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A Systematic Review of Cognitive Ergonomics and Safety: General Trends and Application Areas

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Anahtar Kelimeler

Bilişsel Ergonomi
Literatür taraması
Zihinsel iş yükü
Nöro-ergonomi

Graphical/Tabular Abstract (Grafik Özet)

This study offers, constructive analyses of scientific publications on CE, by combing the literature and summarizing the current knowledge in a cogent way. As a result, it is predicted that CE activities will be used to solve cognitive problems in more and more areas and will take their place soon especially in Metaverse application and software. / Bu çalışma, literatürü tarayarak ve mevcut bilgileri özetleyerek, bilişsel ergonomi (BE) ile ilgili bilimsel yayınların yapıcı analizlerini sunmaktadır. Sonuç olarak BE etkinliklerinin giderek daha fazla alanda bilişsel sorunların çözümünde kullanılacağı ve yakın zamanda özellikle Metaverse uygulama ve yazılımlarında yerini alacağı öngörülmektedir.

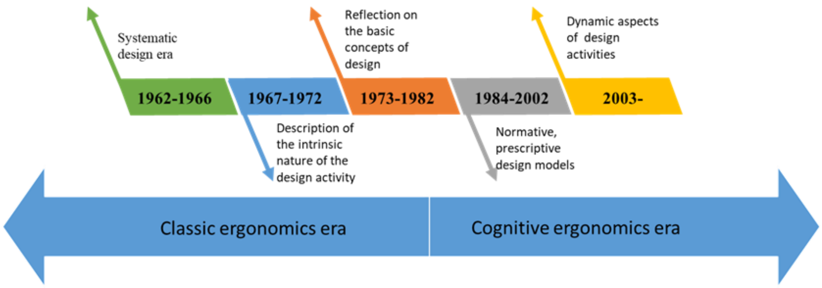

***Figure A**: The evolution of cognitive ergonomics / **Şekil A:** Bilişsel ergonominin evrimi*

Highlights (Önemli noktalar)

- *Cognitive ergonomics has a wide application area from aviation to health. / Bilişsel ergonomi havacılıktan sağlığa kadar geniş bir uygulama alanına sahiptir.*
- *Cognitive ergonomics studies can be classified into 4 main groups with 13 sub-groups. / Bilişsel ergonomi çalışmaları 13 alt grupla 4 ana gruba ayrılabilir.*
- *Neuroergonomics and cognitive ergonomics have a lot of common attributes. / Nöroergonomi ve bilişsel ergonominin pek çok ortak özelliği vardır.*

***Aim (Amaç):** The main aim of this study is to reveal the studies on Cognitive Ergonomics (CE), determine general trends, show the gaps of the literature. / Bu çalışmanın temel amacı Bilişsel Ergonomi (BE) ile ilgili yapılan çalışmaları inceleyerek, literatürün genel eğilimini belirlemek, literatürdeki boşlukları ortaya koymaktır.*

***Originality (Özgünlük):** The literature review on CE is quite limited. The most comprehensive review of the CE literature between 1974-2021 was conducted. / BE ile ilgili literatür araştırması çalışmaları oldukça sınırlıdır. Bu çalışmada 1974-2021 yılları arasında BE literatürünün kapsamlı incelemesi yapılmıştır.*

***Results (Bulgular):** 1958 papers identified from Electronic Databases, 254 of them were selected. The PRISMA technique was used for the review process. As a result, CE studies were classified into 4 main groups with 13 subgroups. / Elektronik Veritabanlarından belirlenen 1958 makaleden 254'ü belirlenmiştir. PRISMA tekniği, BE literatürünün analizi için kullanılmıştır. Sonuç olarak BE çalışmaları 13 alt grupla 4 ana gruba ayrılmıştır.*

***Conclusion (Sonuç):** It is predicted that CE activities will be used to solve cognitive problems in the rapidly digitalizing world and will take their place soon especially in Metaverse application and software. / Hızla dijitalleşen dünyada, BE ile ilgili etkinliklerinin bilişsel sorunların çözümünde kullanılacağı ve yakın zamanda özellikle Metaverse uygulama ve yazılımlarında yerini alacağı öngörülmektedir.*

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Abstract

The primary purpose of this study is to reveal the studies on Cognitive Ergonomics (CE), determine general trends, show the gaps and extract new knowledge from the body of the literature. Ergonomics evolved from classical to physical and CE. The literature review on CE is quite limited. Thus, the most comprehensive review of the CE literature between 1974-2021 to provide an original perspective and extend what is known through analysis, modeling and introduction of new theories was conducted. 1958 papers identified from Electronic Databases, 254 of them were selected and included in the analysis. The PRISMA technique was used for the systematic reviews of CE literature with the statistical evidences and detailed discussions. As a result, CE studies were classified into 4 main groups with 13 subgroups. This study offers, constructive analyses of scientific publications on CE, by combing the literature and summarizing the current knowledge in a cogent way. Thus, a basis to enhance future applications in CE was provided. It is predicted that CE activities will be used to solve cognitive problems in more and more areas in the rapidly digitalizing world and will take their place soon especially in Metaverse application and software.

Bilişsel Ergonomi ve Güvenliğin Sistematik Bir İncelemesi: Genel Eğilimler ve Uygulama Alanları

Makale Bilgisi

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Öz

Bu çalışmanın temel amacı Bilişsel Ergonomi ile ilgili yapılan çalışmaları ortaya koymak, literatürün genel eğilimini belirlemek, literatürdeki boşlukları ortaya koymak ve literatürden yeni bilgiler edinmektir. Ergonomi bilimi yıllar içinde klasikten fiziksele ve bilişsel ergonomiye doğru evrilmiştir. Bilişsel Ergonomi ile ilgili olarak yapılan literatür araştırması çalışmaları oldukça sınırlıdır. Bu çalışmada orijinal bir bakış açısı sağlamak ve güncel literatürü analiz, modelleme ve yeni teorilerin tanıtılması yoluyla genişletmek için 1974-2021 yılları arasında bilişsel ergonomi literatürünün kapsamlı incelemesi yapılmıştır. Elektronik Veritabanlarından belirlenen 1958 makaleden 254'ü seçilerek çalışmaya dahil edilmiştir. PRISMA tekniği, bilişsel ergonomi literatürünün istatistiksel kanıtlar ve ayrıntılı tartışmalarla sistematik olarak gözden geçirilmesi için kullanılmıştır. Sonuç olarak bilişsel ergonomi çalışmaları 13 alt grupla 4 ana gruba ayrılmıştır. Bu çalışma, literatürü tarayarak ve mevcut bilgileri özetleyerek bilişsel ergonomi ile ilgili bilimsel yayınların yapıcı analizlerini sunmaktadır. Böylece, bilişsel ergonomide gelecekteki uygulamaları geliştirmek için bir temel sağlanmıştır. Hızla dijitalleşen dünyada, bilişsel ergonomi ile ilgili etkinliklerinin giderek daha fazla alanda bilişsel sorunların çözümünde kullanılacağı ve yakın zamanda özellikle Metaverse uygulama ve yazılımlarında yerini alacağı öngörülmektedir.

1. INTRODUCTION (GİRİŞ)

Cognition refers to mental processes such as remembering, processing and transforming information [1]. Cognitive processes are examined in three main groups: sensation, attention and working memory. The feeling is the perception of stimuli obtained through sense organs and caution means focusing perception on a specific source of stimulation. Memory refers to the process of storing information. Memory is divided into short-term memory, long-term memory and semantic memory,

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where cognition is stored in the individual's memory.

The operators must perceive, process, comprehend and react to the warnings and information given by the systems used in stressful occupations. Considering that most of the accidents in manufacturing, aviation, health and many other sectors are caused by human-system interaction, cognitive ergonomics aims to reduce mental fatigue, investigates human errors and finds ways to avoid these errors. In this context, it is clear that cognitive ergonomics is one of the essential tools in preventing accidents. Cognitive ergonomics has been applied in different fields, especially electronic devices, software, interface and instrument panel design.

Different types of human-machines or human-computer interaction are likely to emerge with the digitalizing world. The application areas of cognitive ergonomics include determining the mental workload parameters of blue-collar personnel in the manufacturing industry, evaluating the cognitive load of a computer engineer working at a desk and measuring the mental load experienced by a student in distance education. The primary purpose of this study is to examine the studies on cognitive ergonomics to determine the general trends and show the gaps in the literature. As a result, this study conducted an extensive literature search on cognitive ergonomics. It has been observed that the literature research on cognitive ergonomics is quite limited and it has been determined that the most comprehensive study is done by Andrev et al. (1996) includes the articles between 1989 and 1996 [2]. The distinguishing aspect of this paper is that it presents most comprehensive literature review of cognitive Ergonomics. This study aims to create a standard definition of cognitive ergonomics, reveal new application areas and create a hierarchical structure for cognitive ergonomics studies.

The study is structured as follows: The second section introduces cognitive ergonomics with its essentials. In the third section, we explained our systematic literature review approach and a summary of statistical information about the studies in the literature. In the fourth section, studies reviewed are classified. The evaluation of the metaverse concept with cognitive ergonomics is presented in section five. The relationship between neuro-ergonomics and cognitive ergonomics is examined in section six and concluding remarks are given in the last section.

2. RESEARCH METHODOLOGY (ARAŞTIRMA METOLDOJİSİ)

In this study, articles published between January 1974 and December 2022 (including early access publications) were reviewed. Springer, Emerald Insight, CiteSeerX, Taylor Francis, Science Direct, Hindawi, and Google Scholar databases were searched with "cognitive ergonomics". The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was employed for the systematic review of cognitive ergonomics literature (please see Figure 1) [3].

Along with the "cognitive ergonomics" keyword, the research is detailed with twenty-four secondary keywords (please see Table 1). The first 100 titles for each term were analyzed. Secondary keywords were used to classify studies in the literature and the usage areas of cognitive ergonomics. 1958 studies were inspected in total, 467 studies were selected for analysis and 254 of them found to be related with our paper’s subject and they were included in this study. The number of studies reviewed with each keyword is presented in Table 1.

Table 1. Keywords and number of articles reviewed (Anahtar kelimeler ve incelenen makalelerin sayısı)

Secondary Key words	Number of publication reviewed	Secondary Key words	Number of publication reviewed
Aerospace	95	Measuring	13
Application	73	Military	51
Automation	45	Perception	11
Aviation	52	Performance	138
Design	20	Productivity	67
Environments	90	Psychology	91
Experience	53	Risk	47
HCI	208	Safety	60
Health	63	Training	87
Interaction	192	Transport	190
Interface	135	Workload	65
Learning	96	Neuroergonomics	16

The article selection procedure is shown in the PRISMA flowchart in Figure 1. The search yielded 1958 studies from the selected databases. During the first stage of evaluation, papers were assessed depending on their abstracts and duplication. Studies not emphasizing cognitive ergonomics in abstract and duplicate articles were removed from 1958 publications and 1491 papers were eliminated in total. Then, studies that do not refer to cognitive ergonomics in the conclusion section or examine cognitive ergonomics under a single section evaluated as "the unfocused studies on cognitive ergonomics". The unfocused studies on cognitive ergonomics (n=195) and papers that are not retrieved (n=18) were excluded. After excluding all these irrelevant papers in three steps, a total of 254 studies were left to be included in our research.

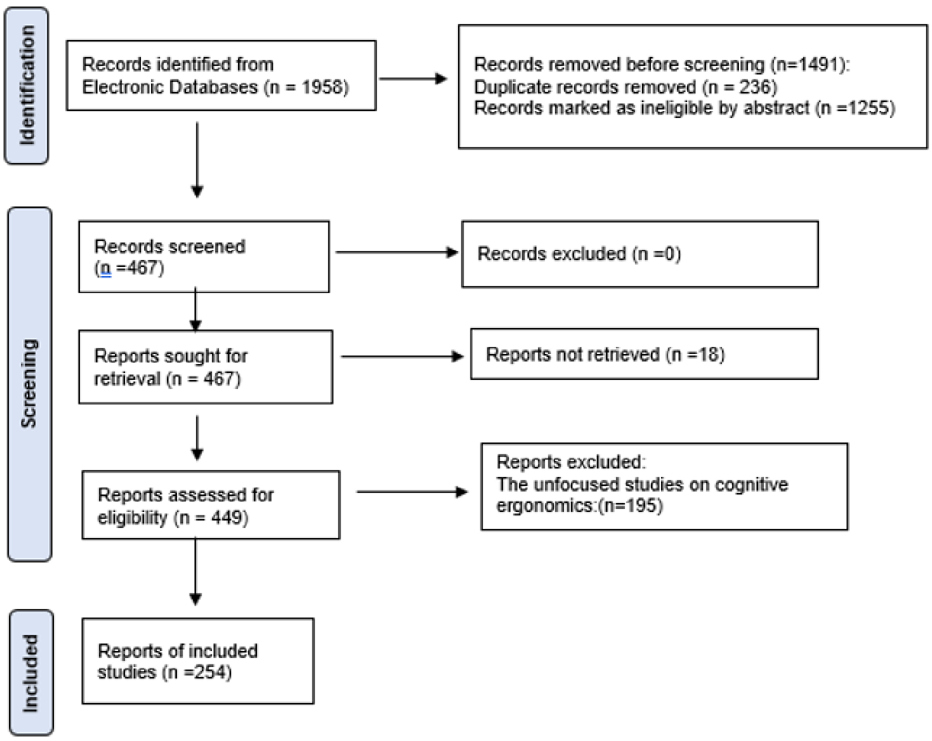

Figure 1. Flowchart for PRISMA protocol (PRISMA protokolünün akış şeması) [3]

3. RELATED WORKS (İLGİLİ ÇALIŞMALAR)

3.1. Cognitive Ergonomics and Respective Studies (Bilişsel Ergonomi ve İlgili Çalışmalar)

Physical and cognitive ergonomics have many similarities and differences. Classical risks, work quality and personnel safety parameters are examined in physical ergonomics. Posture, number of repetitions, vibration, dust, sound level, temperature and environmental factors are reviewed [4, 5]. Empirical research methods determine the physical demands of a job. Different analytical risk assessment methods have been developed for different risk types. There are various risk assessment methods which has revealed different findings. The risk assessment process includes identifying potential threats and assessing the degree of risk.

Cognitive ergonomics includes collaboration of human reliability engineering and psychology field. Risk analyses turns out to be more realistic with the touch of psychology in cognitive ergonomics, Thanks to risk analysis, cognitive ergonomics reveals the chain of events resulting in accidents. Accident anatomy allows individuals to understand how their actions contribute to business risks. On the other hand, the analysis of the casualties and faulty behaviors are emphasized in cognitive ergonomics.

There are also fundamental misconceptions about cognitive ergonomics, such as the user cannot handle defined mental workload or perform defined work, the user-friendly label is not given within a standard and cognitive expectations of users are considered same [6]. Considering purposes, cognitive ergonomics differs from physical ergonomics. There are four cognitive analysis goals in cognitive ergonomics, which are shortening interaction time, minimizing human error, shortening learning time and increasing user satisfaction [1]. The objectives of cognitive ergonomics are presented in Figure 2.

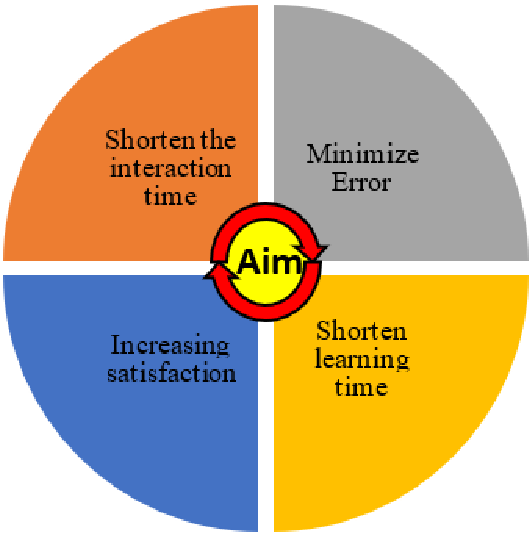

Figure 2. The objectives of cognitive ergonomics (Bilişsel ergonominin amaçları) [1]

Cognitive ergonomics is one of the three methods used to understand the work environment in workers' collaborative environments. Tasks and activities are analysed by using cognitive ergonomics. Tasks express the open side of the job, while activities express the way of dealing with the variability and complexity of the task [7].

Cognitive factors are related to mental processes such as motor response. Activities require cognitive effort as well as physical effort. Although cognitive and physical processes are considered separately, they are essential in balancing multidimensional work demands [8]. The main topics examined within cognitive ergonomics are analyzing and modeling cognitive tasks, decision making, presentation and visualization of information, mental workload, work stress, and collaborative aspects [9]. Factors determining workload in cognitive ergonomics are mental workload, decision making, performance, human-computer interaction, human reliability, job stress and training.

In a study, the relationship between physical task load and cognitive task performance was examined. When high-fit young men do eight minutes or less of physical activity, mental performance is not lost and they respond more quickly to auditory stimuli than to visual stimuli [10]. For this reason, cognitive ergonomics plays a critical role in determining task performance.

The results obtained in cognitive ergonomics are also valid outside the laboratory and generalized, that makes cognitive ergonomics stand out in real-life applications. [11]. Cognitive ergonomics deals with mental processes such as perception, memory and thinking in human and system interaction [8]. Cognitive task analysis helps to understand how people perform tasks using cognitive skills. The cognitive study analysis reveals the relationship between human mental processes and behaviors [12].

Cognitive abilities limit the physical skills. Cognitive performance decreases due to cognitive fatigue just as performance decreases due to physical fatigue. Physical performance increases when a physical action is repeated or learned as a skill and cognitive performance becomes a skill depending on repetition [13]. Light variation, limb and object movements inhibit efforts to keep knowledge active in cognition [14]. Sensible, meaningful sounds in environment impair perception, attention and the way of processing information. Warnings and signals must be distinguishable from audible sounds in the system and machine designs. [15]. In cognitive ergonomics, receiving perception in more than one sensory organ facilitates the processing of information and at the same time, cross-affective connections limit perception [16]. Designers should consider the cognitive load brought by cross-affective links [17].

Learning new skills and related information is a slow process for individuals in workplaces. However, long-term storage memory is unlimited and unique abilities can be acquired at any age [18]. In workplace, individuals use practical rules that result in acceptable solutions with little cognitive load [19]. Many parameters affect the success of cognitive skills in job. [20]. Determining decision support arguments, group work, developing a standard behavior and correcting wrong assumptions can be given as examples of the application areas of cognitive ergonomics in the workplace. It takes time for individuals to specialize in their fields of work by gaining experience. Expertise means performance in tasks that require knowledge and skills. Experienced personnel's performance is evident in some regions of cognition [21]. For a new employee, it takes a certain amount of time for daily tasks to be reflex. It is more efficient for workers to work in their core expertise rather than perform additional tasks requiring other skills. Several factors make it difficult for workers to show the desired performance level. Simultaneous multitasking, noise and interruptions in work are examples of these factors. These factors can cause work accidents. Thus, it is vital to give importance to cognitive ergonomics in terms of occupational safety. Especially the physical and mental needs of the workers in the heavy and dangerous works should be met [22]. The working environment is not always stable. Moving equipment and time pressure in dynamic environments impair situational awareness. Situational awareness consists of three levels. These are perception, comprehension and projection [23]. Cognitive ergonomics improves operator skills by reducing cognitive load and replacing errors. System users interacting with humans should be optimally matched to their cognitive abilities [24].

Mental workload is one of the main application areas of neuro-ergonomics. Employees should be given work that is compatible with their abilities. Cognitive ergonomics is indispensable for complex designs. Cognitive ergonomics practices affect work stress and workplace productivity [25]. Human-computer interaction studies on cognitive ergonomics started in the 1980s with coloring in visual interfaces for laboratories, models for designers, task analysis for information gaps and text display editor applications [26]. Interface design was considered as art until the 1990s. After this period, two different approaches e.g. formal and informal were applied to interface design. These two approaches include Command Language Grammar and Cognitive Complexity [27]. Cognitive ergonomics provide the perception of the information presented to the user through interfaces. Cognitive ergonomics plays a vital role in human-machine interaction.

Cognitive ergonomics is used in all disciplines with human-machine interaction. Especially in the health sector, human-machine interaction is standard and users make critical decisions through this interaction. Lawler (2011) examined the effects of cognitive ergonomics and information technologies on health, [28]. Different industries in which cognitive ergonomics are applied are presented in Figure 3.

Cognitive ergonomics is essential for decision-makers. It has been used as an additional tool in the multi-criteria decision-making process to facilitate the decision-making process [29]. Increasing product comfort depends on the understandable and accessible usage of products with a low cognitive load. A fuzzy-based decision-making technique was developed by Mohanty et al to compare the products' ease of use [30]. Benmoussa et al. (2019) used AHP to prioritize cognitive ergonomics factors in the interface evaluation of information systems [31]. A cognitive model related to the decision-making process of operators performing the monitoring task was created by Vicente et al [32].

Design activities include intense cognitive activity. Defining the cognitive activities of the designer will enable them to overcome the difficulties in both software design and system design. The cognitive activities of the software designer are classified as comprehensive purpose analysis, quick solution search, solution evaluation and continuous evaluation of personal procedures at the early design stage. The disadvantages of cognitive design activities depend on selecting the solution, comparing alternatives, the rapid solution evaluation, insufficient user participation and poor design logic [33]. It is a more accurate approach to model cognition as an interaction between meanings rather than an information processing model in directing individuals' activities towards specific goals [34]. Depending on the development of technology, ergonomics was evolved from classical ergonomics to physical ergonomics and cognitive ergonomics in the early 1980s [35]. In the last fifty years, individual design activities have been handled with different cognitive perspectives. The evolution of cognitive ergonomics is presented in Figure 4.

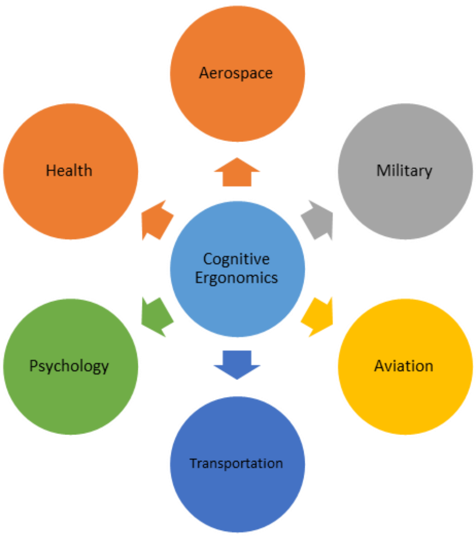

Figure 3. Application of cognitive ergonomics in various industries (Bilişsel ergonominin çeşitli endüstrilerde uygulanması)

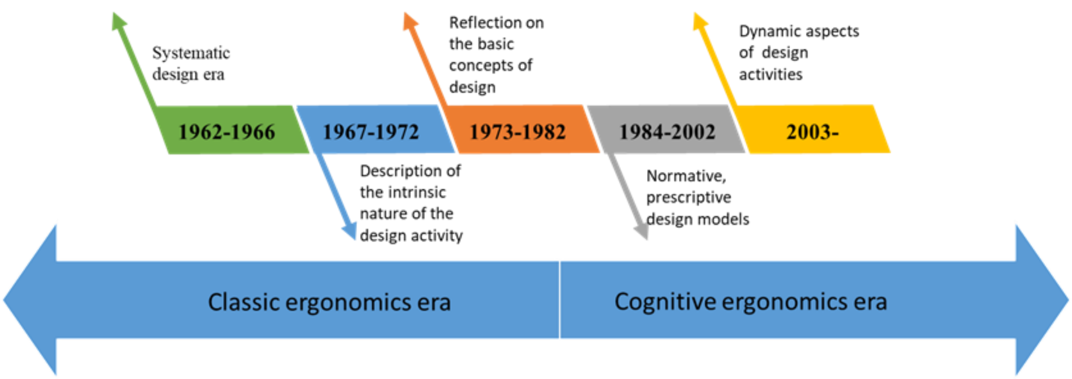

Figure 4. The evolution of cognitive ergonomics (Bilişsel ergonominin evrimi)

Whether cognitive ergonomics can be accepted as a separate discipline or not has been discussed and researchers have raised some doubts [36]. Studies on the process and methodology of cognitive ergonomics in the literature have allowed cognitive ergonomics to emerge as a new discipline.

Examples of these studies are Fason (1991), Venda (2000), Blomé et al. (2006), Bisan (2007, 2008) and Eraslan (2010) [37] [38] [39] [40] [41] [42]. Human-computer interaction promotes the development of interaction between the human mind and information systems. Socio-technical factors are another parameter to be considered in human-computer interaction. [37]. Three fundamental laws of cognitive ergonomics were expressed by Venda (2000). In the first law, any cognitive strategy is defined as a function of work efficiency related to the work factor. Each cognitive task is performed using several cognitive strategies in the second law. In the third law, work efficiency changes depending on the learning processes [38]. An interactive ergonomic guidance system based on cognitive ergonomics was developed by Blomé, et al. (2006). It has been determined that the instructions supported by the text and visual elements are more effective than the classical ones in terms of usage and comprehensibility [39]. The approaches of cognitive ergonomics to job analysis were examined by Bisantz (2007). The studies examined were divided into two groups as data collection and analysis studies [40]. Work-centered applications of cognitive ergonomics were also investigated by Bisantz (2008) [41]. Cognition includes perception, storing and remembering information, processing information and using the senses. Cognitive activities are as tiring as physical activities [42].

The cognitive performance of individuals during they are running on the field was tested by Blakely et al. (2016) to determine whether cognitive performance changes depending on physical performance. Cognitive load increased after running regardless of terrain [43]. The relationship between balance and the mental workload was examined by Cullen and Agnew (2016). It has been reported that cognitive strain may increase when balancing activity becomes difficult [44]. The estimation of subjective recovery times for conditions requiring variable physical and mental processing was examined by Ye and Pan (2016). Cognitive performance has been reported to decrease after brisk work but increase after personal recovery. Considering the studies of Blakely et al. (2016), Cullen and Agnew (2016), and Ye and Pan (2016), it can be stated that there is a relationship between cognitive ergonomics and physical ergonomics where physical condition affects cognitive status [43-45].

The mental workload in decision-making and monitoring tasks was examined by Liu and Wicken (1994). It has been reported that the reactions are sensitive to the presence of perceptual/cognitive workload, but when the behaviors become automatic, the responses also turn into reflexes [46]. Roth et al. (1992) examined mental demands and simulation errors [47]. Barriers to the development of cognitive ergonomics were discussed by Darses (2001). Cognitive ergonomics remains in the field of research rather than practice. The findings of cognitive ergonomics stay in university or company laboratories and do not emerge as practical tools. It has been reported that this circumstance is the biggest obstacle to cognitive ergonomics [48].

All industries affect each other. A technology developed for one sector is used for different industries. Similarly, knowledge transfer between socio-technical systems can provide many conveniences. Complex systems within the same cognitive domain were compared by St-Maurice and Burns [49]. It is crucial to examine the dynamics of cognitive control in complex systems where operators have partial control. Unlike laboratory studies, dynamic cognitive modes and the distribution between modes vary according to job requirements in real life. To the extent that human cognition can adapt to mode change, it has an effective information transfer for systems with dynamic control. Hoc and Amalberti investigated the dynamics of cognitive control to achieve the target performance level in mental mode changes [50]. Activities were prioritized in cognitive control processes by Bodin and Krupenia [51]. The data interface was integrated with the mental model by examining the focus of information processing strategy by Goh and Coury [52]. The history of cognitive ergonomics and its potential future uses were reviewed by Long [53].

As the systems used in information technology develops, the interaction between information technologies and people shifts from physical systems to logical systems. In terms of human-computer interaction, cognitive ergonomics is a science that develops system design by considering individual and cognitive system characteristics. Cognitive ergonomics allow the development of new methods depending on technological development and meets the needs of today's information society. The relevant field of cognitive ergonomics today is logical systems [54]. Cognitive load does not change only with the information perceived through the senses. It is also influenced by collaboration with mission stakeholders. Sharing the cognitive load contributes positively to the physical ability of the individual [55]. Task analysis of complex systems was made by Naikar et al. and these systems were examined with cognitive job analysis [56]. New system designs were also subjected to cognitive analysis by Bisantz et al. Emphasis is placed on the importance of cognitive research in creating large systems such as aircraft carriers and transport aircraft [57]. A new method of cognitive analysis for cost-effective systems engineering has been proposed by Elm et al. [58]. Cognitive analysis was used for reliable intersection designs by Cornelissen et al. [59]. Read et al. (2012) conducted a literature search on the design and applications of cognitive job analysis [60]. Stevens and Salmon used cognitive work analysis to evaluate the relationships between the engineering and urban design of pedestrian roads. It was determined whether the pedestrian paths met the design requirements [61]. Roth examined the usage of cognitive analysis methods in system analysis. It was informed that mental needs should be discussed in detail and that cognitive analysis is error-prone [62]. Militello et al. suggested using cognitive systems engineering to bring together mental needs and goals [63]. Human-machine automation is modeled by cognitive job analysis by Li and Burns [64]. Control task analysis in complex systems was examined by cognitive work analysis by Naikar et al. An application was made for early air control and warning systems in cognitive ergonomics [56].

Cognitive job analysis is also widely used for sociotechnical designs. However, it is challenging to conceptualize the analysis results. Translating unconceptualized results into tangible products is even more difficult. The Cognitive Work Analysis Design Tool (CWA-DT) was developed by Read et al. which enables the transformation of cognitive analysis results into concrete sociotechnical system designs [65]. The software development process is inherently costly and takes long development times. This is an obstacle to cognitive analysis of the software development process. Object-oriented software, which emerged as an effective software development method, allows cognitive analysis. Wei and Salvendy developed a mental task analysis model using an object-oriented program [66]. Cognitive analysis was performed for ideas incubated by Confer and Batra [67]. Cognitive task analysis has begun to receive increasing attention in the ergonomics literature after the 1990s. Job analysis and job development were examined together and the potential of cognitive task analysis was evaluated after the 1990s [68]. Studies on cognitive and physical ergonomics have emerged as a different discipline as a result of studies on cognitive and physical ergonomics.

3.2. Classification of Previous Studies (Önceki Çalışmaların sınıflandırılması)

Studies in cognitive ergonomics can be classified into four main groups under the headings of measuring, applications, safety and HCI. The classification of the previous study is presented in Table 2 in accordance with the hierarchical classification given in Figure-5. Studies examined within the scope of measurement generally focused on reducing and measuring the mental workload that multitasking brings to the individual, determining the cognitive factors that cause human errors and determining the individual's cognitive performance. Studies that prevent human error in cognitive ergonomics can be classified under human error. Studies conducted to predict and measure cognitive ergonomics to individual performance are classified under the title of the performance.

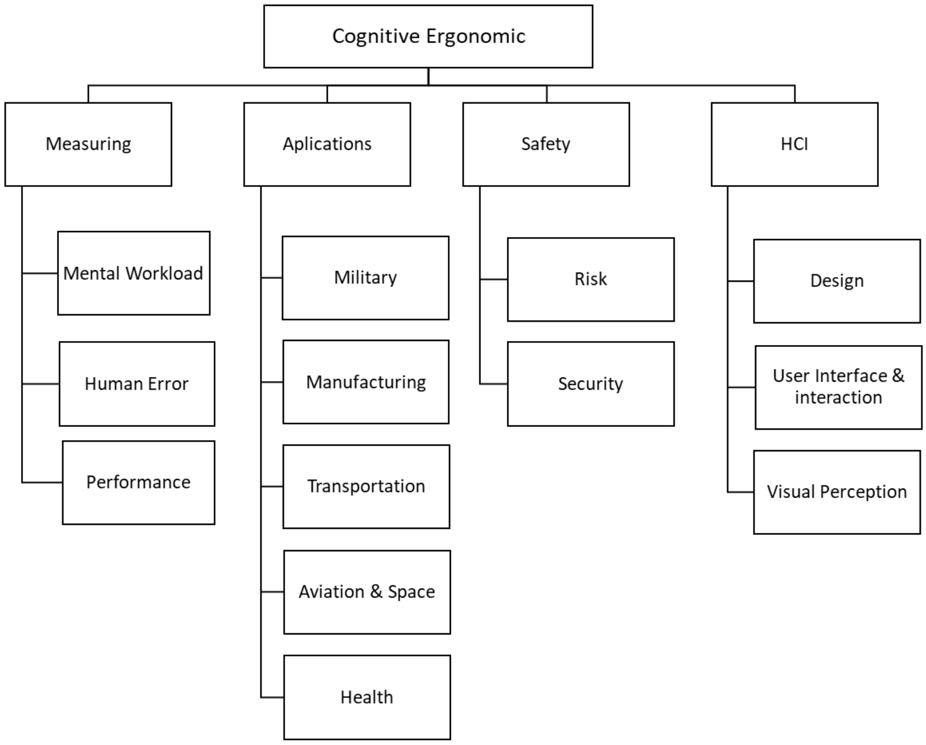

Figure 5. General classification of cognitive ergonomics studies (Bilişsel ergonomic çalışmalarının genel sınıflandırması)

Studies in cognitive ergonomics were examined under five different sub-headings according to the field of application. These titles can be expressed as military, manufacturing, transportation, aviation & space and health. The interface design of the control systems of robots used on the battlefield, the cognition factors in the autonomous control of land vehicles and the complexity of automation systems in flight safety are the studies examined under this title. In addition, studies examining the cognitive performance of drivers in different road conditions, the level of knowledge contained in traffic markers and signs, the detection of driver drowsiness, the mental workload of control rooms and the instrument panels of autonomous vehicles in terms of cognitive ergonomics are examined under the title of the application. Studies classified under the heading of safety are studies related to risk assessment and security. Studies that examine the development of software tools suitable for risk analysis, cognitive ergonomics criteria and the reduction of risks associated to cognitive ergonomics in flight operations are also under the heading of safety.

Studies classified under the title of human-computer interaction are divided into three sub-titles. Cognitive ergonomics is indispensable for user interface and interaction. Whether the interfaces are designed considering the cognitive ergonomics criteria and whether they will reduce the individual's stress is the leading research topic of the studies in this field. Since design activities are carried out in different disciplines, cognitive ergonomics in design activities has spread over a wide range. Cognitive ergonomics in design activities; machine interface design, empowering designers, job design, individual design activities, decision support system design, web design and quality system design can be given examples. Designing systems with a balanced cognitive workload increases the level of detection. The information transfer load between the individual and the interface should be kept at the perception level. Tablet, computer and machine interfaces are expected to facilitate perception. The menu designs used in interfaces and the amount of information presented to the user on the screen should not exceed the level of visual perception.

Table 2. Classification of the previous studies (Önceki çalışmaların sınıflandırılması)

Major Issue	Sub-Issue	Subject	References	Included Publication Number
Measuring	Mental Workload	Studies on the individual's cognitive workload	[6-8, 19, 20, 43, 45-49, 55, 56, 69-113]	34
	Human Error	The effect of cognitive level on human error	[62, 114-127]	58
	Performance	Studies to increase and measure cognitive performance	[10-13, 18, 22, 44, 54, 58, 66, 67, 128-141]	25
Applications	Military	Impact of cognitive ergonomics on education, teamwork, and awareness	[50, 51, 57, 142-147]	9
	Manufacturing	Studies on the performance of critical component design workgroups and inter-team communication in the manufacturing sector	[29-32, 63, 148-155]	13
	Transportation	Studies on the cognitive ergonomics requirements of traffic markers, vehicles, and indicators	[59, 61, 65, 156-168]	16
	Aviation & Space	Studies on cognitive ergonomics in instrument panels in flight towers, aircraft, spacecraft	[23, 169-176]	9
	Health	Cognitive ergonomic reviews of healthcare devices and automation systems	[28, 177-183]	8
Safety	Risk	Cognitive ergonomic evaluation of risk software tools	[4, 5, 184-188]	7
	Security	Cognitive ergonomic evaluation of safety management, occupational health and safety process improvement, evaluation of driver performance and human-related factors.	[14, 15, 189-193]	7
HCI	Design	Cognitive ergonomics in design activities in different disciplines	[17, 39, 42, 194-209]	19
	User Interface and interaction	Cognitive issues during the use of interfaces, visual performance analysis, users' visual attention and pilots' performance in flight simulators were examined.	[1, 16, 24, 26, 27, 34, 37, 41, 52, 64, 210-232]	33
	Visual Perception	Cognitive ergonomics studies aimed at increasing the level of visual perception	[233-242]	10

Different models and software have been used in studies on cognitive ergonomics. Since the studies in cognitive ergonomics cover various disciplines, the software and models used are spread over a wide range. The list of models and software used in cognitive ergonomics studies in the literature is presented in Table 3.

Table 3. Models and software used in cognitive ergonomics studies (Bilişsel ergonomide kullanılan model ve yazılımlar)

Name of Model or Software	Description	References
SOCA-CAT	A tool for communications planning on military platforms.	[147]
CWA-DT	A socio-technical model that enables cognitive job analysis	[65]
SYNOP	Rule-based software that allows cognitive ergonomic evaluation of human-machine interfaces	[221]
PETESE	A tool for cognitive ergonomic evaluation of the educational activity.	[211]
NASA-TLX	Cognitive task load analysis tool.	[77, 100, 102, 103]
Delphi-ORA	An order-relationship technique based on the Delphi technique allows the evaluation of subjective judgments.	[174]
SA	Measurement tool for pilots' cognitive situational awareness	[176, 243]
SID	A tool that allows for reducing the cognitive load imposed by unmanned aerial vehicles on the operator.	[231]
SEEV	A tool for cognitive awareness of warning systems in nuclear power plants.	[92]
Autaki	A recommended tool to support learning at work	[229]
SimTrA	A cognitive model for evaluating the functionality of electronic components.	[131]
CWA	Cognitive business analysis tool	[85]
AAM	A tool for detecting cognitive drowsiness from driver facial expressions.	[162]
SAFERIDER	A tool to improve the driving safety of motorcyclists	[159]
TRACEr	A tool that allows the identification of cognitive factors that cause human error in power distribution systems.	[125]
MATB-II	Multitasking capability measurement tool to determine operator performance.	[94]
NARIDAS	Cognitive risk assessment tool.	[185]

A. Mental Workload

One of the primary purposes of cognitive ergonomics is to keep the cognitive load at an acceptable level and the perception level at the highest level throughout the shift. Cognitive ergonomics deals with the cognitive interaction between people and the work environment. The use of cognitive ergonomics is not limited to human-computer interaction. The primary benefit of cognitive ergonomics in other disciplines is determining the cognitive load [82].

Work environments with a high cognitive workload are call centers. Today, call centers, which provide increased employment opportunities, serve different sectors. Examining call centers within the scope of cognitive ergonomics presents new problems. Operators in call centers should keep in mind only some of the information required to perform any operation and use information technology to enter data in line with the customer's demands and directives [71]. Call center operators interact with the computer screen while meeting with the customer. The mental workload required by the operators to avoid making mistakes during the meeting with the customer is equal to the sum of the content of the conversation and the cognitive load brought by the use of the interface. Another area where mental workload should be considered is design activities. The cognitive workloads of designers can be reduced by using knowledge-based design support systems. The reduction in cognitive workload is primarily indirect. Interface and warning systems developed to reduce mental workload are disabled by experienced designers. When the system's effectiveness and alerting systems are anticipated, preventive steps are taken to avoid workload and less cognitive load is incurred [109].

The combination of cognitive neuroscience and cognitive ergonomics has been termed neuro-ergonomics. Neuro-ergonomics studies situations characterized by poor individual behavior and performance. These situations can be summarized as neurobiological indicators of cognitive processes and capacities, cognitive status and operator activities. The operator's perception of cognitive load is related to his cognitive ability [106]. The mental loads of the devices used in cognitive ergonomics are different. It has been reported that the workload is reduced when palletizing-like operations are performed using a tablet and augmented reality device [89].

Cognitive load analysis is one of the critical ergonomic tools for examining industrial facilities. Eye-tracked jobs have cognitive loads. The cognitive load of visual tracking in complex work environments was reviewed by Durugbo (2021) [78]. Cognitive systems are widely used in the analysis of complex socio-technical systems. Cognitive workload analysis was performed by Jenkins et al. (2008) in the examination of helicopter mission planning software [86]. The cognitive load of fighter and cargo aircraft mission scenarios was examined by Kaber and Kim [88]. It is essential to measure cognitive loads in task analysis. However, it is not clear which unit of measurement the measurement will be made. Gray et al suggested a cognitive metric profile to make measurements healthier [81]. The theory and methods introduced by Salmon et al. (2010) in hierarchical workload analysis and cognitive workload analysis are compared [105]. Peacock (1994) proposed cognitive workload analysis based on fuzzy sets [76]. The cognitive capacity of the machine and computer operators has been examined [75]. Cognitive analysis of e-book reading devices was performed by Wu et al [112].

B. Human Error

Mass production lines are generally made up of robots to minimize human errors. The cognitive aspect of human-robot interaction in the manufacturing industry was examined by Faber et al. (2015) in coming years. In the future, the flexibility offered by humans will be combined with the precision provided by robots in production facilities; therefore, cognitive ergonomics should be considered in the design of production lines [116].

Controlling machines is cognitively challenging for operators, and for that a method called “a morphological box” was proposed by Czerniak et al which allows optimization of the stress level of machine operator and minimizes human error [115]. Workplace design affects employees' mental health and inappropriate workplace designs cause human error. The effects of workplace design-related stress on cognitive activities were investigated by Alyan et al. [114]. Socio-technical systems consist of human and non-human systems in mission-critical areas. A model has been proposed by Jenkins et al. (2017) that aims to increase the capabilities of users to deal with unexpected situations and minimize human errors [119]. Decision makers tend to make systematic mistakes in project management due to their limited cognitive abilities. Mistakes are caused by biases like Anchoring Effects, Accuracy Bias, Managerial Insights [117]. It has been reported that cognition-related human errors occur in the task of monitoring and control, problem coordination and resolution, continuous production activities, abnormal conditions, the uncertainty of conditions, insufficient academic support and lack of direction. Root causes of errors are reported as multiple simultaneous tasks, full-time work tempo and lack of experience [244].

The cognitive load required by each device used is different. Variable cognitive loads cause human error. Lee et al. (2014) examined how cognitive ergonomic workloads changed in robotic and laparoscopic surgery. Specialists who start robotic and laparoscopic surgery have a high cognitive workload and operators may make mistakes due to cognitive load [180].

C. Performance

Cognitive and physical ergonomics affect individual fitness in workplace. Cognitive ergonomics also affect the cognitive and physical performance of worker. Cognitive ergonomics studies were conducted to increase and measure the performance of employees. Parameters such as user response times and error rates were monitored. It has been reported that cognitive performance changes depending on the hardware features of the terminal [136].

The continuous improvement in business is a must due to the increasing competition. It has been reported that the performance of the personnel will increase with the better management of stress and use of cognitive ergonomics techniques in the marketing units [139].

Capabilities needed in flight planning were determined by Volz and Dorneich and it was determined that cognitive performance was related to the planning task during the daily shift [140]. Standing work on mental and physical performance during cognitive tasks was investigated by Kang et al [135].

D. Military

Cognitive ergonomics have been widely studied in mission-critical military fields. Working conditions of military personnel require high physical and psychological readiness. For example, when fighter jet pilots are exposed to high G-forces, they are simultaneously exposed to increased cognitive load.

Designs that reduce the cognitive workload in human-machine interaction should be user-friendly. In this context, user-friendly designs should include mental model support, keep the interaction simple and use appropriate colors. In addition, this concept of usability means that objects that look similar move at the same rate, the results of the same actions in automation are the same and the automation is generally self-consistent. Mental model support means modeling the user's mind, avoiding irrelevant information and presenting all the information necessary for the task. The simplicity criterion means that the notifications are simple, the data is displayed according to the frequency of use and the visual elements are presented hierarchically. The use of color means that the colors are monochrome and the number of colors is kept to a minimum [142]. Military intelligence is another application of cognitive ergonomics in the defense and security sector.

The use of battle platforms also requires high cognitive performance. The role of cognitive analysis in mission planning in military platforms was examined by Stanton and McIlroy (2012). Communication and planning software on military platforms is complex and challenging to learn. A new model named SOCA-CAT, a combination of rich images and cognitive ergonomics, has been proposed to reduce the cognitive load required by military missions and make communication planning effective [147]. The cognitive workload and distribution of the personnel working in the Naval Forces Command were examined by Bridger et al. While stress models only deal with psychosocial factors, it has been emphasized that cognitive factors are important in stress management in complex environments [143].

E. Transportation

Cognitive ergonomics is indispensable for designing transportation systems. Road safety, vehicle gauges and traffic signs should be designed with cognitive ergonomic factors, where the cognitive workload has been taken into account in general. The cognitive workload of drivers against vehicle feedback on the road was investigated. Cognitive processes of receiving information by drivers from the environment and vehicle were revealed. The tools were divided into two groups according to the cognitive feedback level. The high level of feedback increased the drivers' situational awareness [167].

There is a strong link between cognitive ergonomics and safety. Intelligent systems used in driver compartments place a burden on cognition. Even basic tasks that do not impose a cognitive load can cause accidents. For this reason, cognitive activities in the interface design used in vehicles and aircraft should consider the potential threat level [163].

A multi-criteria ergonomic approach has also been developed to select the material handling path in manual handling operations. Cognitive ergonomic factors were considered for decision-makers and it is suggested that directives must be easy to understand [166].

Situational awareness is also essential in traffic. Awareness of many objects in traffic increases driving safety. Tasks of varying complexity and the flow of information from different sources affect the driver's situational awareness. The shortness of use of systems such as vehicles and aircraft positively affect mission performance [127].

F. Manufacturing

Cognitive ergonomics has been widely studied in development, planning and design activities in the manufacturing industry. The effects of cognitive ergonomics in the design and development of commercial products for children, the child's development and the choice of toys were investigated [149].

The presentation of the information to the machine operator on the assembly lines should be analyzed in terms of cognitive ergonomics. The information presentation environment is auditory, visual, written or computer-based. The warning symbols and syntax used in the information presented are the factors to be considered [154].

G. Aviation & Space

In aviation and space, maintenance management, air traffic management and cognitive performances of pilots and astronauts were examined. Cognitive ergonomics has been used in air traffic management, air traffic flow management and unmanned aerial systems. A new human-machine interface (HMI) depending on machine learning for air traffic control panels is investigated [170]. The cognitive task load of workers working on aircraft maintenance lines was measured [124].

The team's situational awareness in aviation is essential in terms of collaborative work. Even if they receive information on the same screen, the situational awareness of team members varies in terms of cognitive ergonomic factors [175]. Airspace management was discussed as a cognitive system by Lintern. A distributed cognitive air traffic management model is proposed for effective and safe airspace management [172]. Adriaensen et al. conducted a case study in the aircraft cockpit within the socio-technical analysis of the function of information flow type changes. The functional resonance analysis method is proposed for cognitive analysis with information transformations layered [156].

H. Health

Cognitive ergonomics also has significant application areas in the health sector. Franks and Briggs conducted cognitive performance analysis in training ventilators. [216]. The mental workload required in anesthesia procedures includes visual and auditory notifications. Information presentation and communication of the interface systems used in anesthesia have been improved [245]. In terms of design, cognitive ergonomics establishes a human-system fit and determines a starting point to improve the health system [151].

The complexity of health device alerts creates a cognitive load on user and it is an obstacle for making right decision [183]. The mechanical arm commonly used in surgical operations is a common form of human-robot interaction. Arm movements were recorded and analyzed with the Electroencephalography signal. It has been reported that there is a close link between cognitive status and human error [227].

A cognitive workload analysis of cardiac nurses was conducted by Burns et al. (2016) [177]. The mental workload of nurses and administrators was analyzed by Effken et al. for decision support tools [179]. A literature search was conducted by Jiancaro et al. on cognitive analysis studies conducted in health between 1990 and 2013 [246].

Cognitive analysis of nurses' control and monitoring tasks was conducted by Lopez et al. (2010) to prevent bedridden patients from falling out of bed [181]. In addition, cognitive ergonomic analysis of clinical devices and 3D stereoscopic screens [178, 204] and cognitive ergonomic analysis of visualized data [182] can be mentioned as cognitive ergonomics studies in healthcare.

I. Risk

Risks affect all areas of life. Risks will worsen cognition and perception levels. The placement and size of the objects on the interface involve risks in terms of cognitive ergonomics [213]. Wearable technology is rapidly taking its place in all areas of our lives. Wearable technology and physical and cognitive risks were evaluated together by Oyekan [153]. Computer games were also used as a cognitive ergonomics risk assessment tool by Tong et al. [209].

J. Security

The increase in technology usage reduces the reliability and efficiency of the system. With cognitive ergonomics, the effect of work on mind and the effect of mind on work are defined. The reliability of cognition and performance are among the main topics of cognitive ergonomics [187]. The problems encountered in the management of complex systems are the number of autonomous devices, the complexity of autonomy and new technologies. The mentioned problems should be examined within the scope of cognitive ergonomics [192]. In the industry, the issue considered in workplace safety is generally physical ergonomics. However, in the study conducted in the Norwegian petroleum industry, it was reported that cognitive processes were not given sufficient attention during the plant design phase [191]. Failure to pay attention to cognitive processes can cause occupational accidents.

One of the essential considerations in cognitive ergonomics is the reliability of cognition. The reliability of the awareness depends on operator's performance being in accordance with reported instructions. The human error rate has increased due to cognitive factors. The main reasons for the increase in human error are:

- Individuals are prone to making mistakes,
- Only human errors can be determined as a result of comprehensive analysis,
- Reduction of system errors as a result of the improvement of security mechanisms,
- The emergence of existing human errors [118].

K. Design

The contribution of cognitive ergonomics in designs has been examined in terms of problem-solving. Cognitive ergonomics significantly impacts problem definition, concept solution development, alternative selection and innovation. Cognitive ergonomics comes to the fore in clarifying the task, determining the solution and in the solution process. In describing the job, ideas with high success value are revealed with group work techniques. A comprehensive explanation of the task is given and concentration on object functions, main functions and goals are determined. The solution search principles, a new solution development strategy, basic solution development strategy and solution constraints are determined. In the solution process evaluation, general and detailed solution stages, processes and outputs are determined [202].

Industry 4.0 has brought a new concept, Engineer 4.0. In Industry 4.0, engineers will engage in more intense cognitive efforts such as communication, monitoring, supervision, collaboration and creativity [194]. Design cognition investigates the cognitive strategies of individuals who work in design processes. Sun et al. (2014) compared the cognitive efficiency of experienced and inexperienced designers in concept designs [208]. Virtual reality devices are used in engineering design processes. The use of virtual reality in design is more effective than computer-aided design [207].

L. User Interface & interaction

For an effective human data interaction, the data transfer process of the interfaces should be defined in terms of cognitive loads. Individuals are exposed to more data load than in their daily lives while interacting with interfaces. As the amount of information increases, the accuracy of individual judgment decreases. Human cognitive limits should be taken into account when designing cognitive processes. Cognitive ergonomic guidelines that facilitate data-based decision-making should be used [220].

Cognitive workload analysis is vital for web designs and users. There is a cognitive difference between the user and the designer [197]. An ergonomic tool has been developed for mental workload estimation in human-machine interface design and evaluation [232]. A rule-based approach named SYNOP is proposed for the human-machine interface's ergonomic assessment [221]. In addition, the cognitive activity index has been submitted to determine visual impact and information load [212]. In addition, human-computer interaction generally encompasses models of design, learning and understanding [215]. As the number of technological devices increases and enters daily life, interface designs have gained importance in human-computer interaction [210]. Cognitive load was also examined in e-learning platforms. Usability level in distance education systems and the visualization level of scale were determined in terms of comprehension, memory, interface, instructional design, attention and learning [228]. A review of video analysis in human-computer interaction has been made. Activities such as keyboard and mouse use were evaluated as cognitive activities. Task-related actions in human-computer interaction have been defined [223].

M. Visual Perception

Designer facial expressions were used to examine cognitive effects [239]. Adaptive control of thought-rational (ACT-R) consists of perceptual-motor, target and declarative memory modules. These modules select a rule to respond to a pattern [233]. In ACT-R theory, cognition consists of a visual module that determines object location, a processing module that determines the appropriate response and a manual module that produces processing output [203]. Kadefors and Forsman) proposed a video-based method for evaluating complex operations [205]. Kolski proposed a rule-based approach for evaluating human-machine interfaces. In the proposed method, ergonomics and cognitive psychology concepts are taken into account [206]. Métayer and Coeugnet evaluated pedestrian interaction with an autonomous vehicle. It has been reported that pedestrian behavior changes according to the vehicle type [238]. Barber (1994) evaluated cognitive ergonomics for designers and users [195]. Cognitive job analysis was conducted by Read et al. to model human factors and ergonomics practitioner roles [247]. Tian et al. compared motor, visual and cognitive factors. Use of mobile phones on cognitive performance was investigated during walking. It has been reported that texting has a negative effect on walking, which is one of the motor activities [241]. Visual analyzes of remote sensing systems have been studied from a cognitive perspective [242].

4. DISCUSSION (TARTIŞMA)

4.1. Metaverse and Cognitive Ergonomics (Metevarse ve Bilişsel Ergonomi)

Today, human-computer interactions are not only through a screen. Virtual Reality (VR) and Augmented Reality (AR) applications have become widespread. With the development of automation systems, human-machine interaction has also increased. The concept of human-machine interaction has entered daily life [248]. One of the areas where cognitive ergonomics is mostly used is computer games. Computer games need intense communication via screen and sound. The primary purpose of the games is to increase the pleasure and usability of the user. New techniques are required to measure emotional and cognitive experience to improve the gaming experience. For this purpose, it is required to determine cognitive elements the user is mostly affected during the game. Physical reactions such as heart rate, breathing and eye movements should also be measured during the game [196]. The primary purpose is to increase the interaction level by using the human sense organs at the maximum level.

Increasing the interaction level is now possible with VR and AR devices. The potential for AR devices in the gaming world and industrial areas such as maintenance lines is relatively high [249]. However, the biggest problem with these devices is the user's needs for compensating cognitive load. The importance of cognitive ergonomics in the designs of VR and AR devices was emphasized by Grajewski et al. [201]. Cognitive loss of individuals in terms of health was examined by Chignell et al. Digital games are designed to measure the mental loss of young and old individuals [198]. Cognitive ergonomics is employed to meet users' needs with different knowledge and experience in VR devices [199]. The use of VR technology and the parameters affecting the perception level were examined to increase the perception levels of 3D models designed in the construction industry [250]. Cognitive interaction in human-machine interaction was discussed within Industry 4.0 and the concept of Operator 4.0 was proposed. The Operator 4.0 concept has been evaluated that the cognitive load of the employees will be higher [155]. An ergonomic index has been defined that allows the human-robot balance to be quantified in product assembly [214]. The task object identification method (TODD) is proposed for displaying the cognitive states of users [224]. Physical and cognitive ergonomic constraints in interface design in human-machine interaction are investigated [219].

AR is a combination of virtual and physical reality. Cognitive innovations presented in this field have a regulatory effect on the spread of AR [218]. Individuals have cognitive difficulties when using AR devices that are not designed ergonomically. Users make more neck and eye movements to meet their cognitive data needs, which leads to physical discomfort. Considering cognitive ergonomic factors while designing the interface for AR devices also reduces physical discomfort and positively affects user performance [230].

The cognitive load of VR device use in assembly line operator training was analyzed by Brunzini et al. [234]. One of the important parameters is the number of sense organ which the data is transmitted to brain. The number of sense organs was classified by Aristotle as five [251]. Jarrett) reported that there are more than five ways the brain communicates with the environment [252]. The general acceptance about the number of sensory organs is eight, which includes touch, hearing, vision, smell, taste, vestibular, proprioceptive and interceptive systems. The vestibular system transmits the body's balance and movement information to the brain. The proprioceptive system transmits information to the brain about the amount of force required to move an organ. The interceptive system transmits data about what is happening inside the body to the brain. [253]. The main way to increase the satisfaction level of VR and AR device users in the metaverse universe is to reduce the cognitive load of the senses. Today, VR and AR devices transfer all the information to the brain with the senses of hearing, sight and partly touch. This means that a maximum of 3 lanes of the 8-lane highway are used. The representation of the cognitive load coming from the VR and AR devices to the sensory system in the concept of metaverse is presented in Figure 6. In order to spread the concept of metaverse and increase user satisfaction, cognitive load should be allocated to the sensory system correctly.

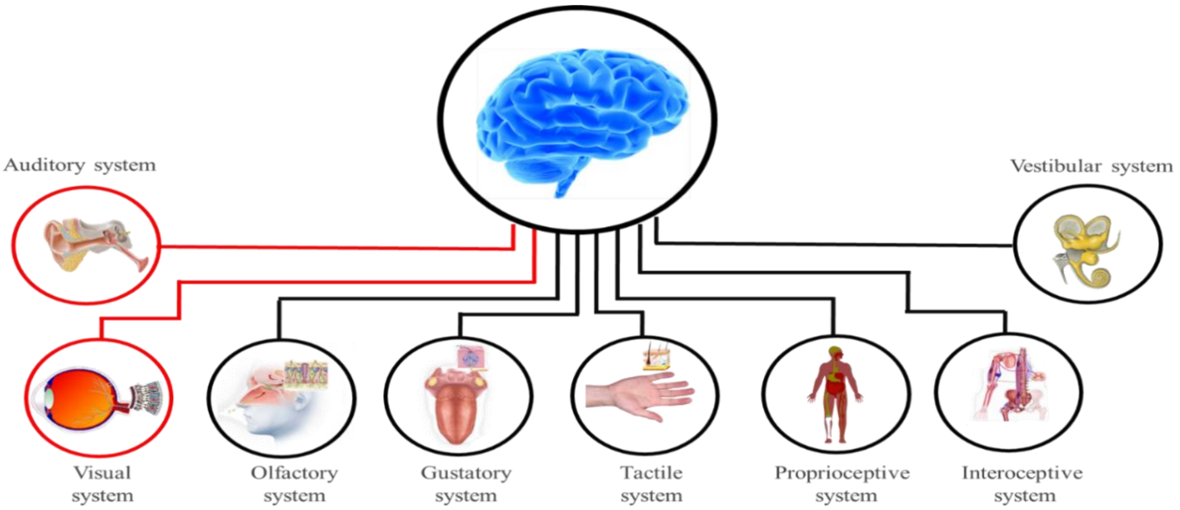

Figure 6. Allocation of cognitive load on transmitter line from sensory system to brain (Duyusal sistemden beyne giden verici hattındaki bilişsel yükün tahsisi)

4.2. Neuroergonomics and Cognitive Ergonomics (Nöroergonomi ve Bilişsel Ergonomi)

Neuroergonomics is a branch of science that aims to design work systems in a safe, effective and usable way by measuring the neural activities of the human brain while working [96]. Neuroergonomics, emerged by integrating neurology and ergonomics, can provide numerical data on the mental fatigue of employee by imaging the human brain while doing any work and measuring the brain waves during work.

The analysis of the brain waves provides a quantitative evaluation of the mental workload of individuals. During all these processes, the sciences of neuroergonomics and cognitive ergonomics interact. Berka et al. used the frequencies of brain waves to measure the workload. Electroencephalography (EEG) measurements of eighty subjects were compared with the workload they felt and the workloads they were actually exposed to. The researchers evaluated the mental workload that the subjects were exposed to while performing arithmetic operations in 2 groups as low and high [72].

Sassaroli et al. (2008) used functional near-infrared marking (fNIRS) method, one of the brain imaging techniques, to determine the level of mental workload and examined the use of neighborhood algorithm. The accuracy rate of the developed method in determining the level of mental workload is between 44% and 72%. Sassaroli et al. (2008) tried to determine whether neuroergonomic methods can be used to measure mental workload [107]. Herff et al. (2014) reported that the prefrontal cortex is related to workload and that measurements taken with fNIRS work with an accuracy of 78% in determining the workload level [83]. Di Sitasi et al. (2015) aimed to reveal the flight procedure complexity of military helicopter pilots with EEG measurements. They tried to determine which flight operations cause more mental fatigue. Researchers stated that intense EEG signals were measured in tasks such as ascent and take-off and lower EEG signals were measured in classical tasks performed during flight exercise and flight [169]. Causse et al. (2016) reported that pilots should evaluate many information together during flight and ignore cognitive noise, which has a disruptive effect on cognition. Especially in terms of auditory noise during flight, they tried to determine how disturbing sounds on the basis of words affect the pilots. Researchers took measurements such as EEG, pupil diameter and analyzed with ANOVA. In experiments conducted with twenty-four people, it was determined how much work memory was affected by stimuli such as disturbing words and false alarms, in addition to normal piloting duties. It has been reported that neuroergonomic methods can be applied in the design of strategic systems by determining the reactions of employees to external environmental stimuli and their level of influence while performing tasks that require attention [148].

Aghajani et al. [69] collected response times and brain signals while performing the n-back task on a computer screen with 17 participants and the measurements were analyzed with ANOVA. The higher "n" in the n-back task, the more working memory is required. Variations in EEG and fNIRS measurements were monitored to prove the theory that the person was mentally fatigued as the study progressed. Borgetti et al. proposed statistical machine learning methods to estimate the operator's workload from EEG measurements. They collected data from 6 participants 16 times in a laboratory; EEG and eye tracking values were measured. Based on these values, a workload estimation model was developed with the discrete event simulation approach and it has been reported that it is possible to estimate the mental workload [130].

Liu et al. determined the mental workload and stress level of marine team members and determined which team member in which position was exposed to the highest level of workload. The EEG values of mariners were measured while performing different tasks in a ship simulator. It has been determined which of the 4 levels (none, minimum, medium and high) that the mental workload falls into [164]. Kosti et al. examined the brain activities of software engineers while performing two different mentally related tasks with wearable EEG devices. With the multiple regression model, they tried to predict the difficulty experienced by the programmer while trying to understand the code. Ten participants who knew the researchers C programming language were asked to debug twenty code samples with errors interspersed between lines of code. They conducted the study based on the use of wearable EEG to measure the difficulty experienced by the developer while debugging [222]. Di Flumeri et al. developed a method based on EEG measurements to observe the effects of different road and traffic conditions on drivers' workloads. During real driving experiments with 20 young participants, the effect of different traffic conditions on participant mental workload was determined. The mental workload index was proposed for workload level measurement [158]. In other studies, mental workload measurements were taken in the laboratory environment during human-computer interaction [79, 161, 254].

5. CONCLUSIONS AND FUTURE REMARKS
(SONUÇLAR VE GELECEK ÇALIŞMALAR)

Cognitive ergonomics emerged as a new scientific discipline with a rapid acceleration after the development of physical ergonomics reached a certain maturity. Applications making cognitive load of employees sustainable have been developed in different industries. Industrial revolutions (during Industrial Revolution 1.0, 2.0 and 3.0) increased the physical presence of man in the production environment, but when the revolutions reached to a certain stage machine started to replace the physical labor force. Then human beings are employed more as a controller, regulator or designer. As the role of man in production changes, the nature of the strain and fatigue he experiences has also changed and physical fatigue has left its place to mental fatigue.

Moreover, as the interaction of human with machine and computer increased, different types of problems emerged. While measuring the stress to be experienced, application areas for making designs to reduce fatigues and preventing human errors was also developed. It is clear that this development will make continuous progress in the present and in the future, where time and efficiency are very important from a strategic point of view. From this point of view, it is only possible by a comprehensive literature review to determine the areas of which today's cognitive ergonomics applications will change and develop. In this study, the general tendency of the related literature within the scope of cognitive ergonomics studies and the areas that it has expanded in order to show improvement have been examined through a comprehensive literature review. This research was carried out systematically with certain keywords and 254 studies were examined in depth.

As a result of the research, it is seen that there has been a transition from subjective techniques to objective techniques for the calculation of cognitive workload. Today, studies have begun to determine the levels of fatigue based on the brain waves of the individual/operator while working and this has contributed to the emergence of a new scientific discipline. Similarly, critical studies were carried out to prevent human errors in user interface design and contributed to proactive ergonomic approaches. On the other hand, studies were carried out within the scope of cognitive ergonomics, not only for the blue-collar personnel, but also for both blue-collar and white-collar personnel in the transportation, aerospace, health and defense industries. The general tendency of the literature has been evaluated as the expansion of the application areas of cognitive ergonomics and the emergence of new application areas with triggering mechanisms. Moreover, it is predicted that activities for cognitive ergonomics will develop in a way that will cover completely newly discovered areas such as AR or Metaverse in daily life, as well as production environments triggered by digitalization.

DECLARATION OF ETHICAL STANDARDS
(ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

Uğur ATICI: He conducted the literature review and took part in the writing process of the article.

Literatür araştırmasını yapmış ve makalenin yazım süreçlerinde yer almıştır.

Aylin ADEM: She conducted the literature review and took part in the writing process of the article.

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Mehmet Burak ŞENOL: He conducted the literature review and took part in the writing process of the article.

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CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

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