Exploring the Research Trajectories in VR Environments: A Systematic Review on Spatial Ability and Presence

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Abstract

Virtual environments provide researchers with a platform for standardizing experimental conditions and protocols. To investigate specific research concerns on behavioral studies, researchers may use a virtual reality environment because the manipulation of various aspects, such as visual and auditory signals, social interactions, and task parameters are easier than in a real environment. For this reason, the number of prospective studies in this field increases daily. Behavioral science has been studied in the context of design cognition in relation to the design process, in recent years, it has gained prominence in relation to spatial cognition in game design research. Examining the spatial cognition research areas studied in the VR environment reveals that learning, navigation, and social interaction predominate. The notion of presence has gained importance with the VR headsets development which increase the place illusion and immersion with the increased display quality, haptic feedback, and sensor technologies.

This comprehensive review of the literature examines the development of virtual reality environments in the context of spatial cognition studies. The literature review revealed that the concept of spatial presence has received less attention in this field. For this reason, an effort has been made to present the subject's treatment over the years in detail. The current of dual link between spatial ability and spatial presence in virtual reality environments is investigated using data mining methods. One of the motivations for using data mining in this study is to give the systematic review a new perspective. Within the scope of this study, a file of research articles from the scientific literature

was compiled by searching the Scopus and Web of Science databases with word strings comprising the main topic and subthemes. Using the Rapidminer application, the abstracts of the compiled studies and the word association rules criteria were created. This field's prime age of research occurred in the 10s. This may hinge on the headsets' technological progress. It is possible that the number of studies has decreased over the years, that researchers may have opted to change their research methods, that the use of certain words in the literature has increased, and that some tests (pre-post) may have been conducted within the scope of research. Instead of manually reading the results, it is possible to automate and scan the databases. Taking into account the small number of articles within the scope of this study, it should be noted that more exhaustive literature searches using this method will save time and result in accurate future predictions.

Keywords: Spatial ability, Spatial presence, Data mining, Virtual reality, Virtual reality game

1. INTRODUCTION

The integration of virtual reality tools into daily life has accelerated through technological developments, especially with the marketing strategies gaming. Virtual Reality (VR) headsets used in research laboratories in the 90s have become one of the technologies accessible to society within two decades. Accordingly, the virtual environment, which was questioned through the concepts of simulation, representation, and reality, started to be questioned through the sense of existence with the increase in experiences in the virtual world. While the sense of presence in these environments is being studied through the definition of reality in terms of cognition, perception and ability/ skill issues have started to gain importance, especially for design-oriented research areas.

Virtual reality technologies can potentially improve spatial ability and provide spatial awareness through immersive and interactive experiences. In this context, it is crucial to investigate the concepts of spatial abilities and spatial presence and the relations of these concepts in the virtual reality environment within the scope of cognition and game development matters. Virtual environments provide a unique opportunity to study spatial capabilities because of their ability to manipulate objects in a controlled and configurable environment.

While behavioral science has been being studied in the context of design cognition in relation to the design process, design thinking, and design education, it has started to come to the forefront concerning spatial cognition in game design research in recent years. Game design in virtual environments is a multidisciplinary field. The production of virtual spaces in game design is directly related to architectural design. The production of this environment includes different approaches in terms of architectural methods. Architectural spaces are designed within the framework of the game's qualification/essence and needs. As the study of developments in VR games occurs in multidisciplinary areas, it can potentially reveal unexplored spatial relationships from both cognitive and architectural frameworks. The measurement of the spatial quality of the games developed in this context is also related to the spatial presence matters. The created environment can be transformed through the concept of presence and the game environment can be developed to support this.

This study examines the trajectory of virtual reality environments in the context of spatial cognition research through a systematic literature review methodology. The state of the dual relationship between spatial ability and

spatial presence in VR game environments is examined using data mining methods. Revealing the fields and methods of researching the relationships is essential to identify gaps in the field and potential future research areas. The relationships of the resulting literature data will be mapped and visualized, and research trajectories will be represented on a diagram. The visualization of literature data will serve as input for future studies at the intersection of architecture, virtual reality, gaming and spatial cognition.

Table 1: The structure of search terms identified from the literature.
(Source: authors)

Table 1. Structure of search terms

domain	independent variable	dependent variable	intervention	targered subskills
design	diff. media types	presence	game development	spatial visualization
cognition	dif. mediated environment	immersion	SP test development	spatial orientation
education	gender	cybersickness	HMD vs. Desktop	spatial relation
gaming	game experience	enjoyment	diff. SP Tests	perspective taking
	sound & video quality	interaction time	diff. media types	navigation
				mental imagery

2. THEORETICAL BACKGROUND

2.1. Virtual Environments

“Virtual” is typically defined as an adjective that suggests something is almost accurate or considered valid. The current definition of virtual reality (VR) is an artificial environment, experienced through sensory stimuli provided by a computer. This definition can be applied to various activities. Still, modern VR typically refers to experiences that take place while the user is donning a head-mounted display or headwear (Coyne et al., 2019). In computing, virtual objects are generated to mimic natural objects found in the physical world. Virtual environments are computer-generated representations of either real or imaginary worlds. These digital environments are designed to replicate the appearance and behavior of physical environments, allowing users to interact with them as they would interact with the real world. Virtual Environment (VE) delivers more precise and comprehensive spatial information than

previous virtual environments, such as computer screens and augmented reality settings. This technological innovation may enhance viewers' spatial awareness, resulting in more precise mental representations.

The use of virtual reality technology has expanded across various fields, including entertainment (Arrighi et al., 2021), gaming (Seibert & Shafer, 2017; Toth et al., 2020; Roij, 2021), education and learning environments (Chang et al., 2017; Bilgin & Thompson, 2021; Breves & Stein, 2022), and military training (Bhagat et al., 2016). These domains, variables, and interventions can be examined in Table 1 below. Virtual reality allows users to experience situations that may be dangerous, costly, or unfeasible to experience in real life. This technology can simulate medical procedures, military training exercises, or even travel to remote or inaccessible locations. For instance, VR can provide a realistic simulation of an operation or take users on a virtual trip to a distant location.

2.2. The Development of Headsets

A virtual reality headset is a new form of human-machine interaction that transcends the keyboard, mouse, and even the touch screen. With the developments of Oculus Rift headsets, instead of relying on a mouse or analogue stick to control your view in a game, the head tracker continuously analyzes the player's head movement and uses it to control the view. This creates a completely natural method of observing the environment, a crucial element of immersion (Desai et al., 2014).

Google Cardboard, Google Daydream, Oculus Quest 2, and HTC Vive are virtual reality headsets. To enhance the immersion and provide place illusion as Slater mentioned in 2009, the headset should provide high-quality computer-generated visual data and precise head and body tracking. In March 2014, Facebook announced Oculus and released Oculus Rift in 2015 (Meta, n.d.). HTC Vive headset and community were awarded in 2015 when they just release their first headsets (HTC VIVE, 2015). Recent advancements in video card technology have made it possible to create VR headsets with high-resolution visual displays (Coyne et al., 2019). For instance, Meta recently released an update for their headsets that can identify your hand even when the remote controller is disconnected. These developments lead to behavioral studies in VR Environments.

2.3. Spatial Ability Studies in VR

Spatial skills refer to a range of cognitive functions that allow individuals to comprehend, remember, and manipulate spatial information and relationships

in space. According to Gardner (2011), spatial skills are crucial for successfully managing cognitive tasks, such as imaging and reasoning about changes in spatial positions.

These skills are very crucial for many domains and occupations. The former studies that investigate spatial ability in the VR environment focused on navigation and wayfinding (Chen, 1995; Areke et al., 2022), perspective-taking ability (Chang et al., 2017), spatial visualization (Guzsvinecz et al., 2022), mental cutting (Chang et al., 2017), compatibility and the possibility of teaching spatial abilities (Ben-Zeev et al., 2020).

2.4. Spatial Presence Studies in VR

The sense of occupying a virtual space while mentally being a part of the virtual world might be described as "presence" (Cummings & Bailenson, 2015). The immersion in the Virtual Environment (VE) may result in presence, defined as a feeling of "being there" (Slater et al., 1994). Although presence may be studied in three subcategories: physical presence (spatial presence), self-presence, and social presence (Lee, 2004), we concentrated on spatial presence.

Coxon et al. investigate the link between spatial ability and spatial presence by using a computer-mediated environment and HMD in 2016 and found that self-report measures were associated with spatial presence, while objective testing was not, as Hartmann et al. clarified while developing SPES Questionnaire in 2016.

2.5. Behavioral studies in VR

To investigate the influence of the surroundings or intervention on behavior, researchers prefer to set up a simulation to avoid losing money (Shwebel et al., 2008) or because it may be difficult to control outside the lab (Ledoux et al., 2013). Mockups, sketches, photographs, models, and immersive virtual environments (IVEs) are examples of potential simulations which can be controlled environmental by manipulation examples (Neo et al., 2021).

Researchers may immerse individuals in fictitious environments and explore their reactions to controlled environmental alterations with VR. The benefits of virtual reality as a tool for social science research were anticipated by Blascovich and colleagues as early as 2002.

Behavioral research, such as investigating avoidance behavior (Binder and Spoormaker, 2020) and diagnostic assessments are conducted in a virtual reality environment Maneuvrier and Westermann studied whether personal characteristics influence the perception of presence in virtual reality (2020). There are diverse perspectives on gender factors in terms of VR game

experiments. Although some researchers contend that gaming experience and geographical presence have no correlation and no impact (Bilgin & Thompson, 2022), others have shown the effect via their trials.

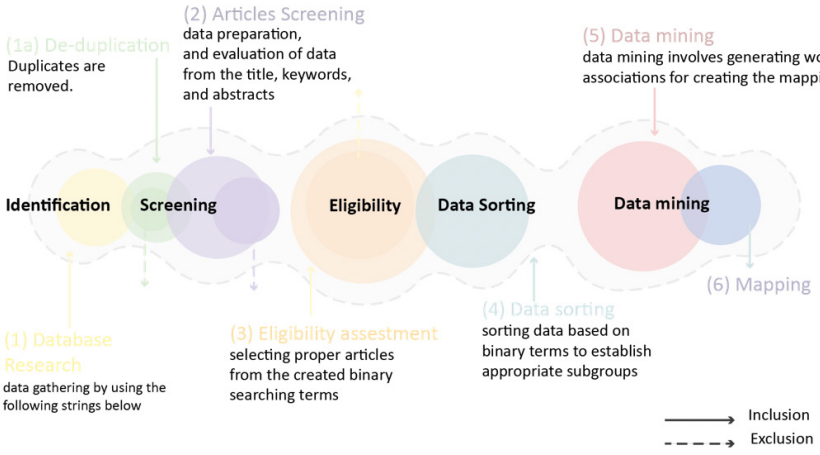


Figure 1: The phases of the cross-disciplinary evaluation
(Source: authors)

3. METHOD

To reveal the trajectories in the literature, the cross-disciplinary evaluation method was adopted as co-word mapping via data mining (Yazar&Uysal,2017; Yakut & Kavakoğlu, 2022). The study contains six phases, (1) identification, (2) screening, (3) eligibility assessment, (4) data sorting, (5) data mining, and (6) mapping. High-order databases Scopus and Web of Science are used for data gathering by using the following strings below which are divided into notions. The reference management software Zotero was used to re-organize all selected citations during the screening phase while(2) data preparation, selection and evaluation from the title, keywords, and abstracts. Eligibility assessment covers selecting proper articles from the created binary searching terms and after this phase, the data is sorted on binary terms to establish appropriate subgroups. According to the revealed subgroups word associations are generated via data mining to create the ingredients of mapping. Keyword analysis and data mining techniques highlighted the discrepancies and absences in the relevant literature on the spatial ability, spatial presence and VR gaming phrases. Figure 1 depicts the procedures for the structure of the study.

3.1 Search Strategy: Identification and De-duplication

As shown in Table 2, we organized our search phrases into three string categories that correspond to the different facets of our study issue. In general, search phrases were used for titles, keywords and abstract fields, and the largest date range allowed by each database was utilized. Where feasible, only English results were returned in search results. A total of 55 items were collected, 16 articles gathered from Scopus and 39 articles from Web of Science for phase 1 as an identification part. 16 articles have been removed in the de-duplication so far.

As shown in Figure 2, Search 1 contains string 2 and string 3 which will show relations between spatial presence and VR gaming, Search 2 contains string 1 and string 3 which will show relations between spatial ability and VR gaming,

Search 3 contains all the strings and interdisciplinary areas for VR game industry. Figure 2 also illustrates the number of published articles in two databases in 2023 of March proportionally with the diameter of the circle according to database scanning of concepts.

Table 2. the strings combination for databases.

		keywords	synonyms ← or →	broader terms	narrower terms
← and →	string 1	spatial ability	spatial skill spatial aptitude	spatial capability spatial performance	spatial orientation spatial relation mental imagery mental rotation
	string 2	spatial presence	presence telepresence**		
	string 3	VR game	virtual reality game artificial reality game	VR game environment gaming environment virtual worlds virtual environment	

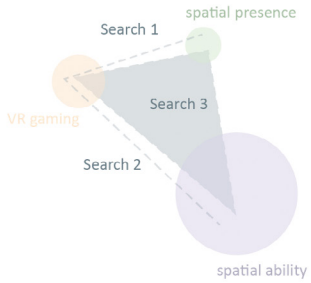


Table 2: The strings combination for databases (left)

Figure 2: The illustration of the number of articles found in searches in Web of Science (right). *(Source: authors)*

3.2 Screening and Eligibility

In the word group queries conducted on the databases, 33 articles were eligible after 7 articles were removed due to the irrelevant research areas. This elimination part contains subjects such as the medical and psychological studies. 33 articles that remained are 23 from Web of Science (WoS), and 10 articles from Scopus. These articles were published between 1996 and the present. Most of them are associated with engineering, technology, psychology, and architecture. These articles were stored in an Excel file with the year, title, keywords, and abstracts, and then these two databases' articles were merged.

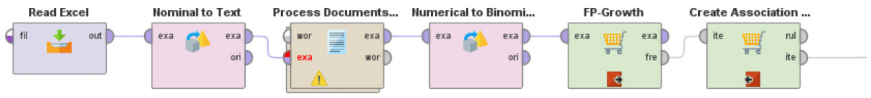


Figure 4: The steps of the process of the association rules in Rapidminer.
(Source: authors)

WOS database contains more articles about the subject than Scopus, respectively 23 and 10. In the past five years, fewer articles have been written about this topic, 20 articles before 2018 and 13 articles after 2018.

3.3 Data Sorting and Data Mining

We begin by uploading the articles collected into the Rapidminer data mining application with the Read Excel command which provides scanning data from the Excel file and sorting them through the frequency of occurrence in the abstracts. In the third step, depicted in Figure 4, the data are pre-processed. This phase may consist of data purification, tokenization, stop word removal, and stemming. These stages aim to reduce noise in the dataset and convert it to a more functional format for data mining operations. In order to conduct a co-word analysis to provide data sorting, it is necessary to establish an association rule. The association rule is a method for identifying patterns of relationship between words or phrases in a corpus of text (Yakut & Kavakoğlu, 2022). In the fifth step, Rapidminer analyses extracted words from the Excel table to find significant patterns. The application found 172 significant association rules by using FP-Growth which is an algorithm to find out common patterns determined by pattern fragment growth. In the association rules, the highest and the most meaningful word combinations are set as rules to investigate the literature to reveal trajectories by authors' selection.

Table3: Association rules comparison chart and overall support values through decades *(Source: authors)*

association rule no	term groups	support values	90's	00's	10's	20's
r1	presence - virtual - environment	0.727	1	4	13	5
r2	presence - virtual - spatial	0.697	1	4	12	4
r3	presence - virtual- results	0.545	1	2	8	3
r4	presence - environment - spatial	0.545	1	4	11	4
r5	presence - environment- result	0.515	1	2	9	3
r6	presence - virtual- reality	0.485	0	0	10	5
r7	presence - virtual - stud*	0.424	0	3	8	5
r8	presence - virtual - participants	0.424	0	3	10	1
r9	presence - virtual - performance	0.394	0	3	10	1
r10	presence - environment - reality	0.394	0	0	9	5
r11	presence - virtual - environment - result	0.515	0	0	9	5
r12	presence - virtual- environment- spatial	0.545	1	4	11	4
r13	presence - virtual- environment - task	0.364	1	4	6	0
r14	presence - virtual - environment - participant	0.364	0	3	8	1
r15	presence - virtual - spatial - performance	0.333	1	4	5	0

3.4 Review: Mapping the Trajectories

The support metric quantifies the frequency in a given set of items that appears in a dataset. Therefore, the greater the support value of an item set, the greater the occurrence of that item set in datasets. Moreover, the lift metric indicates not only the frequency in which an item set is viewed, but also its uniqueness relative to other item sets. We will mainly focus on support and lift values to compare the rules in the given data sets to find out trajectories about the cognitional studies in VR environments to reveal the trends and possible gaps in the literature containing connections between VR gaming environments and spatial cognition. If we examine Table 3, we find there may be interesting connections and tendencies among the three keywords "presence," "virtual," "environment" and "spatial." "Presence" and "virtual" are frequently associated with virtual reality and augmented reality technologies. In addition to that, phrasal co-words such as participant, result, performance and study are more prevalent. Based on this, we can conclude that investigations in this

field are conducted with a study and an endeavour is made to contribute with participant data.

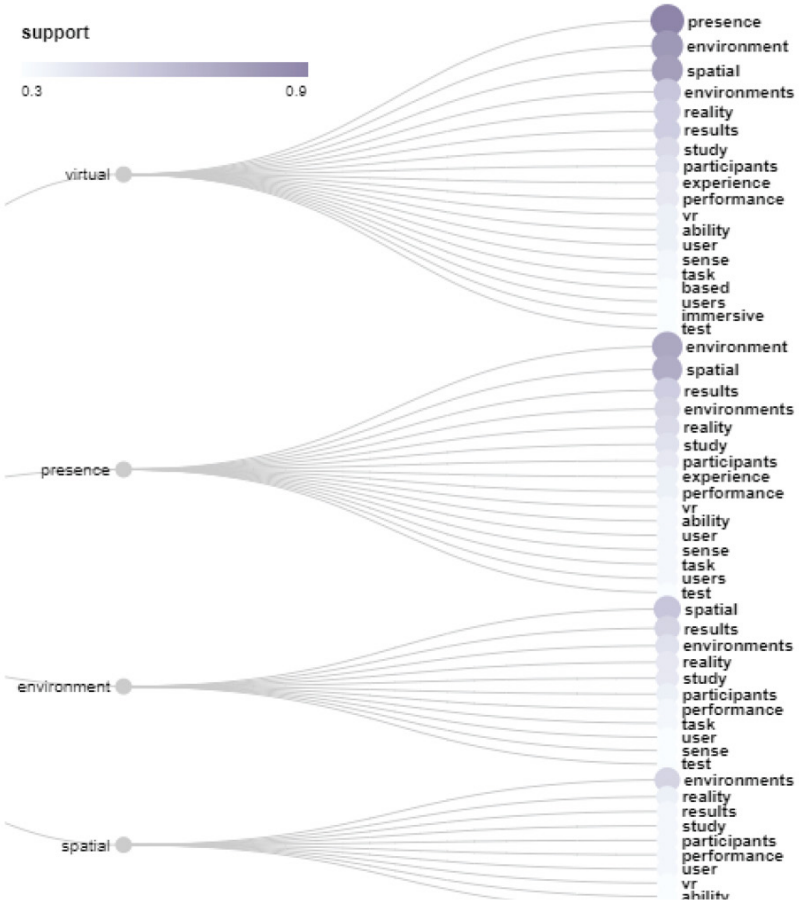


Figure 5: Linear triple co-word analysis *(Source: authors)*

Within these collections, the 15 most frequently used rules are listed according to Table 3. The relationship between all the concepts, r6, and r10 appears to have been the subject of more articles in recent years. It can be said that these concepts are more popular than the others. In the table, "result" has a significant percentage, it can be argued that researchers reveal their experiment results in the abstract to give information to its readers.

In general, "task" and "performance" are used together, but in the Table 3, there is a slight difference between these notions. It can be said that some researchers conducted an experiment with different purposes rather than

measuring the task performance. Although not included in the table because the support value is low, the terms “virtual” and “test” appeared together in 33% of all articles. In investigations, it may be advantageous to administer tests to determine the intervention’s effect.

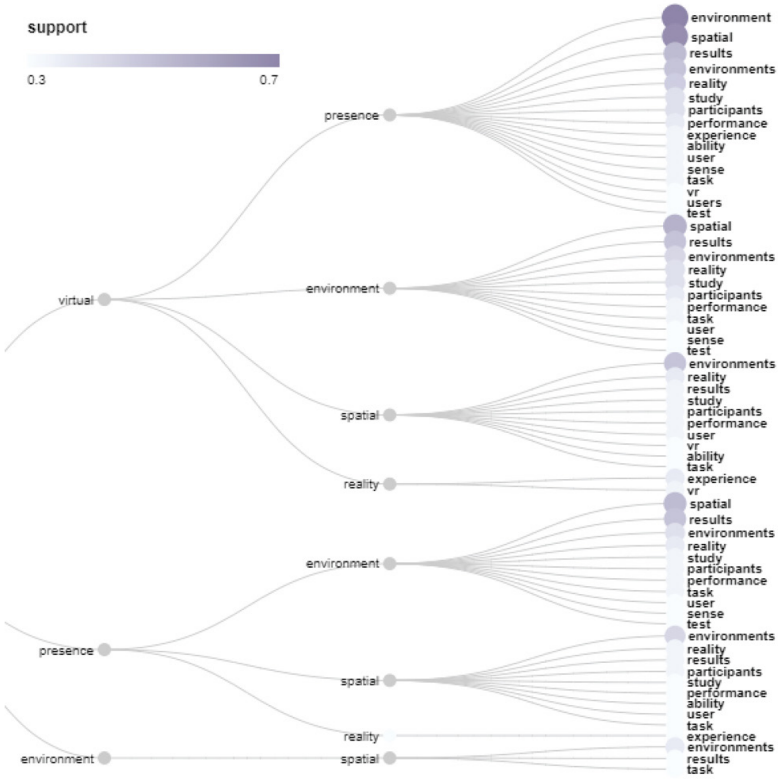


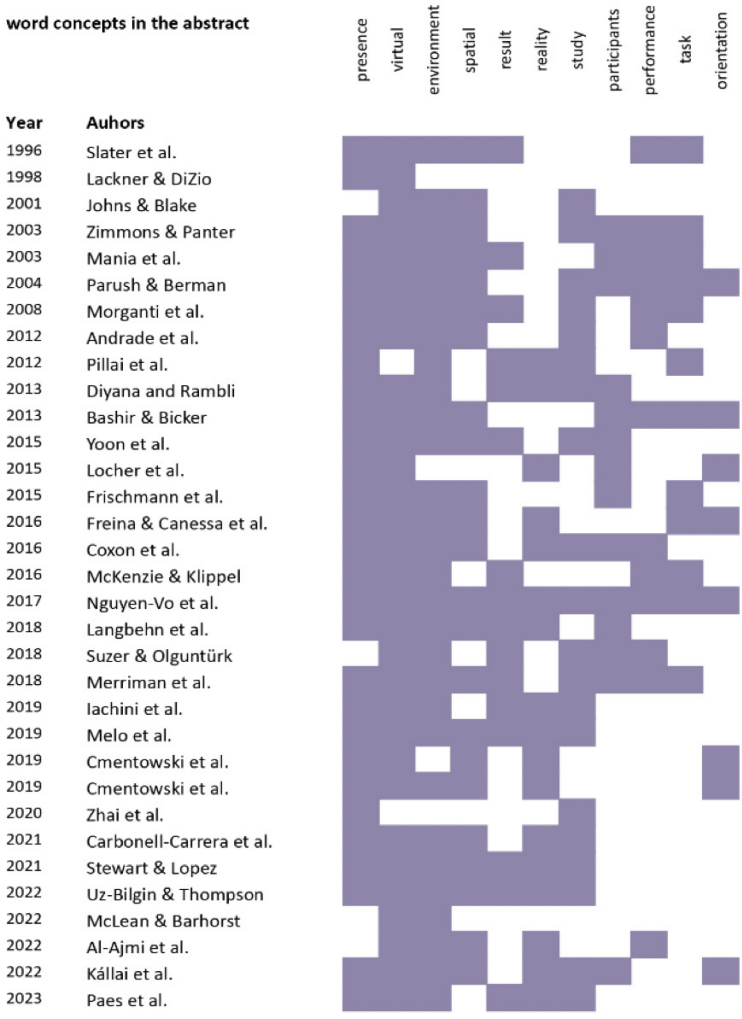
Figure 6: Linear triple co-word analysis *(Source: authors)*

If we look at the binary and triple co-word analysis In the Figure 5, 45.5% of all articles include “virtual-participant”; 42.4% include “virtual-experience” and “virtual-performance”; 39.4% include virtual-user, 36.4% include “virtual-sense and virtual-task”; and 33.3% include “virtual-immersive” and “virtual-test” groups. Based on this, we believe it is possible to assert that there are experience-based tasks in virtual environments and that users’ performance on these assessments is evaluated.

In the final steps of the co-word analysis, the significant associations begin with virtual and presence with other triple combinations. For instance, in Figure 6, the “virtual - presence - environment - spatial” combination takes

part together in the %50 of the scanned articles. Unlike the last notion which is spatial for the aforementioned example, “virtual - presence - environment - test” only takes part together in the %30 of the articles. The notion of “reality” has been used more through the years. According to Table 4, the concept of “presence”, “virtual” and “environment” are used together, and “spatial” accompany these notions. It has been observed that the concepts of “participants”, “performance”, “task” and “orientation” decreased through the years. This may show that the method of the investigation might change. From the beginning of the 2000s until the 2020’s beginning, researchers might prefer to study with participants and measure task performance.

Table 4: Word mapping in the abstract *(Source: authors)*



4. RESULTS

The link between spatial abilities and spatial presence holds significant implications for research and practical applications related to game design and other use of virtual environments. The development of this game industry incorporates a variety of architectural manufacturing processes. It is essential to disclose the disciplines and methodologies of relationship research to identify investigation gaps and prospective future research topics. The findings of this research can serve as a foundation for future studies at the intersection of architecture, virtual reality, gaming and spatial cognition.

Based on the data obtained through data mining, the decade of the 2010s was the golden period of research in this field. This result may depend on technological advancements in headsets and technological achievements. Because of Meta and HTC releasing headsets with high render quality, the majority of researchers use these brands' headsets due to their efficacy and pricing.

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