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Fire exit signs: The use of neurological activity analysis for quantitative evaluations on their perceptiveness in a virtual environment

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ABSTRACT

Emergency signs represent the easiest way to assist a person during an emergency building evacuation, such as in a fire. However, previous studies show that signs can also not be correctly perceived (because of: smoke/lighting conditions, sign positions in relation to individual's position, pictograms dimensions), consequently becoming useless. This study focuses on the effectiveness of exit signs, in terms of type and position. The related numerical quantification is founded on an objective experimental neurological method. A neurological stimulus (P300) is generated when the individual understands the meaning of the sign. It is so possible to objectively evaluate by using a neuro-headset the performance of each subject in terms of perceptual attention. The use of similar direct data overlooks errors connected to conscious or unconscious individual mediation in answers. Evacuation motion simulations are performed using a virtual reality environment because of limits in the neuro-headset use when walking. Two types of exit signs (reflective and photoluminescent) are tested considering different positions and environmental conditions (illuminated and not). The sign identification distance is retrieved and compared to results of real-world experiments. Finally, the sign effectiveness is also inquired in terms of statistical P300 presence on the analysed sample.

1. Introduction

Finding the faster way to escape from a building is fundamental during an emergency situation, especially in case of fire: previous studies investigated the relation between this aspect and people's behaviour during the evacuation [1,2]. Wayfinding systems are designed and installed in buildings in order to help people during the evacuation process: they include safe condition signs and exit signs systems [3,4]. Many regulations define their characterization and positioning [5–8]. These systems are fundamental during the whole evacuation procedure [2,9]: for this reason, the accurate design of evacuation facilities layout cannot exclude investigations on their perception and use by the pedestrians. Their effective support can be often influenced by the pedestrians' perceptive aspects in relation to signs features (mainly, position, used symbols and dimension) and environmental conditions [10–14]. In order to gain this result, three main aspects should be defined: interactions between evacuating pedestrians and exit signs; traditional methods for inquiring these interactions; innovative methods for similar investigations by focusing on perceptual phenomena [15,16].

1.1. Interactions between evacuating pedestrians and exit signs

Methods for defining evacuating individual's perception of a sign are generally based on experiments evaluating the distance of visibility or identification of the sign [13,17–19]. They contributed to regulations about signs dimensions and characteristics [5] for both reflective and PLM signs. They are able to determine "when" the signs is identified (identification distance), also by introducing different degrees of confidence [19]. However, experiments seem to not deeply investigate "how" the signs is really perceived by the pedestrian. Although experiments provide quantitative results (e.g.: distances [m] [19]; influence on egress time [s] or motion speeds [m/s] [11,20]), they seem to underestimate the direct investigation on human coordination of perception and cognition aspects and the related set of mechanisms. According to previous works involving the so called "psychonomics" [2,21] and "Psychophysiology" points of view [15,22], the effective interactions between man and signs can be influenced by the human perceptual attention [16,23]. Similar aspects are really influent in many other

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evacuation phenomena, such as risk perception, wayfinding activities, social group relationships, attachment to things effects [24–27]. A delay between the perceptual attention activities and the effective individuals' response could be introduced for the presence of reaction time and excitement time lag [28]. In other terms, a time lag (and so a difference in terms of distances while a pedestrian is moving) could appear between the instant (and the related individual's spatial position) that the individual activates its perceptual attention mechanisms and the effective instant of the pedestrian choice. For this reason, effective identification distances could be underestimated also in dependence of experimental conditions.

1.2. Current main methods for experimental evaluations

Previous studies were generally conducted by using direct questionnaires on the involved individuals [14,20,27,29–31] and direct videotapes analyses of evacuation drills [11,27,32,33] or real evacuation cases [34,35]. Questionnaires' results could be affected by some biases [36] due to conscious or unconscious individuals' mediation in answers. However, they are a good way to quickly collect data about the individuals' comfort and safety felt in relation to the tested wayfinding system, and overall subjective evaluation of the system itself [37]. Videotapes analyses allow to determine the motion quantities but do not succeed in defining the effective instant of individuals' choice and the related perceptual attention aspects. Moreover, they could be also affected by the analyser's interpretation. These two problematic issues should be overcome by using innovative techniques, tools and methods [31].

1.3. Perceptual phenomena and electroencephalography (EEG)

Behavioural aspects suggest the introduction of direct quantitative investigations concerning human perceptual phenomena [15]. One of the most interesting analysis methods is represented by the direct recording and analysis of people's neurological activity. The neurological stimulus P300 [38–41] denotes the attention of the subject under different types of stimuli[1] [38,39,41] and could be detected by using an electroencephalography (EEG) [22,42,43]. This kind of analyses directly refers to human brain activity: aspects involving human consciousness in response could be consequently avoided. Many applications included the investigation of people's reaction to different stimuli (visual [44,45], acoustic [46,47]). Other applications also refer to medical sciences [48], marketing [49] and also wayfinding activities [50–52]. Provided methodologies concern: acquisition techniques [38,53], measurement tools [54,55], recording and analysis software [56,57],[2] neurological data processing methods[3] [58–61]. The P300 event-related potential (ERP) often is elicited by using the oddball paradigm [38] in which two stimuli are shown in a random series, such that one of them appears relatively infrequently (i.e. target stimulus). The subject has to focus on the target stimulus (e.g. button press or mentally counting) and not respond to the non-target stimuli. Other studies provide single-stimulus paradigm in which all non-target stimuli are replaced with absence of stimuli [62,63]. Single-stimulus paradigm produces ERPs comparable to those obtained with oddball paradigm. P300 elicited from single-stimulus paradigm responds to target stimulus probability, in terms of target stimulus appearance, in the same manner as oddball paradigm [63,64]. In particular, in single-stimulus paradigm, target stimulus probability can be manipulated varying inter-stimulus interval (ISI) [65]. Additional measurements can be jointly performed in order to simultaneously characterize other human behavioural aspects: eye-tracking [45], head movement [66,67], human emotions [68,69].

1.4. Work purpose

Many studies on wayfinding activities in virtual reality (VR) were done during the last years [9,70–74] so as to define individuals' behaviours in different architectural spaces and environmental conditions and also investigate cognitive processes in wayfinding [75]. Other works deal with wayfinding activities in WR (in both 2D and 3D environments) by jointly recording EEG data, such as studies about e.g.: landmarks recognition and wayfinding in mazes [51,52,76], robotics simulations and/or command of simulated elements such as cars or wheelchairs [77,78]. Although literature underlines the importance of "psychonomics" and perceptual attention investigations in this field [2,16], no attempts in performing joint EEG-VR wayfinding experiments for individuals' safety in emergency and evacuations conditions seem to be yet performed. Furthermore, studies involving similar activities in relation to exit signs are still missing. Evacuation (and exit) signs represent ones of the main "landmarks" while performing correct wayfinding activities in buildings[4] evacuation: the application of EEG techniques could offer significant information about man-signs interaction.

For this reason, this work deals with individuals' perceptual attention in relation to emergency wayfinding signs [16] by taking advantage of the EEG techniques. Problems in recording EEG data are essentially due to possible interferences between the neurological signal and individual's conditions [61]: movements (large head motion or walking activities) can mainly affect the data by introducing anomalous peaks in EEG. New enhanced EEG tools for experiments with moving pedestrians [79–81] seem to reduce related problems, but to not sort out them at all. On the contrary, the use of VR allows to eliminate related individual's large movements during the test.

We focus on two of the main kinds of evacuation signs: reflective [82] and photoluminescent (PLM) [83–85]. They are very robust wayfinding systems because do not need any supply. The reflective signs are the most common ones but they become useless in smoke or black-out conditions: in these situations, PLM signs are effectively efficient [37,85,86]. The signs identification activities [19] are combined to P300 stimuli analysis techniques for outlining numerical results concerning "when" (quantitatively represented by the individual's distance from the sign [13,17,19]) and "how" (the directional information is easy-to-be understood, and perceptual attention mechanisms seem to be correctly performed [11,16,23,37]) the sign is "perceived" by the individual. A P300 based single-stimulus paradigm has been considered since it is an approach operationally easy to implement and it is used in VR application because may provide a more reliable and less intrusive tool for cognitive workload assessment than the conventional oddball task [87]. In order to verify possible correlations between neurological signals and human response, traditional data related to individuals' direct answers (identification distances, questionnaire) and EEG results are jointly analysed. A comparison of identification distances in real world and VR experiments is provided in order to relate results. The two types of signs are evaluated in different positions and the sign effectiveness

[1] http://www.schalklab.org/research/bci2000; last access: 28/10/2014.

[2] http://www.bci2000.org/wiki/index.php/User_Tutorial:BCI2000_Tour and http://www.bci2000.org/wiki/index.php/User_Tutorial:Performing_a_P300_Spelling_Session; last access: 28/10/2014.

[3] 72. http://www.bci2000.org/wiki/index.php/User_Reference:SourceFilter; last access: 28/10/2014.

[4] That can be seen as a "maze" for people, especially when they are not familiar with the architectural space [11,113].