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Role of Physical Environment Factors in Semantic Memory and Cognitive Performance in Open-Plan Offices Users: A Systematic Literature Review

MP Serrano-Ruiz[1], AL Ramírez-Quintana[1], and G Ibarra-Mejía[1,2]

[1]Departamento de Ingeniería Industrial y Manufactura
Instituto de Ingeniería y Tecnología
Universidad Autónoma de Ciudad Juárez
Ciudad Juárez, Chihuahua, México

[2]Department of Public Health
University of Texas at El Paso
El Paso, Texas, USA

Corresponding author's Email: maria.serrano@uacj.mx

Author Note: María P. Serrano Ruiz has a bachelor's and a Master's degree in Industrial Engineering from the Instituto Tecnológico de la Laguna. She is a current Ph.D. student at the Universidad Autónoma de Ciudad Juarez. Her areas of interest are cognitive ergonomics, physiology, quality, and statistics. Ana L. Ramírez-Quintana has a bachelor's degree in Mechanical Engineering from the Instituto Tecnológico de Chihuahua and a Master's degree in Industrial Engineering in the ergonomics area from the Universidad Autónoma de Ciudad Juarez. She works at the ergonomics laboratory at the UACJ. Hear areas of interest are biomechanics, biomedical, ergonomics, and physiology. Dr. Gabriel Ibarra-Mejia has an MD and MS degree from Universidad Autonoma de Ciudad Juarez, an MS degree in Ergonomics from Lulea Tekniska Universitet in Sweden, and a Ph.D. in Environmental Science and Engineering from the University of Texas at El Paso. He is currently an Assistant Professor in the Department of Public Health Sciences at the University of Texas at El Paso.

Abstract: The purpose of this literature review is to discern among the different physical environment factors and assess its impact on semantic memory and cognitive performance. More specifically, this review focuses on the cognitive performance of open-plan office users through a human factors approach. We used the SPIDER search strategy, based on the questions about the sample (S), a phenomenon of interest (PI), design (D), evaluation (E), and results (R). This review includes articles published between 2015 and 2020. Articles reporting applications, simulations, or devices generating masking sounds were discarded. Cross-sectional and experimental research aiming were selected and considered to explain the relationship between semantic memory abilities and wellness perception of users with productivity in open-plan offices. Results show how physical environmental factors impact the semantic memory abilities of open-plan office users. From all physical environmental factors considered in this review, acoustic factors are the most relevant, negatively impacting semantic memory ability, especially when exposed to background noise and affected by the level of speech intelligibility. These findings allow us to identify the impact of acoustic factors in the design of productive open-plan offices and the promotion of worker well-being.

Keywords: Cognitive Performance, Semantic Memory, Open Plan Office, Physical Environment

1. Introduction

The space design is a crucial factor in enhancing productivity and wellness in work centers. The open-plan office design offers benefits in the use of space and to minimize costs (Hedge 1982). It depicts lower costs due to proven flexibility in the characteristics of a workstation, such as size, enclosure, spatial density, as well as room conditions, and physical indoor environment (Hongisto et al. 2016). Furthermore, it is possible to assign fewer square meters per person, minimizing the costs of maintenance and energy (Al Horr et al. 2017).

Open-plan offices improve communication among users due to the layout flexibility that adapts to the needs of the work centers (Balazova et al. 2008). However, noise is a relevant environmental, physical factor. Background noise generated by office equipment and murmuring from colleagues is perceived as annoying and has negative effects on the performance of workers (Hedge 1982). Background noise has negative effects related to the increased distraction of workers, which affects

productivity (Banbury and Berry 2005). Besides, well-being is affected by background noise, which influences stress effects, loss of time, and an increase in human errors in their work activities (Jahncke 2012).

The research about open-plan offices has examined environment effects in occupants, physical factors as temperature, lighting, noise, and air quality. Studies have been analyzed how the effects of Indoor Environment Quality (IEQ) affect the wellness and productivity of workers. The IEQ has a relation with the wellness of building occupants, which is reflected in workers' behavior and perception about space comfort, thereby the importance of comparing different types of offices to find how it influences occupants during a workday (Lou and Ou 2019).

2. Method

The systematic literature review was carried out through a strategic search on the influence of physical environmental conditions on the productivity of open offices. The methodology to select articles was made using the SPIDER search strategy, which through a reference questionnaire, identified for identifying those that included the topic of interest, the human factors approach (Cooke, Smith, and Booth 2012). The SPIDER search strategy is an exploratory analysis that is based on a questionnaire to select articles. Table 1 presents questions made to collect information on this systematic literature review. The questionnaire was used to identify effects on productivity and its relation with the physical environment of open-plan offices under the human factors approach (McDonagh et al. 2008).

Table 1. Questionnaire SPIDER

Topic	***Question***
(S) Sample	Who are the study subjects?
	What is the sample size?
(PI) Phenomenon Interest	What are the authors' perspectives about human factors elements used to evaluate semantic memory abilities?
	What are the experimental conditions done to depict open-plan offices?
(D) Design	What are the dependent and independent variables studied?
	Which is the hypothesis of the study?
(E) Evaluation	What type of research is developed in the study?
	What are the models used to assess cognitive performance?
(R) Results	What are the study outcomes?
	Do outcomes have any practical results?

The systematic literature review consisted of three stages, inclusion and exclusion criteria were established in stage one, the database query was carried out in stage two, the database searching tools were used to filter the search according to the inclusion and exclusion criteria. Finally, stage three comprised a review of the literature to confirm that the articles responded to the SPIDER questionnaire, and the review matrix was carried out (McDonagh et al. 2008).

2.1 Stage 1. Selection criteria

Keywords were used to applicate inclusion criteria on searching tools of each database. The keywords were “Human Factors,” “Semantic Memory,” and “Open Plan Office.” On the other hand, only documents with publication dates between 2015 and 2020 were considered, according to set exclusion criteria. The databases were selected based on availability and the scope of the disciplines related to the approach of the review (McDonagh et al. 2008). These were Science Direct from Elsevier, host of EBSCO, Emerald Insight, Springer Link, and Cambridge Core.

2.2 Stage 2. Database searching

The database searching consisted in using the searching tools of each database with keywords and inclusion/exclusion criteria. In this case, the use of another filter was necessary because only research articles were considered, other documents were discarded. The organization of key findings they were classified and saved in the Zotero reference manager (Cyrus 2019). Selected articles were evaluated in the first place by the title. It should contain keywords as a reference. If were necessary, the questions of IP should be answered in the abstract to be a chosen paper and to be included in the next stage.

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2.3 Stage 3. Literature analysis

In stage two, each selected article paper was read, and by the level, it answered the questionnaire. The collected information was recorded in the review matrix. In this systematic literature review, 363,642 articles were found, which articles from five databases were classified that contained within keywords "Human Factors, Semantic Memory, and Open plan office." Additionally, after using the date and type filter, 690 articles were found and registered to be read, whereas only 36 articles were fulfilled after answering the SPIDER questionnaire, Table 2.

Table 2. Overview of the review articles

Database	Refine by					Abstract Analysis		Overall Review	
	Keywords	Years		Article type					
	I	I	E	I	E	I	E	I	E
Science Direct of Elsevier	1,551	392	1,159	67	325	25	42	17	8
EBSCO host	45,796	16,754	29,042	170	16,584	26	144	13	13
Emerald Insight	318	140	178	98	42	9	89	6	3
Springer Link	3,599	1079	2,520	215	864	0	215	0	0
Cambridge Core	312,378	64,256	248122	140	64,116	0	140	0	0
Total	363,642	82,621	281,021	690	81,931	60	630	36	24

I = Include article **E = Exclude article**

During stage two were found topics associated with keywords, especially topics related to Semantic Memory and Human Factors. Figure 1 indicates the human factor approach concerning open plan office design as the basic background noise of an open plan office. The background noise in the office is generated by soundscape and voices, which have effects on perceptions users of disturbances, distraction, privacy, and semantic memory (Kaarlela-Tuomaala et al. 2009) (Jahncke et al. 2011).

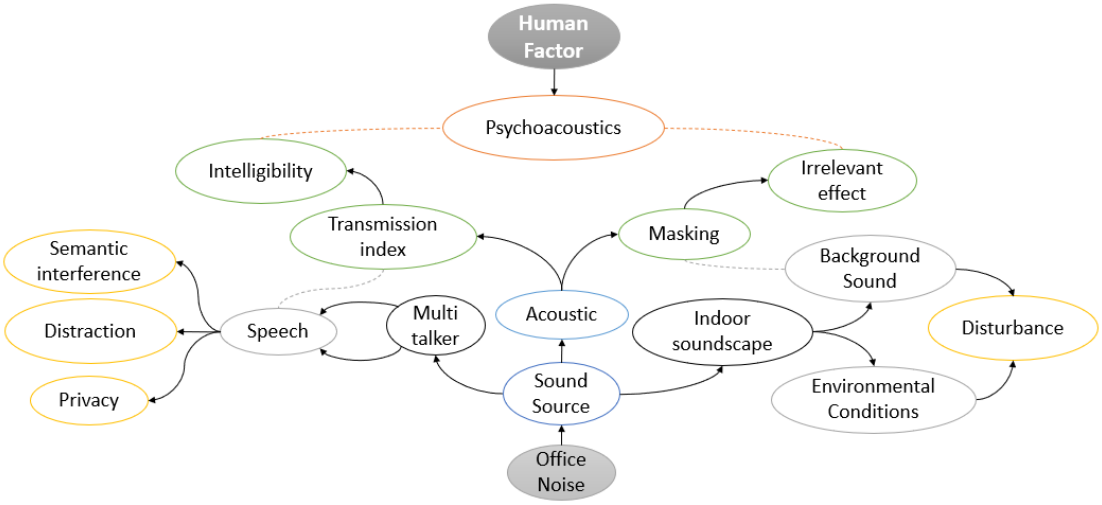

Figure 1. Mind map of keywords related to Human Factors

The human factors approach evaluates environmental conditions according to the impact on performance through psychoacoustics that studies how humans perceive sound. Some measurements used are intelligibility, which evaluates voice quality to be heard with clarity, and masking sound, that evaluate produced effects by different sound perceived at the same time (Howard and Angus 2013). After review and analysis, 60 articles were included (27 articles were duplicated on databases)

that contained the keywords. Finally, the review matrix was used to accomplish literature analysis, where results were 36 articles that fully answered the SPIDER questionnaire (Jonnalagadda, Goyal, and Huffman 2015).

3. Results

The literature analysis shows results related to different topics of cognitive performance on open plan office users. The answers of the SPIDER questionnaire were collected in the review matrix, which was made with 36 articles drew from journals on Buildings (36%), Acoustic (31%), Psychology (28%), and Ergonomics (06%).

3.1 Sample (S)

The sampled subjects were characterized by studies of open-plan office users (53%), students (44%), and mixed (03%). Most studies used sample sizes between 31 and 100 subjects. Experimental studies were mostly conducted using students as participants. In the case of experimental studies using open-plan users, sample sizes were of 100 or more subjects.

3.2 Phenomenon of Interest (PI)

The phenomenon of interest showed studies that compared different acoustic (50%), indoor environmental (25%), and type of office (25%) conditions. Most studies evaluated acoustic about background office generated by multitalkers and how the sound was masking in workspaces. On the other hand, indoor environmental was studied to analyze how physical environmental factors interacted together to evaluate how open plan office users perceived concerning well-being and productivity. Finally, other perspectives were comparing the type of office to identify how workspaces are perceived with the self- perception of wellness and productivity of open plan office users.

3.3 Design (D)

The design topic presents eight types of relations. Control variables were characterized by the effects of indoor environment quality (IEQ) with well-being and productivity. Another relationship was background noise impact and effects on performance. In this case, outcome variables were the effects on semantic memory abilities and collaboration activities. Furthermore, background noise generated by voices was evaluated to identify how irrelevant sound effects and multitasker sound masking have an impact on workers' performance. Finally, it was evaluated how the effects of the relocation of workers in offices affect the self-perception of well-being and productivity of open plan office users.

3.4 Evaluation (E)

In this section, the type of research was analyzed, as results were identified 44% experimental studies, 42% crossover studies, and 14% of quasi-experimental studies. Moreover, acoustics conditions were analyzed in experimental studies to evaluate indoor environmental were made quasi-experimental studies, and the comparison of the type of offices was carried out with crossover studies.

Another topic of interest was the model used to evaluate the effects of cognitive performance. Thirteen different methods were found. Mainly, the Performance Resource Function was used in 36% of studies, which describes the relation between performance and investment of resources to execute a task (Sanders and Sanders 2013). The Job demands-resource model of work stress was used in 22% of the studies, which evaluates occupational stress in relation to task-demand and investment of resources by workers (Dewe and Cooper 2017).

3.5 Results (R)

In this review, was found that 70% of studies were related to the effects that indoor environmental conditions have on cognitive performance, 22% of the studies use a special factor to the acoustics conditions related to performances, and 8% of the studies use linear regression to predict performance behavior.

Additionally, the results indicated that 78% of the studies present a relationship between the indoor environment and the performance of open-plan users' offices. It should be noted that the distribution of the studies was as follows: 36% presented the impact of the acoustic condition on performance, 19% indicated that the indoor environment has an influence on performance, and 22% explained how the type of office influences the perception of open office users.

4. Concluding remarks

The lines of research to assess the performance and well-being of workers in open offices between 2015-2020 can be classified into (1) effects of the interior environment, (2) the impact of space parameters, and (3) background noise.

Research on the effects of the indoor environment, in the first place, evaluate the physical environmental factors, such as temperature, air quality, and intelligibility. In this case, Varjo (2015) did not found significant effects on the performance and satisfaction of users. However, Roaskams (2019) and Haynes (2019) retook the analysis of the impact of environmental conditions, finding a correlation with production, well-being, and satisfaction, as well as a correlation with attention and collaboration. Notably, the effects of lighting were studied by Jamirozik (2019), who found a correlation with performance. On the other hand, Aries (2020) found no significant effects of lighting on performance and well-being.

Also, office comparisons were carried out, Hongisto (2016) found no effects on satisfaction related to the indoor environment. Still, Lou (2019) found a correlation between the effects of indoor environmental quality and productivity. On the other hand, the activities performed in offices were studied to study the relationship between the use of spaces with performance. Smith-Jackson (2016) found the effects of the environment with performance, and Haapakangas (2018) found a relationship with the perception of productivity and worker well-being.

Another line of interest was the effect of the space parameters on performance, meaning how the layout arrangement and the general design of the open office spaces are formed. In 2015 Seddigh related the type and size of the office to users' performance. In 2017 Morrison and Palvalin also studied the type of office with coexistence and work practices with collaboration, respectively. In addition, the design is another relevant factor for the perception of the well-being and productivity of workers. In this case, in 2018, Ayuso evaluated the design of the office with performance and health, while Oseland evaluated the relationship between design and perception of well-being and productivity. Alternatively, in 2019 Roberts found the effects of privacy with cognition, and Yildrim identified the effects of spatial organization with the perception of well-being.

The last line was about background noise effects on the performance of open plan office users. This line has 2 ways, room acoustic, and voices as sound sources. Seddigh, Berntson, et al. (2015) found background noise impact on worker disturbance, after Hongisto, Varjo et al. (2016) found that background noise on performance and satisfaction of workers, thus as Haynes, Nunnington, and Eccles (2017) and Roskams et al. (2019) agree that background noise has relation with productivity. Furthermore, Haapakangas, Hongisto, et al. (2018) identified speech effects on concentration, while Golmohammadi et al. (2020) found fluctuating noise on worker attention. However, Mama, Fostick, and Itchy (2018) and Braat-Eggen et al. (2019) did not found background noise on the performance of long-term memory and collaboration activities, respectively.

The voices as sound sources were studied according to the number of talkers, their effect as a sound masker, and the impact of multi-talker sound source position on a workspace. The number of talkers influence on performance was studied by Keus van de Poll and Sörqvist (2016), who did not found significative effects of voices number on semantic activities, especially writing, but Keus van de Poll, Sjödin, and Nilsson (2018) found a relation between sound source, the position of talkers and writing. Besides, Yadav et al. (2017) carried out research about babble effects on perception, whereas Yadav and Cabrera (2019), as well as Braat-Eggen et al. (2020), evaluated sound source ubication of talkers with writing.

The sound masking generated by multi-talkers has been studied to evaluate the impact on performance, primarily Brocolini, Parizet, and Chevret (2016), and Chevret (2016) did not found an influence of Irrelevant Sound Effect on performance. However, Zaglauer, Drotleff, and Liebl (2017) found sound masking has effects on users' concentration. Also, Acun and Yilmazer (2018) presented a correlation between multi-talkers and soundscape perception, while Renz, Leistner, and Liebl (2018) presented two studies related to how sound masking play on performance and disturbances of workers.

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