, however, is challenging as creating real building fire emergency environment is prohibited due to legal and moral reasons. Immersive Virtual Environments (IVEs), which are built on Virtual Reality (VR) technologies, provide a promising alternative approach (Zou et al., 2017). IVEs can present virtual building fire scenes and make users feel stressful, and hence have been introduced in evacuation wayfinding experiments (Gamberini et al., 2015). This paper aims to study the gender effect on wayfinding performance under both normal condition and building fire emergency conditions, by conducting an VR-based experiment. The remainder of this paper is organized as follows: section 2 presents a brief overview of related research, followed by section 3 that introduces the methodology of this study. Section 4 discusses the findings of the experiment, and section 5 concludes the paper.

2. RELATED RESEARCH

2.1 Wayfinding behavior and gender

Cognition research has found significant gender difference in spatial abilities, such as mental rotation (De Goede and Postma, 2015). Thus, several studies tried to analyze gender effect in wayfinding behavior under normal

condition. Prior findings indicated that females relied more on route strategy, whereas males relied more on orientational strategy (Lawton, 1996). Meanwhile, Schmitz (1997) reported that females were better at learning and using landmark knowledge while males were better at learning and using directional knowledge. She explained the gender effects on wayfinding strategies by two mediators, including wayfinding strategies formed and practiced during childhood, and affective-mediators such as wayfinding anxiety. Livingstone-Lee et al. (2014) claimed that the gender effect on wayfinding strategies might be small and could be eliminated by other impact factors, such as prior choices of wayfinding strategies. De Goede and Postma (2015) found the spatial ability of forming and retrieving cognitive map was affected by gender. They found males usually actively manipulated and transformed mental images in their cognitive map, whereas females were good at using static images of spatial knowledge. Despite the above studies about gender effects on wayfinding strategies, however, gender effect on people's actual wayfinding performance, as measured by travel time and travel distance, has been barely studied in indoor environments, neither under normal conditions nor under emergency conditions.

2.2 VR and wayfinding in evacuation

VR technologies have been used in a range of research domains, such as cognitive science (Matheis et al., 2007) and wayfinding behavior (Kinateder, et al., 2014a). VR technologies provide a promising alternative for conducting indoor wayfinding behavior studies, because spatial cognitive process and behavior in IVEs are similar to those implicated in the navigation of a real environment (Wallet et al., 2011). Due to moral and legal constraints, evacuation wayfinding experiments cannot be conducted in a real building emergency environment, such as a real building fire. Therefore, IVEs have been introduced in these experiments. The virtual stressful environments can be used to elicit similar mental and behavioral responses that people have in real stressful environments (Gamberini et al., 2015). A comparison of advantages and disadvantages of VR technologies with other methods used in fire evacuation research can be found in (Kinateder, et al., 2014b). A number of studies have used IVEs to examine different evacuation wayfinding behaviors in fires, such as route choice (Kinateder, et al., 2014a) and evacuation time and distance (Duarte et al., 2014). Kinateder, et al. (2014a) used IVEs to analyze the impact of social influence on tunnel fire evacuation behavior. Duarte et al. (2014) studied behavioral compliance for signage system in IVE. The ecological validity of VR-based experiment is critical for justifying the use of VR technology to support emergency evacuation studies. Zou et al. (2017) developed an emotional response–based approach for assessing the sense of presence in virtual building evacuation studies as an indirect way to assess the ecological validity.

3. METHODOLOGY

3.1 Experiment design and participants

The experiment used a 2 × 2 design and lasted approximately seven weeks. The two independent variables were gender (male and female) and environmental condition (normal condition and fire emergency condition). Thirty-six Chinese undergraduate and graduate students from a major university in Beijing, China, were recruited in this study. Having normal or corrected-to-normal vision, and having no color blindness were used as exclusion criteria during the participant recruitment. Each of the participants received fifty CNY as monetary incentive for taking part in the experiment, which took around thirty minutes to complete. This study was approved by the Ethics Committee of the Psychology Department of Tsinghua University. Of all thirty-six recruited participants, four participants were not able to complete the experiment as scheduled. A total of thirty-two participants completed the experiment, and their experiment data were collected and analyzed in this study. The thirty-two participants were randomly divided into four groups of the same size, with the constraint of having uniform gender in each group, as summarized in Table 1.

Table 1: Assignment of participants into four study groups.

	Gender	Number of participants	Environmental condition
Study group A (SG A)	Male	8	Fire emergency
Study group B (SG B)	Female	8	Fire emergency
Study group C (SG C)	Male	8	Normal
Study group D (SG D)	Female	8	Normal

3.2 Apparatus and VR environment

An HTC VIVE head-mounted-display (HMD) virtual reality system was used. Unity3D game engine was used to create IVEs and run the experiment. The virtual building used in this experiment was a 38 m (length) × 15 m (width) × 3 m (height) monetary museum (see Fig. 1 for the layout). All participants were kept at least 50 cm away from the display cabinets and showcases with crowd control queue stanchion posts and barriers. The spreading of fire and smoke under the condition of fire emergency was computed using the Fire Dynamics Simulator (FDS) software and visualized and displayed using the particle system in Unity3D (see Fig. 2 for an illustration). Standard fire alarm with medium volume would be heard by the participants from headphone (default headphone in HTC VIVE set) at the same time. During the experiment, the participants physically sat still on a chair, and manipulated the Xbox joystick to move forward or make turns in the IVE at a constant speed of 1.5 m/s. The system automatically monitored and recorded their travel distance, travel time and travel routes.

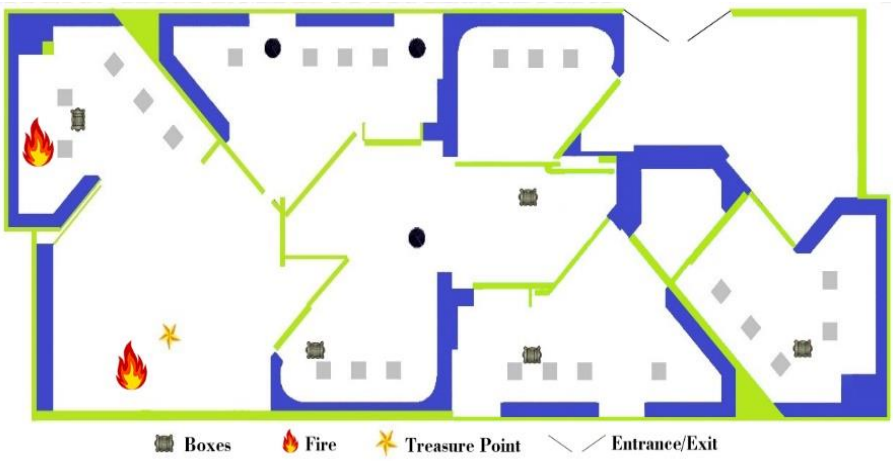

Fig. 1: Layout of the virtual monetary museum.

Fig. 2: Fire and smoke in the virtual monetary museum.

3.3 Experiment procedure

Participants answered a recruitment questionnaire hosted on an online survey service (Wenjuanxing, 2017) when they first signed up for this study. The recruitment questionnaire included questions on basic demographic information about the participants, such as age, gender, and the Chinese version of Santa Barbara Sense of Direction Scale (SBSOD; Hegarty et al., 2002).

When the participants arrived at the laboratory, they were asked to sign a consent form for signing in to the experiment, and informed that they could choose to quit the experiment at any time if they felt sick or uncomfortable. Then, the participants were instructed to put on a skin conductivity sensor for collecting electrodermal activity (EDA) data throughout the entire experiment. The experiment included a pre-experiment questionnaire, a training phase, an experimental phase and a post-experiment questionnaire. The pre-experiment questionnaire was composed of the Chinese revision of Positive Affect and Negative Affect Scale (PANAS; Qiu, Zheng, & Wang, 2008) and the Simulator Sickness Questionnaire (SSQ; Kennedy et al., 1993). During the training phase, participants played with a simply demo IVE to get familiar with basic VR operations such as navigation and interaction with virtual objects, and the sense of immersion in the virtual environment. In the experimental phase, participants were instructed to complete two tasks. The first task was a treasure hunting task, in which they needed to find five boxes in the monetary museum and retrieve five treasure keys (see Fig. 1 for locations of the boxes), which could then be used to retrieve a hidden treasure in a treasure point (see Fig. 1 for its location). The second task was an egress task requiring the participants to egress from the museum as fast as possible through the only exit. The default position of the participants in the IVE when the experimental phase started was the entrance of the museum. Immediately after they finished the treasure hunting task, a visual sign with the following instructions would pop up to instruct the participants to exit the museum: “Treasure found, please exit the museum immediately”. For participants in SGs A and B, who were assigned to egress under fire emergency, they would witness the breakout of fire and smoke and start hearing fire alarm at the same time. The experimental phase ended when the participants reached the exit. It was followed by the post-experiment questionnaire, which included PANAS, SSQ, and a self-report questionnaire about their wayfinding spatial anxiety (Lawton, 1994).

3.4 Data collection and analysis

To evaluate wayfinding performance, participants’ travel time and travel distance in the two tasks were recorded and analyzed, including travel distance (d1) and travel time (t1) in the treasure hunting task, and the travel distance (d2) and travel time (t2) in the egress task. Possible confounding factors, including simulator sickness, spatial anxiety, and sense of direction, were also recorded and assessed by standard scales, SSQ, wayfinding spatial anxiety questionnaire, and SBSOD, respectively. The presence of stress was measured by emotional responses reported by PANAS and physiological responses recorded by EDA sensor. The change in EDA sensor data, which is associated with the sympathetic activation of the autonomic nervous system, is reflective of the change in emotions (Zou et al., 2017). Prior VR-based studies also validate the emotional arousing and sense of presence of participants in virtual environments by EDA (Zou et al., 2017). Skin Conductivity Mean (SC Mean) was the indicator of EDA used in this study. ErgoLAB platform (Kingfar International Inc., 2017) was used to record and process raw segment EDA data and report the value of SC Mean.

4. RESULTS AND DISCUSSIONS

4.1 Demographics of participants

To avoid the impact of inherent confounding factors, the following variables were measured and compared among four study groups: age, wayfinding anxiety, sense of direction, and prior VR experience. Results of one-way analysis of variance (ANOVA) (Mchugh, 2011) are shown in Table 2. Significance level of 5% and marginal significance level of 10% were used. The results showed that participants in all four study groups had comparable age, scores of wayfinding anxiety and scores of simulator sickness (p-value>0.10). Participants had marginally different scores of sense of direction ($F(3, 28)=2.793$, p-value=0.059). There was significant difference in their prior VR experience among the four groups (p-value=0.042). Such difference of sense of direction and prior VR experience could affect the participants’ wayfinding performance in IVE, which were therefore taken into further consideration in the following analysis.

Table 2: One-way ANOVA results of participants' demographics among four study groups.

Demographics	Study group	Mean	SD	F (3, 28)	P-value
Age	SG A	20.75	1.753	1.021	0.398
	SG B	21.75	2.053		
	SG C	20.88	1.356		
	SG D	20.25	1.753		
Wayfinding anxiety	SG A	17.50	3.423	0.269	0.847
	SG B	16.75	8.481		
	SG C	18.13	6.958		
	SG D	19.88	8.887		
Sense of direction*	SG A	68.38	4.534	2.793	0.059
	SG B	61.63	6.886		
	SG C	66.88	4.704		
	SG D	62.25	6.205		
Simulator sickness	SG A	0.03	0.149	0.892	0.458
	SG B	0.11	0.150		
	SG C	0.09	0.214		
	SG D	0.18	0.215		
Prior VR experience**	SG A	1.88	0.641	3.111	0.042
	SG B	1.38	0.518		
	SG C	1.13	0.354		
	SG D	1.63	0.518		

Note: ** indicates p-value < 0.05 between groups. * indicates p-value < 0.10 between groups.

4.2 Wayfinding performance in treasure hunting task

Multivariate General Linear Model (MGLM) based on Pillai's Trace (Olson, 1974) was applied to analyze the gender effect on the participants' wayfinding performance in treasure hunting task. MGLM was firstly conducted with one between-subjects factor (gender) and two covariates (sense of direction and prior VR experience) on two dependent variables (t1 and d1). Backward stepwise in MGLM based on the significance was applied to find all the significant factors. The stepwise process ended with adjusted R^2 value of 0.906 for t1 and 0.921 for d1 when only one between-subjects factor (gender) was considered, as shown in Table 3. The results indicated that the effect of gender was significant ($F(4, 60)=16.297$, p-value=0.000) and had strong power of explaining the difference in participants' wayfinding performance in the treasure hunting task.

According to the experiment results, male participants traveled shorter distance and spent less time on completing the treasure hunting task than female participants, which was consistent with prior studies that examined the gender difference in outdoor wayfinding (De Goede and Postma, 2015). One possible reason for such difference could be related to the theory that males, unlike females, usually actively manipulate and transform mental images in their cognitive map (De Goede and Postma, 2015). Specifically in this study, it could be that male participants were able to complete the task with less time than female participants (t1) because male

participants actively processed and retrieved spatial knowledge from newly formed cognitive map. Another possible reason could be the gender difference in spatial ability. Prior studies (De Goede and Postma, 2015) found that males could learn and memorize relative positions of different places more accurately than females. This might help male participants to find the short paths and avoid searching spaces that they had already been to, leading to savings of time (t1) and distance (d1) to complete the treasure hunting task.

Table 3: MGLM results of wayfinding performance in treasure hunting task.

Performance indicator	Gender	Study groups	Mean	SD	N	F (2, 30)	P-value
t1	Male	SGs A and C	116.75	45.112	16	155.230	0.000
	Female	SGs B and D	145.75	39.489	16		
d1	Male	SGs A and C	944.81	295.031	16	186.651	0.000
	Female	SGs B and D	1012.44	278.110	16		

Note: p-value < 0.05 indicates significant effect of gender.

4.3 Wayfinding performance in egress task

Then, MGLM based on Pillai's Trace was applied to analyze the effect of gender and environmental condition and their interaction effect on participant's wayfinding performance (t2 and d2) in egress task. MGLM was conducted with two between-subjects factors (gender and environmental condition) and two covariates (sense of direction and prior VR experience) on two dependent variables (t2 and d2). Backward stepwise in MGLM was used to find all significant factors. The backward stepwise resulted in adjusted R^2 value of 0.798 for t2 and 0.827 for d2 when two between-subjects factors (gender and environmental condition) and one covariate (prior VR experience) were considered. The results are shown in Tables 4 and 5.

Table 4: Wayfinding performance in egress task.

Performance indicator	Study group	Mean	SD	N	Performance indicator	Study group	Mean	SD	N
t2	SG A	50.50	27.959	8	d2	SG A	512.88	260.665	8
	SG B	63.75	37.522	8		SG B	562.38	325.835	8
	SG C	27.00	4.175	8		SG C	306.63	39.511	8
	SG D	45.00	20.050	8		SG D	390.63	116.175	8

Table 5: MGLM results of wayfinding performance in egress task.

Performance indicator	Factor	F (1, 27)	P-value	Performance indicator	Factor	F (1, 27)	P-value
t2	Gender*	3.325	0.079	d2	Gender	0.830	0.370
	Environmental condition*	3.539	0.071		Environmental condition*	4.033	0.055
	Gender× Environmental condition	0.465	0.501		Gender× Environmental condition	0.475	0.497
	Prior VR experience*	4.091	0.053		Prior VR experience*	3.832	0.061

Note: * indicates p-value < 0.10.

As the results showed, gender was a marginally significant factor for t2 (F(1, 27)=3.325, p-value=0.079) but was insignificant for d2 (p-value>0.10). Compared with treasure hunting task, the significance of gender effect on wayfinding performance decreased in the egress task. The difference in the objective and setting of the two tasks was possibly responsible for such difference in observed gender effect. The treasure hunting task required more complete spatial knowledge in cognitive map to quickly find all six positions, whereas the egress task only required spatial knowledge related to the exit. Prior research found that gender difference in spatial abilities helped males outperform females in difficult wayfinding tasks in unfamiliar outdoor space (De Goede and Postma, 2015). The results in this paper again validated this hypothesis, but in a virtual indoor setting.

Environmental condition was a marginally significant factor for both t2 (F(1, 27)=3.539, p-value=0.071) and d2 (F(1, 27)= 4.033, p-value=0.055). Participants under fire emergency traveled longer distance and spent more time than participants under normal condition. The results were consistent with findings in prior studies (Meng and Zhang, 2014). Fire emergency environment reduced the visibility of the environment by fire and smoke, which negatively affected the search and recognition of landmarks and hence decreased wayfinding performance (Darken and Peterson, 2001). Besides, fire emergency made participants stressful. Stress accelerated information processing, such as environmental perception and retrieving of cognitive map, which could result in random route choice of participants (Meng and Zhang, 2014). The results showed no interaction effect of gender and environmental condition on t2 or d2 (p-value>0.10). Prior VR experience, a marginal significant factor for both t2 (F(1, 27)=4.091, p-value=0.053) and d2 (F(1, 27)=3.832, p-value=0.061), might have affected the wayfinding performance through it effect on the level of stress participants experienced in the VR environment (Grandin, 1997).

4.4 Validity

The validity of this study was evaluated by internal validity, statistical validity, construct validity and external validity. For internal validity, confounding factors of this study, including simulator sickness, sense of direction and wayfinding anxiety (Kennedy et al., 1993; Lawton, 1994; Hegarty et al., 2002), were assessed and no significant effect on wayfinding performance was found. Sample size, level of significance and statistical method were carefully selected to meet the requirement of statistical validity (Mchugh, 2011; Olson, 1974).

Furthermore, to assess whether the virtual fire emergency environment aroused psychological and physiological reactions of participants, such as mental stress, the change of the positive emotions, negative emotions and skin conductivity of the participants before and after the experiment were analyzed. SC Mean were used to analyze the change of skin conductivity. The MGLM based on Pillai's Trace was conducted with one between-subjects factor (presence of fire emergency) on three dependent variables (positive emotions, negative emotions, SC Mean). The results are shown in Table 6. The results indicated that the virtual fire emergency environment significantly affected negative emotions and SC Mean, but did not affect positive emotions. The results suggested that the virtual fire emergency environment was generally effective in arousing psychological and physiological reactions of participants under fire emergency.

Table 6: MGLM results of psychological and physiological reactions of participants.

Reaction	Environmental condition	Study groups	Mean	SD	N	F(2, 30)	P-value	Adjusted R^2
Positive emotions changes	Normal	SGs C and D	-0.44	4.844	16	2.368	0.111	0.079
	Virtual fire	SGs A and B	-2.63	4.938	16			
Negative emotions changes**	Normal	SGs C and D	0.19	2.167	16	7.231	0.003	0.280
	Virtual fire	SGs A and B	3.56	4.844	16			
SC Mean changes**	Normal	SGs C and D	3.25	4.123	16	6.049	0.006	0.240
	Virtual fire	SGs A and B	-5.06	8.873	16			

Note: ** indicates p-value < 0.05.

Different aspects of external validity were also considered. Various prior studies reported that findings about spatial knowledge and wayfinding behavior from virtual environment might also be applied in real environment (Wallet et al., 2011), suggesting reasonable external validity of the results reported in this paper. Yet, two limitations related to external validity of this study should be noted. First, the sample of participants was composed of university students. The external validity of the results on elders or children would require further investigation. Second, Lawton & Kallai (2002) found no statistically significant cultural effect on wayfinding strategies, although, they noticed that significant gender effects on wayfinding strategies were observed in some but not all countries. Considering that all participants in this study were Chinese, generalizing the findings of this study to populations with different cultural backgrounds would require caution.

5. CONCLUSIONS

This study assesses the gender effect on indoor wayfinding performance in both normal condition and fire emergency conditions. An experiment utilizing IVE was conducted. The travel distance and travel time of participants when conducting two wayfinding tasks in the IVE were collected to analyze the gender effect on indoor wayfinding performance in both normal condition and fire emergency conditions. Physiological and emotional responses, sense of direction, wayfinding anxiety and simulator sickness were collected to ensure the validity of the study. The results revealed significant or marginal significant gender effect on wayfinding both in treasure hunting task and in egress task. Male participants spent less time and traveled shorter distance for hunting all treasures than female participants due to difference in spatial abilities. Fire emergency marginally significantly decreased wayfinding performance of the participants in egress task. No interaction effect between gender and environmental condition was observed. Future research could be done to further investigate the gender effect under various other wayfinding scenarios, and explore the necessary and design of gender-specific strategies for wayfinding training and emergency evacuation preparation.

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7. REFERENCES

Darken, R.P. and Peterson, B. (2001), "Spatial orientation, wayfinding and representation", *Handbook of Virtual Environment Technology*, Vol. 4083 No. 2001, 1–22.

Duarte, E., Rebelo, F., Teles, J. and Wogalter, M.S. (2014), "Behavioral compliance for dynamic versus static signs in an immersive virtual environment.", *Applied Ergonomics*, Vol. 45 No. 5, 1367–1375.

Gamberini, L., Chittaro, L., Spagnolli, A. and Carlesso, C. (2015), "Psychological response to an emergency in virtual reality: Effects of victim ethnicity and emergency type on helping behavior and navigation", *Computers in Human Behavior*, Vol. 48, 104–113.

De Goede, M. and Postma, A. (2015), "Learning your way in a city: Experience and gender differences in configurational knowledge of one's environment", *Frontiers in Psychology*, Vol. 6 No. MAR, 1–9.

Grandin, T. (1997), "Assessment of stress during handling and transport", *Journal of Animal Science*, Oxford University Press, Vol. 75 No. 1, 249–257.

Hegarty, M., Richardson, A.E., Montello, D.R., Lovelace, K. and Subbiah, I. (2002), "Development of a self-report measure of environmental spatial ability", *Intelligence*, Vol. 30 No. 5, 425–447.

Kennedy, R.S., Lane, N.E., Kevin, S. and Lilienthal, M.G. (1993), "Simulator Sickness Questionnaire : An Enhanced Method for Quantifying Simulator Sickness", *The International Journal of Aviation Psychology*, Vol. 3 No. 3, 203–220.

Kinateder, M., Müller, M., Jost, M., Mühlberger, A. and Pauli, P. (2014a), "Social influence in a virtual tunnel fire--influence of conflicting information on evacuation behavior", *Applied Ergonomics*, Vol. 45 No. 6, 1649–1659.

Kinateder, M., Ronchi, E., Nilsson, D. and Kobes, M. (2014b), "Virtual reality for fire evacuation research", *Computer Science and Information Systems*, 313–321.

Kingfar International Inc. (2017), "ErgoLAB 'Person-Machine-Environment' Synchronization Platform", Kingfar International Inc., Beijing, available at: http://www.kingfar.cn/.

Lawton & Kallai. (2002), "Gender Differenced in Wayfinding strategies and anxiety about wayfinding: across-cultural comparison", *Sex Roles*, Vol. 47 No. November, 380–401.

Lawton, C.A. (1994), "Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety.", *Sex Roles*, Vol. 30 No. 11–12, 765–779.

Lawton, C.A. (1996), "Strategies for indoor wayfinding: The role of orientation", *Journal of Environmental Psychology*, Vol. 16 No. 2, 137–145.

Livingstone-Lee, S.A., Zeman, P.M., Gillingham, S.T. and Skelton, R.W. (2014), "Navigational strategy may be more a matter of environment and experience than gender", *Learning and Motivation*, Elsevier Ltd, Vol. 45 No. 1, 30–43.

Matheis, R.J., Schultheis, M.T., Tiersky, L.A., DeLuca, J., Millis, S.R. and Rizzo, A. (2007), "Is learning and memory different in a virtual environment?", *Clinical Neuropsychologist*, Vol. 21 No. 1, 146–161.

Mchugh, M.L. (2011), "Multiple comparison analysis testing in ANOVA.", *Biochemia Medica*, Vol. 21 No. 3, 203–209.

Meng, F. and Zhang, W. (2014), "Way-finding during a fire emergency: An experimental study in a virtual environment", *Ergonomics*, Vol. 57 No. 6, 816–827.

Olson, C.L. (1974), "Comparative robustness of six tests in multivariate analysis of variance", *Journal of the American Statistical Association*, Taylor & Francis, Vol. 69 No. 348, 894–908.

Qiu, L., Zheng, X. and Wang, Y. (2008), "Revision of the Positive Affect and Negative Affect Scale", *Chinese Journal of Applied Psychology*, Vol. 14 No. 3, 249–254.

Schmitz, S. (1997), "Gender-Related Strategies in Environmental Development: Effects of Anxiety on Wayfinding in and Representation of a Three Dimensional Maze", *Journal of Environmental Psychology*, 215–228.

Wallet, G., Sauzéon, H., Pala, P.A., Larrue, F., Zheng, X. and N'Kaoua, B. (2011), "Virtual/Real Transfer of Spatial Knowledge: Benefit from Visual Fidelity Provided in a Virtual Environment and Impact of Active Navigation", *Cyberpsychology, Behavior, and Social Networking*, Vol. 14 No. 7–8, 417–423.

Wenjuanxing. (2017), "Wenjuanxing", *Changsha Ranxing Technology Inc*, available at: https://www.wjx.cn/ (accessed 1 January 2018).

Zou, H., Li, N. and Cao, L. (2017), "Emotional Response–Based Approach for Assessing the Sense of Presence of Subjects in Virtual Building Evacuation Studies", *Journal of Computing in Civil Engineering*, Vol. 31 No. 5, 04017028.