Tabriz Islamic Arts University of Iran
Faculty of Islamic Designing

Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Ph.D. of Industrial Design

DESIGN STRESS: AN INVESTIGATION OF STRESS CAUSED BY THE DESIGN THINKING PROCESS

By:
Samira Ashari

Supervisor:
Dr. Babak Amraee

Co-Supervisor:
Prof. Gaetano Cascini

Adviser:
Prof. Stefan Schmidt

January 2025

in the
name of
God

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دانشگاه هنر اسلامی تبریز
۱۳۷۸

Student Declaration

I, **Samira Ashari**, a full-time **PhD** student in **Industrial Design** at the **Faculty of Design, Tabriz Islamic Art university,** with student **ID 98147601**, hereby declare that the research presented in this thesis, titled ***Design Stress: An Investigation of Stress caused by the Design Thinking Process*****,** has been conducted solely by me, and the accuracy and authenticity of the written content is affirmed. In cases where the work of other researchers has been utilized, the relevant references have been properly cited. Additionally, I commit that the content included in this thesis has not been previously submitted for any degree or qualification by myself or any other individual, and I have fully adhered to the university's approved framework in drafting the thesis. Furthermore, any article derived from the findings of this thesis will be published with the acknowledgment of my supervisors and myself. All material and intellectual rights related to the outcomes of this study, as well as its publication, reproduction, translation, and adaptation, are reserved for the University of Islamic Art, Tabriz.

Student's Signature: Samira Ashari
Date: 1st February 2025

In the name of God

Minutes of PhD Defense Session (B)

Tabriz Islamic Arts University of Iran

Faculty of Islamic Design

In accordance with the regulations of the **PhD** program, the defense session for the PhD thesis of **Ms. Samira Ashari**, student number **98147601**, in the field of **Industrial Design**, Industrial Design specialization, worth **18** credit hours, was held at **10:30 AM** on **01/01/2025** with the title "**Design Stress; An Investigation of Stress caused by the Design Thinking Process** " in the Al-Ghadir Hall at the University of Islamic Art in Tabriz. The defense session was attended by the jury members, and based on the quality of the thesis, the defense presentation, and the manner of answering questions, the final decision was made as follows:

The thesis was approved with **excellent** distinction.

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Acknowledgments

In the name of the One who instilled in me the passion for learning and the strength to persevere. This dissertation is not solely the product of my pen and intellect; it is a tale of love, empathy, and the hands that became my support in difficult moments, walking beside me at every step of this journey.

To **my kind and loving parents**, the steadfast pillars of my life; you whose prayers unraveled every knot and whose smiles illuminated the darkest of my days. Every step of this path is indebted to the love you have selflessly given me.
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I sincerely acknowledge the support of the **Iran National Science Foundation (INSF)** and **Mohammad Reza Shabanloo Jewelry Design Studio**, whose financial contributions made the completion of this dissertation possible.

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This dissertation is not merely an academic achievement but a reflection of love, unity, and unwavering support. Every word within these pages carries the imprint of your presence; you who, through your boundless generosity, have become an eternal part of this journey. This accomplishment is a piece of your kindness and faith, and from the depths of my heart, I thank you.

Dedication

Line by line, I dedicate these words ...

To the girl who stood tall amidst the fiercest storms, unwavering in her belief in her dreams…

To her silent tears that feel unnoticed, yet echoed with the voice of hope…

To her smiles that soothed the wounds of exhaustion…

And to her hands that, even in the darkest of nights, never ceased to create…

To myself, who turned failures into stepping stones and weariness into wings for flight…

Who now embraces the fruits of years of patience and perseverance?

To my parents,

To the hearts that beat tirelessly for me…

To the prayers that became the pillars of my strength…

And to the embraces that sheltered all my weariness…

You, with boundless love, unfolded my wings and lifted me high, even when my flight was unsteady.

To all those who walked this path with me,

Who, with their words, kept the flame of hope alive in my darkest moments…?

And to the professors whose knowledge and guidance paved my way forward…

These words are a testament to dreams nurtured in the light of love-dreams that have now soared to the heights of the sky.

In the name of God

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Postgraduate's Dissertation/Thesis Information & Abstract

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Abstract:
Introduction and Objective: Research in design studies with a focus on stress indicates that stress is a persistent factor in the design profession and process. However, the nature, causes, and impacts of this stress have not been comprehensively and transparently examined. Despite efforts to clarify this issue, significant ambiguities remain, as no cohesive and systematic study has addressed the topic, and the fragmented nature of related discussions is evident. Recognizing stress in design as a prevalent and impactful phenomenon is crucial, as inadequate management can lead to acute or chronic stress, ultimately negatively affecting designers' mental health, professional performance, and the quality of design outcomes. Accordingly, the present study aims to investigate stress arising from the design thinking process through a meta-synthesis approach.
Methodology: This study employs a systematic review based on the PRISMA protocol, scientometric analysis using the VOSviewer tool, grounded theory, and qualitative content analysis through coding to demystify the concept of design-related stress and propose a comprehensive framework for the ontology of design stress. Semi-structured clinical interviews (SCID-5/DSM-5) and the PANAS questionnaire were used to evaluate designers' mental health, while EEG tools, alongside the PSS and PAQ questionnaires, measured stress arising from the design thinking process. The MetaCogno tool was utilized to capture designers' emotional and cognitive experiences during the four main stages of the design process (problem analysis, ideation, idea evaluation and selection, and implementation of the final idea). Additionally, the CSI questionnaire assessed designers' coping strategies in response to perceived stress levels. Stress pattern analysis was conducted using machine learning models, including Random Forest and SVM. Variables such as time constraints and handedness were also examined.
Findings and Contributions: After identifying appropriate methods for measuring design stress, the results categorized stress into three domains: cognitive design stress, neuropsychological design stress, and physiological design stress. Based on these categories, the novel MetaCogno approach was developed. The findings indicate that a unique type of stress, inherent to and arising from the design process itself, exists and introduces a new research domain termed "design stress." All findings were structured into five ontology categories. Furthermore, the analysis revealed varying levels and intensities of stress across different stages of the design thinking process, impacting designers' performance differently. Most designers experienced moderate stress levels, with continuous changes in mental states contributing to their adaptability. The ideation stage was

identified as the most stress-inducing phase, where designers reported the highest number of negative experiences, while the implementation stage showed reduced stress and improved performance. Moderate time constraints helped mitigate excessive stress and enhance focus, whereas the absence of time constraints led to fatigue and performance decline. Left-handed designers demonstrated better performance, greater mental stability, and lower stress levels compared to right-handed designers.

Keywords: Design stress, Design thinking process, MetaCogno, Machine learning, Electroencephalography

Supervisor's signature:

Dr. Babak Amraee

Date: 03/02/2025

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Introduction

Stress, as a significant factor threatening mental and physical health, profoundly affects not only individual well-being but also the quality and effectiveness of professional performance, including design-related activities. In the field of design, stress can seriously disrupt the design process and its associated tasks. Design is recognized as a complex cognitive process encompassing stages such as problem definition and structuring, analysis, decision-making, evaluation, ideation, creativity, and problem-solving. Each of these stages presents its own unique challenges and stressors, necessitating precise studies and research investigations for their understanding and management. On the other hand, stress resulting from the design thinking process refers to the mental, physical, cognitive, psychological, and emotional pressures that designers experience during the various stages of this process. This stress may stem from internal factors, such as the complexity of design thinking, its cognitive demands, the constant need for generating innovative ideas, and engaging in creative activities. External factors, such as time constraints, client expectations, design critiques, workplace environment, and professional conditions, can also play a significant role in the emergence of such stress.

While moderate levels of stress may serve as a motivator and enhance creativity, excessive stress-whether acute or chronic—can have significant negative impacts on designers' cognitive abilities, ideation process, decision-making, evaluation, overall performance, and the quality of design outcomes. Studies have shown that stress can impair the brain's ability to think creatively and generate innovative ideas. Furthermore, stress often leads to reduced motivation and energy, making it difficult for designers to maintain focus on their work. Experiencing stress during the design thinking process can result in various negative consequences, including decreased productivity, increased errors, diminished creativity, and ultimately, the production of low-quality, non-innovative outputs. Prolonged stress may also lead to serious physical and mental health issues, as well as lower job satisfaction among designers.

Addressing the issue of stress in the field of design is therefore not only essential for improving the quality of design processes and outcomes but also for enhancing designers' professional performance and promoting their mental and physical well-being.

This research primarily aims to establish a novel field of study termed "Design Stress" and to propose a conceptual framework for the ontology of this concept. Additionally, it seeks to identify, analyze, and measure stress arising from the design thinking process and examine its impacts on designers from various perspectives. In this context, the study strives to answer the following questions: What is design stress? How can an ontology be designed to effectively model and represent design stress? How can stress resulting from the design thinking process be measured and evaluated? How can stress experienced during the design thinking process be identified and assessed? What impact do the variables of time and handedness have on the stress levels and performance of designers during the design thinking process? How does handedness influence the stress levels and performance of designers in the design thinking process?

Chapter 1
General Overview of the Research

1-1- Introduction

Design is one of the most critical cognitive activities of human beings, playing a central role both in the general aspects of life and in professional domains. Particularly in the modern world, with the increasing specialization and differentiation of professional fields, a wide range of occupations are centered around design, such as industrial design, architectural design, graphic design, landscape design, interior design, and many others. Although various theoretical frameworks have uncovered profound dimensions of design, there remain significant scientific gaps in this field. Therefore, design studies aim to explore the multifaceted aspects of this complex activity to achieve not only fundamental understanding but also practical and educational goals to enhance designers' performance and their training.

One relatively overlooked issue in this area is the bidirectional relationship between design and stress. The challenges and processes of design are inherently stress-inducing and can have both positive and negative impacts on designers' health, performance, and the quality of their work. This highlights the importance of conducting studies in this direction. Researchers in this field have turned to cognitive science approaches to effectively study this topic, as design is a highly complex cognitive process capable of generating stress for designers. The variety of skills designers must employ to solve design problems—such as analysis, evaluation, decision-making, and ideation—combined with the inherent complexity of design problems, the stress unique to the design profession, and other related factors, all contribute to the stress experienced by designers. This stress may persist even after the design process has concluded.

However, the ways in which the design profession and the various stages of the design thinking process induce stress in designers remain unclear. Of particular importance is understanding how such stress can significantly influence designers' performance and overall well-being, both positively and negatively. Thus, research in this area provides a deeper and more comprehensive analysis, which can contribute to the development of effective and structured approaches for managing stress in the context of design.

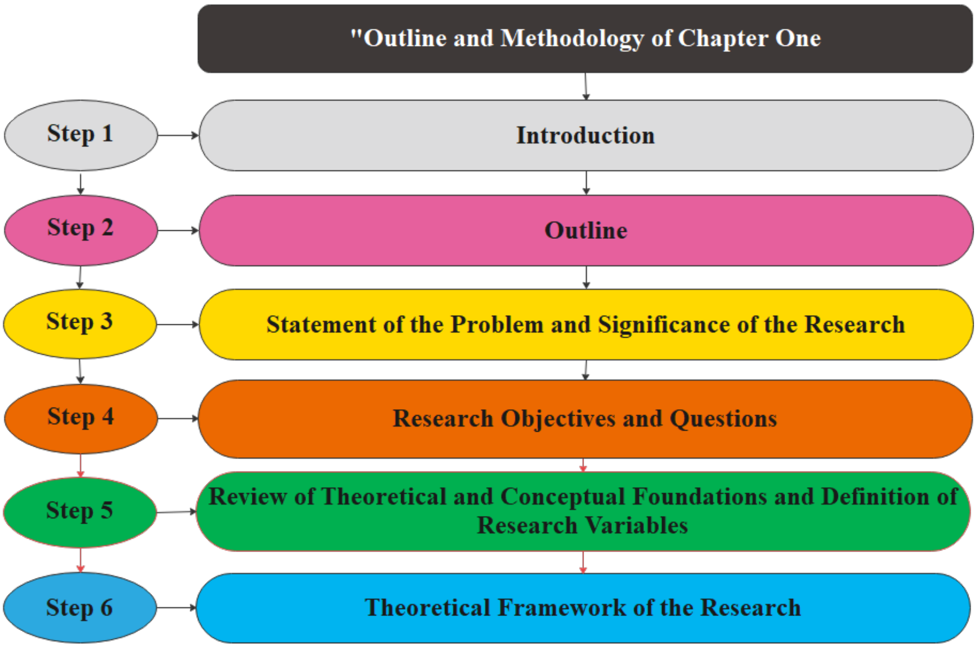

Figure 1-1: Overview of the General Framework and Methodology of Chapter One

1-2- General Framework and Methodology

This study aims to define a novel research domain, namely "Design Stress," and to present the ontology of design stress. Chapter One serves as the introduction and theoretical framework for the research. The chapter begins with a general introduction, followed by an overview of the study framework. Section 3 addresses the problem statement, elaborating on the importance and necessity of investigating stress within the design research domain. Subsequently, Section 4 outlines the objectives and research questions, providing a broad perspective on the expected outcomes of this study. In Section 5, the theoretical and conceptual foundations are reviewed, and the study variables are defined, laying the groundwork for establishing a new research domain. Finally, Section 6 describes the theoretical framework of the study in detail, covering the systematic review and meta-synthesis of prior studies, the identification and presentation of methods for measuring design stress, the assessment of stress induced by the design thinking process, and the evaluation of mental health, stress levels, and coping strategies using questionnaires. Each of these components is explained step by step. This chapter essentially provides an overview of the research structure and the sequence of chapters (refer to Figure 1-1).

1-3- Problem Statement

Stress, as an inseparable part of human life, is a phenomenon that individuals constantly encounter (Blum, Borglund & Parcells, 2010). However, stress-inducing conditions often exceed the capacity of contemporary humans, leading to mental and physical imbalance. Research has shown that approximately 75% of physical and mental illnesses stem from stress (Thompson, Eggert, Randell &

Pike, 2002). In modern life, one of the significant sources of stress is the products and tools that individuals interact with daily, ranging from items such as cars and household appliances to simple objects like cups. Products that fail to meet necessary standards can be a source of stress and lead to serious negative consequences for users.

One of the fields of cognitive sciences that addresses these issues is neuroergonomics. However, before delving into user-product interactions, it is crucial to focus on the designer and the design process itself, as design is a complex cognitive activity that ranges from solving everyday problems to developing specialized solutions. This process, especially in professional environments, is invariably associated with stress. Therefore, designers face stress-inducing challenges in all aspects of their work. From this perspective, it is important to understand the extent to which designers are aware of their professional stress and how they respond to daily pressures and environmental triggers. Understanding how designers think and perform not only advances effective design methods and tools but also plays a fundamental role in enhancing the outcomes derived from them. If designers lack sufficient awareness of their stress and cannot find appropriate strategies for managing and controlling it, the stress can gradually become chronic, leading to serious physical and psychological consequences (How stress affects your health, 2013). Chronic stress can lead to diseases such as depression, Alzheimer's, cardiovascular disorders, and even cancer (Salleh, 2008). The American Psychological Association offers strategies to empower individuals in effectively coping with stress-inducing factors, some of which are outlined below:

- An individual must recognize the stress-inducing factors within themselves (Coping with stress at work, 2019). By identifying stressors, the individual will be able to manage and cope with them (Healthy ways to handle Life's Stressors, 2019).
- The individual must recognize the effects and disturbances caused by stress and understand the cause-and-effect relationship between them.
- The individual must be familiar with methods to induce relaxation and be able to manage the disturbances caused by stress (Coping with stress at work, 2019).

Based on the strategies provided by the American Psychological Association, this research aims to achieve the same understanding within the field of design studies. Initially, the designer should be aware of the presence of stress within themselves, recognize its causes, impacts, and levels, and, by employing coping strategies, control their stress or prevent the full or partial occurrence of its harmful effects.

1-4- Significance of the Research

Stress in design, particularly in professional environments, plays a fundamental and dual role in designers' activities. On the one hand, stress can negatively impact designers' performance and the quality of their final designs, resulting in stress-inducing products for users. On the other hand, chronic stress has long-term detrimental effects on designers' physical and psychological health, job satisfaction, professional standing in society, and overall quality of life. However, a balanced level of stress can act as a positive factor, improving designers' performance and leading to the creation of higher-quality products. Accurately identifying the sources of stress, understanding its effects, and offering strategies for managing stress are of utmost importance. This understanding can help reduce designers' psychological stress and enhance their performance, ultimately fostering the design of more effective and user-friendly products. Despite the existing evidence on the significance of this issue, there is still no comprehensive and precise understanding of stress within the design process, its impact on designers and their performance, or methods for coping with it. Research in this field has been limited, generally addressing the topic in a broad and scattered manner, without sufficient attention to its deeper and more extensive dimensions. In the field of design stress research, most studies have focused on the relationship between stress, problem-solving tasks, and creativity, as well as its impact on personality traits. However, studies on the effect of stress on design creativity, as a critical component of the design process, have not received adequate attention. Another significant challenge in these studies is the limited sample sizes, where a larger statistical population, exceeding 30 participants, could enhance the accuracy of the results. Furthermore, most research in the fields of creativity and design focuses on engineering design, interior design, and architecture, while crucial design disciplines such as industrial design, product design, and service design have not received adequate attention. In addition, factors such as design thinking and complex, ill-structured, and ambiguous problems, which require extended time periods and can themselves be sources of stress affecting design quality and outcomes, have been overlooked. Other challenges include the scarcity of studies in this field, the lack of empirical and laboratory-based research, the provision of general opinions, the absence of a clear and comprehensive definition of stress in design, its various levels and concepts, the failure to investigate the types of stress in design, its impacts and mediators, methods for identifying and measuring this type of stress, and the lack of attention to internal and external stress factors affecting design. Furthermore, there is a lack of comprehensive and practical theories and models, robust theoretical frameworks, and a clear delineation of design activities that lead to stress. Research has predominantly concentrated on acute and chronic mental stress, exploring only one coping mechanism for design stress. These scientific gaps, coupled with the practical and educational benefits of understanding this topic, highlight the need for more comprehensive studies to better examine and manage the effects of stress on design, its processes, and activities. Therefore, systematically and scientifically investigating this issue is not only essential but could also fill existing gaps in this area and lay the foundation for new research approaches.

1-5- Objectives of the Research

Main Objectives of the Research

1. To define design stress
2. To propose an ontology for effectively modeling and representing design stress

Secondary Objectives of the Research

1. To recognize and propose methods for measuring and evaluating stress caused by the design thinking process
2. To recognize and analyze stress caused by the design thinking process
3. To recognize the effects of time constraints on stress levels and designers' performance during the design thinking process
4. To recognize the effects of handedness on stress levels and designers' performance in the design thinking process.
5. Investigating the effect of stress induced by the design thinking process on designers' emotional-cognitive experiences.

1-6- Research Questions

Main Research Questions

1. What is design stress?
2. How can an ontology be designed to effectively model and represent design stress?

Secondary Research Questions

1. How can stress caused by the design thinking process be measured and evaluated?
2. How can stress caused by the design thinking process be recognized and analyzed?
3. What are the effects of time constraints on stress levels and the performance of designers during the design thinking process?
4. How does handedness effects stress levels and designers' performance in the design thinking process?
5. How does stress induced by the design thinking process affect designers' emotional-cognitive experiences?

1-7- Definition of Research Variables

The clarification, analysis, and explanation of the research variables will help establish the conceptual framework and facilitate data analysis. In this study, the following variables are used:

1. **Stress Resulting from the Design Thinking Process**: This is a dependent variable measured throughout the various stages of the design thinking process. It arises from the design stages and, in turn, impacts the performance of designers.

2. **Designers' Performance**: As a dependent variable, designers' performance is influenced by stress during the different stages of the design thinking process, time constraints, and design expertise. In this study, the variable of designers' performance refers to a set of cognitive and executive abilities and capacities that are essential for carrying out various activities in the design thinking process. This performance is influenced by factors such as stress, which can have both direct and indirect effects on the ability, quality, and speed of task execution in design. Stress may lead to changes in the design process, decision-making, creativity, accuracy in performing different design stages, and ultimately, the final output. In other words, stress can significantly impact the design thinking process. In this study, designers' performance was measured and analyzed based on EEG data, without directly referencing design outcomes or final results. By utilizing EEG data and machine learning analyses, changes in designers' brain activity across different stages of the design thinking process were examined. These analyses provide the opportunity to assess different levels of designers' performance from cognitive and neural perspectives.

   The highest level of performance refers to a state in which designers exhibit optimized brain activity during various stages of the design thinking process, such as problem definition, idea generation, idea evaluation and selection, and idea implementation. This level is indicative of high cognitive abilities, focus, and appropriate mental rest. Conversely, the lowest level of performance refers to a situation in which designers experience stress or cognitive issues, leading to reduced cognitive efficiency in performing various design tasks. In other words, machine learning analyses based on EEG data allow us to simulate different levels of brain performance and evaluate designers' performance patterns throughout the design process.
3. **Time Variable**: As an independent variable, time can significantly impact the level of stress and the performance of designers. Time constraints might either exacerbate or mitigate stress levels and influence the decision-making and creative processes.
4. **Expertise Level**: Expertise, acting as an independent variable, may influence other variables, such as stress arising from the design thinking process and designers' performance. Experienced designers might have developed better stress management strategies and problem-solving skills, affecting their overall performance during the design process.

1-7-1- Stress

Stress is an inevitable aspect of human life, and in psychology, it refers to the physiological, emotional, cognitive, and behavioral responses of the body when faced with challenging conditions (Monroe, 2008). This concept is often associated with states such as anger, anxiety, and depression (Fattahi et al., 2020). From a psychological perspective, stress is defined as a potential threat in which individuals perceive the arising situation as exceeding their capacity to resolve it. This perception can result in reduced ability to cope with stressors and inflexibility in performance (Chauhan et al., 2015). The level of perceived stress in individuals is influenced by factors such as personal characteristics, lifestyle, life events, and occupational variables (Rollings et al., 2017).

Despite extensive research in this area, a precise and universally accepted definition of stress remains elusive, leading to inconsistent results in measuring its causes and effects (Fink, 2000; Monroe, 2008). In general, stress is one of the primary threats to health, as its management and control are challenging for affected individuals and can lead to diminished social and occupational performance (Bitran et al., 2009). The detrimental effects of chronic and severe stress on physiology, physical health, and mental well-being have been confirmed by numerous studies (Everly, 1986; Harris, 1991). Research has shown that prolonged exposure to stress can predispose individuals to serious mental disorders, including anxiety and depression. According to Grahn and Stigsdotter, many mental illnesses are the result of long-term stress and inadequate responses to it (Grahn & Stigsdotter, 2010).

Chronic stress not only alters individuals' physiological and psychological responses but also impacts their overall health and disrupts their daily functioning (Julia & Edward, 2008). Despite differing definitions, researchers agree that the emergence of stress compels individuals to either modify the conditions or adapt to them (Estura, 2007).

1-7-1-1- Stress Theories

In a comprehensive description of stress, three main components—individual, time, and environment—play a fundamental role. Stress, as a dynamic phenomenon, changes over time and is influenced by environmental conditions and individual characteristics. Personal traits such as age, gender, experience, culture, and physical condition significantly affect the level of stress perceived by an individual (Grassmann et al., 2017; McEwen & Stellar, 1993). The various definitions of stress can be classified into three general approaches.

In the first approach, stress is defined as an environmental stimulus, one that can provoke feelings of tension. In the second approach, stress is considered a response, encompassing the psychological and physiological reactions to disturbing changes. This approach primarily focuses on general adaptation syndromes. In the third approach, stress is seen as a complex network of factors, including stimuli, responses, individual characteristics, evaluations, and coping styles, all of which interact with each other (Estura, 2007).

From the perspective of Lazarus and Folkman, stress is an interactive phenomenon between the individual and the situation, depending on the individual's assessment of the conditions and their ability to cope with them (Lazarus & Folkman, 1984). This view considers stress as a result of the individual's evaluative judgment of events and situations. According to this approach, individuals evaluate stressors as threats based on their personality traits, experiencing varying levels of stress (Pourmohammadi, 1399; Mirmandi, 1398). In other words, stress is a state that results from the interaction between the individual and the environment, creating a mismatch between the demands of the situation and the individual's biological, psychological, and social resources (Sarafino, 1974).

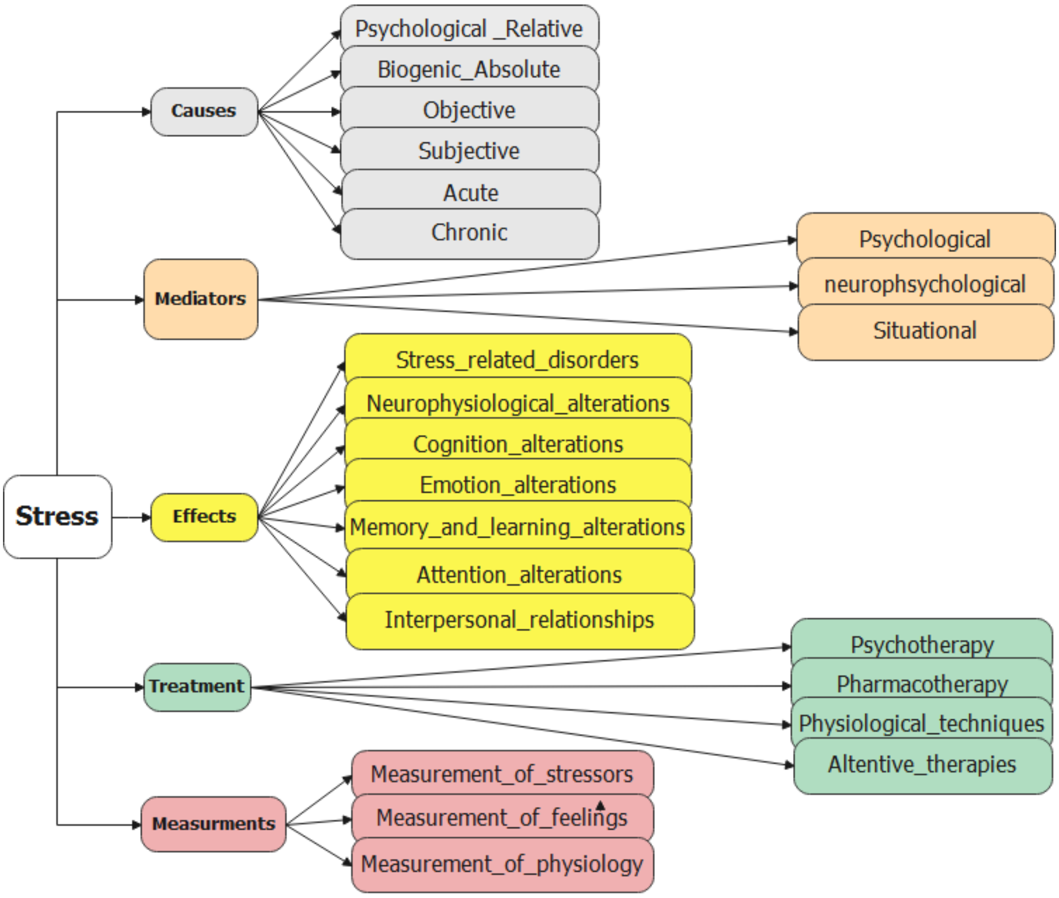

Figure 1-2: Ontology of Human Stress

Source: Nasiri Khoozani & Hadzic, 2010: 260

1-7-1-2- Ontology of Human Stress

The first attempt to classify all information and findings related to stress was made by Hans Selye through the development of a symbolic system (Selye & Miklos, 1958). Since then, various researchers have proposed numerous systems to categorize concepts associated with stress, including coping strategies (Ryan & Wenger, 1992). One of the most comprehensive systems is the *Encyclopedia of Stress*, which organizes hundreds of stress-related concepts into subject categories and provides articles, definitions, and explanations for each concept (Fink, 2007). In this context, this research adopts the classification of stress-related information based on the article "Ontology of Human Stress." The purpose of this ontology is to discuss and analyze some common stress-related terms, provide definitions, establish classifications, and identify interrelationships among these concepts. The ontology is structured into five main components: causes of stress, stress mediators, effects of stress, stress management, and stress measurement (Figure 1-2). Each component encompasses associated concepts and categories. This classification is designed to create a hierarchical structure of stress-related concepts and categories, revealing interconnections and potential linkages among them. All concepts within the domain of human stress knowledge are organized into relevant categories under this ontology. Such a structure enables a more detailed observation and systematic analysis of the relationships between various categories, thereby contributing to a deeper understanding of stress mechanisms (Nasiri Khoozani & Hadzic, 2010: 260).

1-7-1-3- Types of Stress

Stress is one of the most significant human responses to life's challenges and pressures, and it can have various effects on individuals. Broadly speaking, stress can be categorized into different types, each with its own characteristics and impacts. Below, the different types of stress and their effects on individuals are explained:

- **Eustress:** Eustress refers to a type of stress that motivates individuals toward effort, growth, and achievement while activating hidden energy reserves. This form of stress contributes to personal development and success and is essential for both the body and mind. The absence of eustress in life can lead to feelings of apathy and boredom (Brian, 2002). Eustress typically occurs in situations where manageable challenges are present, such as starting a new job or preparing for an important exam. This type of stress can enhance resilience and improve overall well-being.
- **Neutral Stress:** Neutral stress has neither positive nor negative effects. For instance, learning about an incident in a remote part of the world may trigger neutral stress. This type of stress typically has minimal impact on an individual's mental or physical state and does not elicit a strong emotional or coping response (Arfa & Jazayeri, 2014: 18). Neutral stress may simply serve as a reminder of one's surroundings without imposing significant pressure or tension on the individual.
- **Distress:** This type of stress includes two categories: acute stress and chronic stress. Acute stress is an immediate reaction that disrupts an individual's calm and inner balance but quickly subsides. The negative effects of this type of stress are typically transient and, with effective management, do not lead to long-term problems. However, if the individual is unable to respond appropriately to this stress, it may result in temporary issues in physical or psychological functioning. In contrast, chronic stress persists continuously and over a long period. Although it may not appear to be severe, its destructive effects, due to its duration, are highly significant. Chronic stress can lead to or exacerbate various physical and psychological disorders (Arfa & Jazayeri, 2014: 18). Research indicates that if an individual's level of stress exceeds their coping abilities and capacities, it may lead to psychological and physiological disorders in the long term (Cran, 1993:

76). This type of stress, particularly in high-stress environments, takes a more severe form and can result in conditions such as anxiety and depression. Many of these conditions are caused by long-term stress and inappropriate responses to it (Grahn & Stigsdotter, 2010: 266).

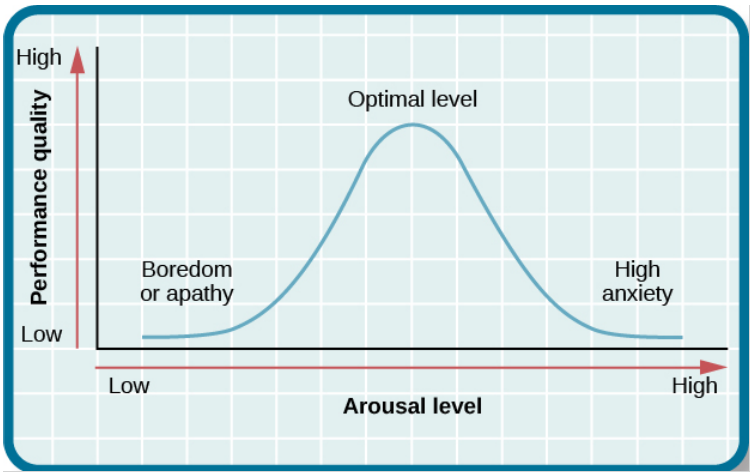

Figure 1-3: The Yerkes-Dodson Law of Arousal

Source: (Yerkes & Dodson, 1908).

According to this, two psychologists, Robert Yerkes and John Dodson, in 1908 introduced the Arousal Theory, which is an inverted U-shaped model (Figure 1-3). This theory, known as the Yerkes-Dodson Law, suggests that human performance is influenced by the level of arousal or stress. According to this model, individuals perform their best when they are at a moderate level of stress or arousal. This optimal level encourages greater activity, attention, and concentration. When stress or arousal is too low, individuals may become unmotivated and indifferent. In such conditions, the focus and energy required to perform tasks decrease, and performance declines. On the other hand, when stress levels are too high, it can lead to intense pressure, anxiety, and decreased focus. This situation may result in a significant drop in performance and even failure to complete tasks (Yerkes & Dodson, 1908).

1-7-1-4- Effects of Stress

In his research, Eysenck classified the effects of stress into four main types: emotional, physiological, cognitive, and behavioral (Eysenck, 2000). Each of these categories represents a different aspect of stress's impact on humans. Below, the details of each type are provided.

- **Emotional Effects**: These include feelings such as anxiety, depression, anger, and an increase in both psychological and physical tension. Stress hormones typically activate areas of the brain associated with depression. As a result, individuals experiencing chronic psychological pressure are more vulnerable to depression. These emotional effects can severely reduce an individual's quality of life and hinder their ability to manage daily challenges (Arfa & Jazayeri, 2014: 14).
- **Physiological Effects**: Stress affects two primary hormonal stress systems: the autonomic

nervous system (sympathetic nervous system) and the adrenal glands. The sympathetic nervous system is activated within fractions of a second, secreting hormones like norepinephrine and adrenaline. These hormones prepare the body for a rapid response. The adrenal glands, which operate more slowly, secrete cortisol, a hormone that plays a crucial role in stress management (Adli, 2011: 1). Physiological effects of stress include an increased heart rate, disrupted breathing, constriction of blood vessels, and digestive system disturbances (Sadeghpour, 2019: 30). These effects may lead to more serious problems, such as cardiovascular diseases, brain disorders, and even cancer (Bartun, 1980: 81).

- **Cognitive Effects**: Stress can impair an individual's cognitive abilities. According to Cohen, stress resulting from efforts to cope with stressors leads to reduced concentration, decreased short-term memory capacity, and increased distractibility. These cognitive effects can diminish an individual's efficiency in problem-solving and task management, and increase feelings of confusion (Khanifar, 2008: 6).
- **Behavioral Effects**: Stress can also affect individuals' behavior. One such effect is an increase in aggression when confronted with triggering factors. Stress can provoke more intense reactions to frustration, threats, or insults (Khanifar, 2008: 7). Additionally, stress may lead to a decrease in motivation, disruptions in sleep patterns, reduced academic and job performance, and social isolation. These behavioral effects can negatively impact quality of life and interpersonal relationships (Sadeghpour, 2019: 30).

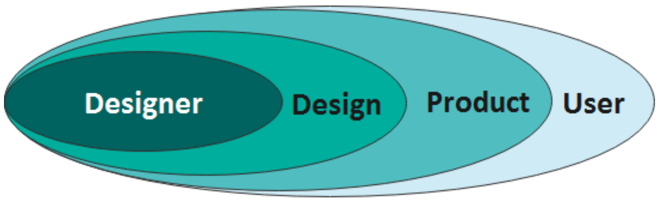

Figure 1-4: The Relationship Between Designer, Design, Product, and User

1-8-Theoretical Framework of the Research

The image above illustrates the relationship between the designer, design, product, and user, demonstrating how these elements interact (Figure 1-4). A designer creates a product for the user through the design thinking process. Design, as a profession, has various dimensions. It encompasses general aspects such as time pressure, employers, workload, and more, as well as specialized aspects such as analysis, decision-making, evaluation, problem-solving, and design evaluation, which designers encounter throughout the different stages of the design thinking process. Aside from the general and specialized characteristics of the design profession, the work environment or workspace where the designer creates the product, along with its ergonomics, impacts the designer and their performance. If this environment induces stress, it can influence the design outcome and the product.

Furthermore, design thinking, as a complex cognitive activity, involves multiple cognitive processes, each with its own specific stresses that designers frequently face and must be studied and researched. The present research will adopt a multi-phase approach to provide a comprehensive insight into design stress. This goal will be achieved step by step through various chapters of the research (Figure 1-5). The framework consists of several main sections, which will be explained in the following.

- **Systematic Review and Meta-Synthesis of Previous Studies**

In the first step, the research utilizes the PRISMA protocol to analyze and classify previous studies in the field of design stress. This phase includes a systematic review and meta-synthesis of studies in the design domain related to stress. The aim of this phase is to analyze existing studies in order to identify research gaps and provide a comprehensive perspective on the research conducted in this area. This will enable the development of a novel research domain and ontology for design stress, establishing a framework for future research opportunities in this field.

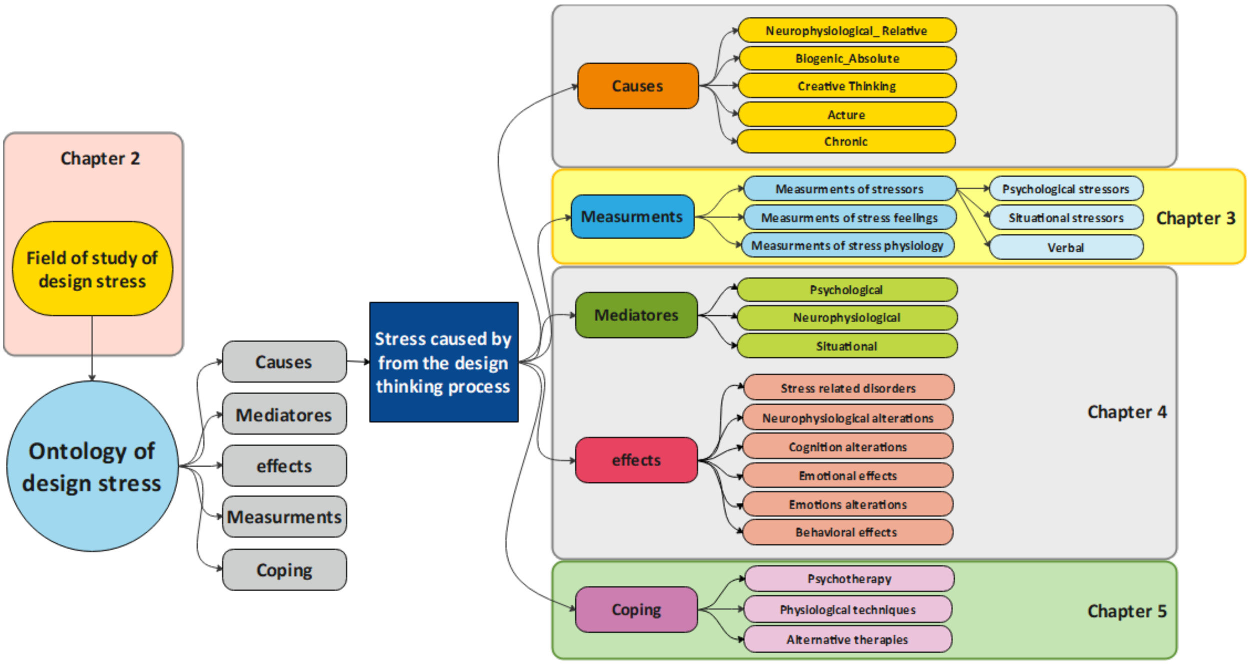

Figure 1-5: Overview of the Research in Five Chapters

- **Recognizing and Developing Methods for Measuring and Evaluating Design Stress**

The next step of the research focuses on examining and detailing various methods for measuring and evaluating design stress, and proposing novel approaches for this purpose. First, all existing methods will be reviewed, and the best and most suitable ones for measuring design stress will be selected and introduced. Then, based on these methods, stress caused by the design thinking process will be measured using a combination of methods and the innovative MetaCogno tool across several research steps. This step aims to recognize stress induced by the design thinking process, its impacts on designers and their performance, and ultimately to find suitable solutions for managing it across four steps: (1) problem analysis, (2) idea generation, (3) evaluation and selection of the final idea, and (4) implementation of the final idea and sketching.

- **Recognizing and Evaluating Stress Caused by the Design Thinking Process**

The design thinking process for a product is a long and challenging journey accompanied by various stresses. As shown in previous research, the level and intensity of stress vary across different steps of the design thinking process. This study will examine the most stressful step of design thinking, the temporal patterns, the distribution of states, the level and intensity of stress at each step of the design thinking process, and its impact on designers' performance. This research specifically focuses on the overall analysis of designers and a comparison among three main groups: designers working under time constraints versus those without time constraints, right-handed designers, and left-handed designers.

- **Evaluating Mental Health, Stress Levels of Designers, and Coping Strategies**

Several questionnaires and interviews have been used to evaluate the mental health, stress levels of designers, and their coping strategies, with the goal of identifying and explaining the stress caused by the design thinking process through precise and multi-dimensional analyses. In addition to helping determine the extent and levels of stress, these methods provide information about the coping strategies designers employ when facing stress. Ultimately, based on the results obtained, solutions for managing design stress and improving designers' performance will be proposed. The following image displays the steps of the current research.

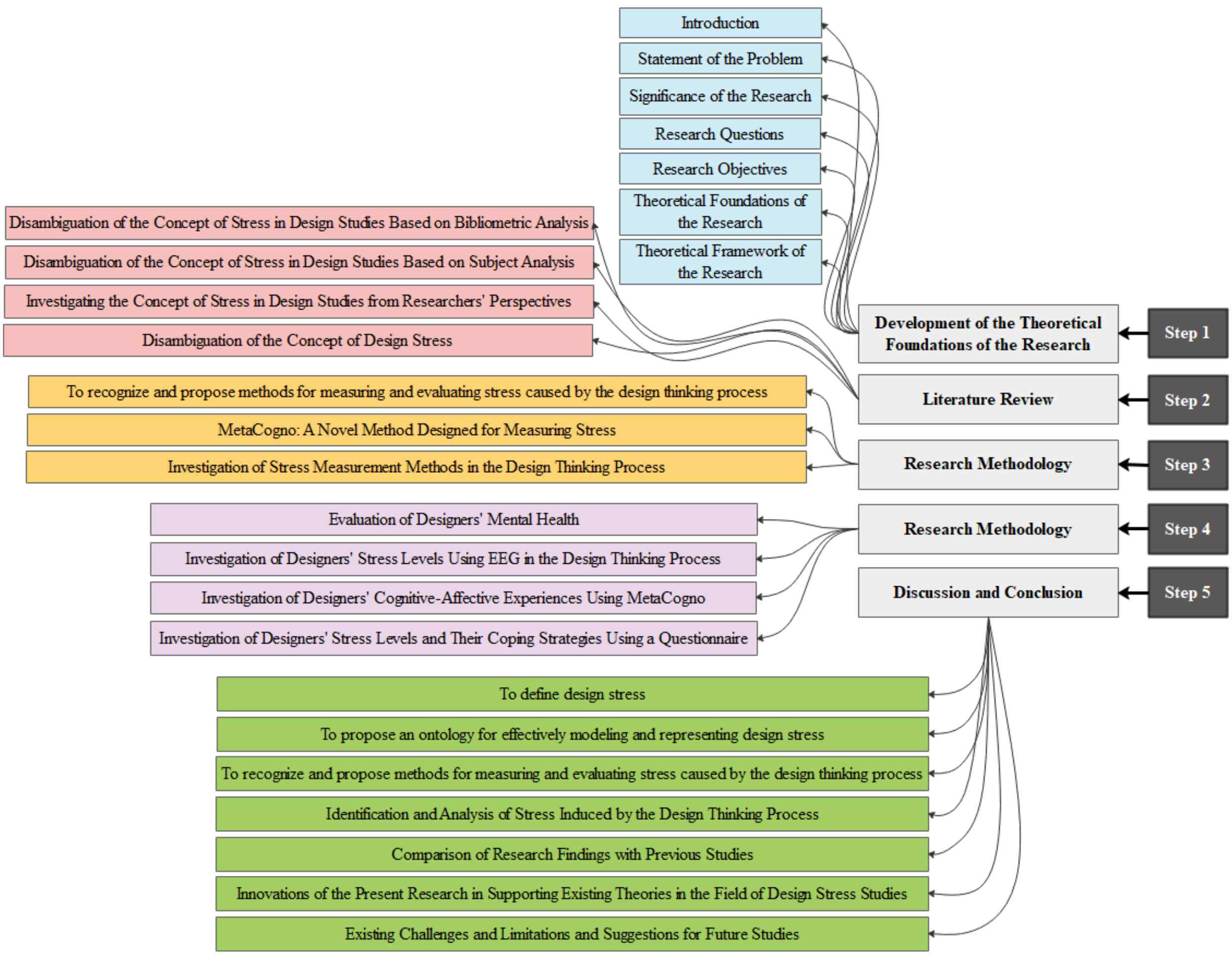

Figure 1-6: Research Process in Five Stages and the Results Obtained

Chapter 2
Literature Review

2-1- Introduction

Today, there is a vast volume of research on design, design thinking, and its processes. Numerous studies have described and explained the nature and mechanisms of design and its unique characteristics. Given the importance of this subject, the nature of design, the development of the design concept, and its impacts in various fields, as well as the significant growth of scientific journals in recent times, the importance of a systematic review and meta-analysis of the existing studies in this field is evident. One of the most crucial topics in contemporary scientific research is systematic review as a powerful method in the research process, reviewing the results of studies that have been published in articles, books, or dissertations. This importance is particularly evident in fields such as medical sciences; however, it has not received sufficient attention in areas of study like design.

While exploring new areas of study, frameworks, and modern theories, a systematic review of literature is essential to obtain accurate, complete, and comprehensive information to foster the development of new concepts. A systematic review is carried out by collecting and organizing precise data from all publications related to a specific phenomenon, ensuring full coverage and minimizing bias. Systematic reviews, when performed following prescribed protocols such as the PRISMA statement (Moher et al., 2009), are accurate, transparent, repeatable, and consistent with the standards of empirical research (Hay et al., 2017).

Therefore, this section of the current research aims to, for the first time, conduct a systematic and meta-analytic review of studies in the field of design studies that address the topic of stress. By following the PRISMA protocol, this review will analyze and evaluate the relevant literature, with the goal of presenting a new area of study and identifying challenges and opportunities for future research in this domain.

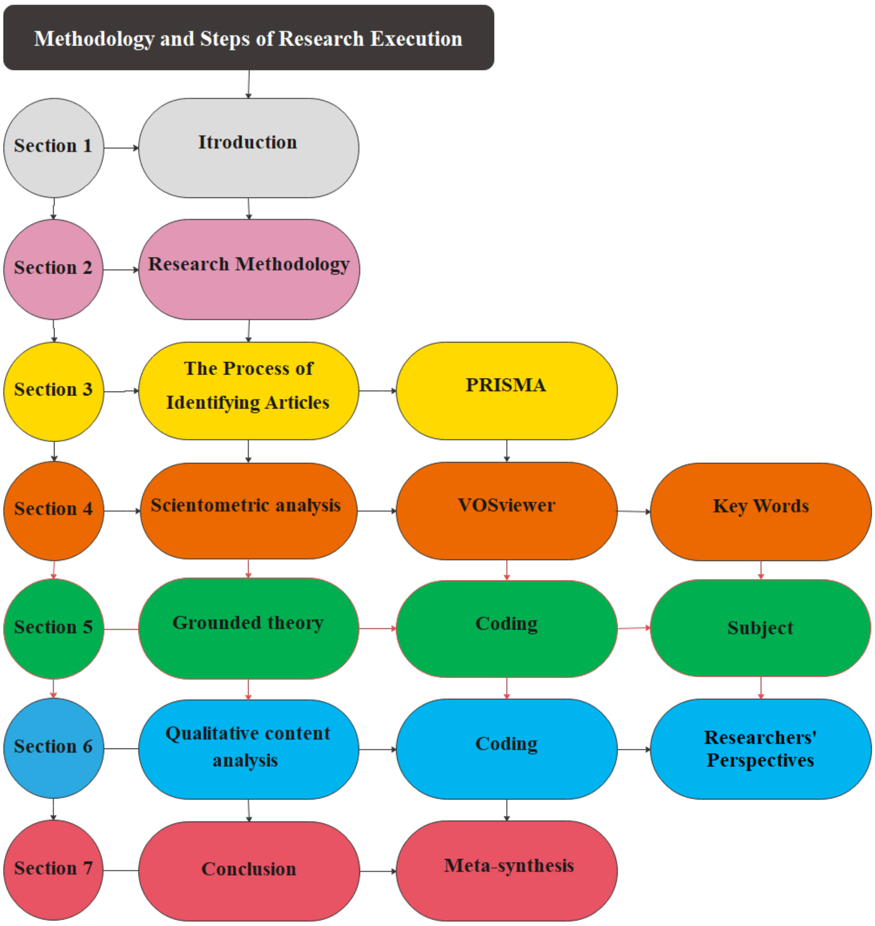

Figure 2-1: An Overview of the Research Process Stages in Chapter Two: Literature Review

2-2- General Outline

This study aims to explore research trends and emerging topics related to stress in design, with a comprehensive content and theoretical framework for understanding and further investigating its multiple aspects. Based on the PRISMA protocol, the research systematically reviews the existing literature. We identified 21 relevant articles by searching for keywords related to the design research domain and its branches and concepts (industrial design, product design, engineering design, architectural design, service design, graphic design, interior design, design thinking, conceptual design, design process, design creativity, and design problem-solving) in reputable scientific databases (Section 3). The research then employs bibliometric analysis using VOS viewer to quantitatively examine and analyze keywords from these articles (Section 4). For qualitative and Subject analysis of the existing literature, grounded theory is applied through three stages of coding: open coding, axial coding, and selective coding (Section 5). Content analysis is used to extract semantic units and analyze the underlying theories within the research area (Section 6).

In Section 7, findings from the previous sections are integrated, analyzed, and synthesized to define and outline a new research domain along with its broad dimensions. Section 8 presents the results of the research findings, discusses the challenges in this research area, and provides recommendations for future research. Figure 2-1 illustrates an overview of the research methodology (Figure 2-1).

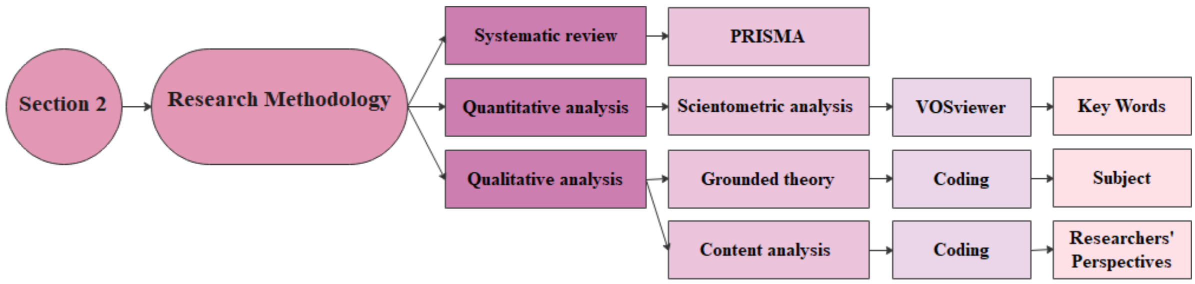

Figure 2-2: Overview of the Research Methodology in Chapter Two

2-3- Literature Review Methodology

This study falls under the category of research that involves the synthesis of studies and the use of integrative methods, employing meta-synthesis through multiple approaches and stages. Following the meta-synthesis process model, the data were analyzed, compared, and integrated. Meta-synthesis is a qualitative approach used to provide interpretations and theories by synthesizing and comparing qualitative studies within a specific domain (Sarasvathy, 2001). In other words, it offers new interpretations through the redefinition and reorganization of findings (Finfgeld-Connett, 2008). In this study, concepts related to the topic of stress within the field of design research were used as the basis for analysis, comparison, and integration. This research, which explores the existing literature on stress in design through a systematic review and meta-analysis, utilized both quantitative and qualitative methods for data analysis. Ultimately, this approach facilitates the development of a novel research domain enriched with comprehensive content and a robust theoretical framework, derived from the analysis of keywords, topics, theories, and trends identified in the studies. This process not only enhances the understanding of the subject matter but also offers valuable insights for researchers, addressing existing knowledge gaps within the field. The comprehensive view of the research methodology can be seen in the image below (Figure 2-2). The methodology employed comprises four main steps:

2-3-1- Systematic Review Using the PRISMA Protocol

A systematic review of previous studies employs a methodical, explicit, and transparent approach to identifying, selecting, and critically appraising research. It also involves collecting, analyzing, and synthesizing data from studies conducted in a specific field, treating the results as a single data set, and quantitatively summarizing the findings. The use of the PRISMA protocol enhances the effectiveness of systematic reviews and meta-analyses (Moher et al., 2009). PRISMA provides guidelines designed to improve and standardize the reporting of systematic reviews and meta-analyses. Consequently, authors of scientific papers rely on PRISMA guidelines for preparing and publishing systematic reviews (Dijkers et al., 2015).

The PRISMA flow diagram visualizes the flow of information through the different stages of a systematic review. It details the number of articles identified through library searches, the number of studies included or excluded, and the reasons for their inclusion or exclusion. The flow diagram comprises four main stages: the identification of articles, screening, eligibility assessment, and inclusion of relevant articles (Hay et al., 2017)

2-3-2- Bibliometric Analysis

Various methods are available for examining and analyzing the quantitative aspects of a collection of articles related to a specific journal, country, or topic. One widely used method is bibliometric analysis, which involves conducting a bibliometric analysis to obtain quantitative insights (Rialp et al., 2019). Bibliometric analysis falls within the realm of library and information science research and focuses on the quantitative study of bibliographic documents (Rialp et al., 2019; Laengle et al., 2021). This technique serves as a comprehensive and precise method for analyzing and sorting extensive scientific data. Its aim is to provide a shared understanding of the relationships between articles and offer an updated summary of the current or evolving state in a specific research field (Kuzior & Sira, 2022; Tamala et al., 2022). Researchers use this analysis for various reasons, including discovering content and intellectual frameworks in the literature, identifying new patterns in article and journal performance, and understanding collaboration patterns among researchers (Filho et al., 2022).

2-3-3- VOSviewer Software

Data visualization is a method that supports the understanding of structures and connections among thousands of documents. Specialized tools have been developed for this purpose, including the VOSviewer software. VOSviewer, which stands for "Visualization of Similarities," is used to study the links between articles and apply clustering in reference databases. This software primarily focuses on visualizing bibliometric networks using specialized algorithms for labeling and visual metaphors for data density (Barroso & Laborda, 2022; Mallick & Debasish, 2022; Laengle et al., 2021). It is renowned for its capability to visualize and create maps from bibliometric data efficiently, allowing for the compilation of literature and mapping of relationships between selected studies (Kuzior & Sira, 2022). Additionally, the tool can generate keyword co-occurrence maps and is compatible with databases such as WOS, PubMed, Scopus, CrossRef JSON, and RIS (Barroso & Laborda, 2022).

2-3-4- Grounded Theory

Grounded theory is an analytical tool used to systematically extract new concepts from data collected during research. Rather than testing existing theories, researchers use this approach to develop their own theories (Strauss & Corbin, 1994). The process includes open coding, axial coding, and selective coding, through which each article is carefully analyzed to identify key topics and concepts. In the open coding phase, each concept is assigned a code and label that reflect its content and meaning, with the codes being directly derived from the collected data (Miles & Huberman, 2002). In the subsequent phase, known as axial coding, the data is summarized under the primary categories of these concepts. This process involves categorizing similar codes into related groups through iterative reading and re-reading of the texts (Goulding, 2002; Boeije, 2010). Axial coding focuses on conceptualizing and moves from an open to a more specialized form, where the principal axes within the data are identified and future stages of the research are organized around these axes (Strauss & Corbin, 1994). Selective coding, the third step in grounded theory analysis and closely related to axial coding, focuses on the central axis of concepts. This step involves refining, integrating, and linking concepts (Strauss & Corbin, 1994; Lee, 2001), organizing them into a coherent theory through a specific arrangement of categories. In grounded theory, a new theory is developed by meticulously extracting data from study texts and categorizing it into three types of coding: open, axial, and selective.

This theory can be presented in three different forms: as a diagrammatic representation, an explanatory and narrative description, or a set of propositions (Creswell, 2005). Overall, this method is a process of designing and constructing a documented and systematic theory, approach, and research domain through the systematic collection and inductive analysis of data (Faragh & Ashari, 2023: 7).

2-3-5- Qualitative Content Analysis

Berleson, a pioneer in content analysis, introduces this technique as a research method for systematically and quantitatively examining the manifest content of messages (1952). Similarly, Weber (1991) defines content analysis as a research method for extracting reliable and replicable results from data derived from texts. This method is applied for analyzing textual and non-numerical data, with the goal of identifying themes and meanings within the data (Creswell, 2013). Typically, an inductive approach is used with content analysis to uncover underlying themes and categories through coding and is derived directly from systematically collected content throughout the research process. Coding (initial and core concepts), as a key step in this method, allows researchers to mark important textual segments with specific codes and categorize them into related conceptual groups (Braun & Clarke, 2006). Finally, the researcher analyzes and presents the results. Due to its focus on deeper and hidden meanings within data, this method is frequently used in the social sciences and humanities and can contribute to a deeper understanding of research topics (Saldana, 2015).

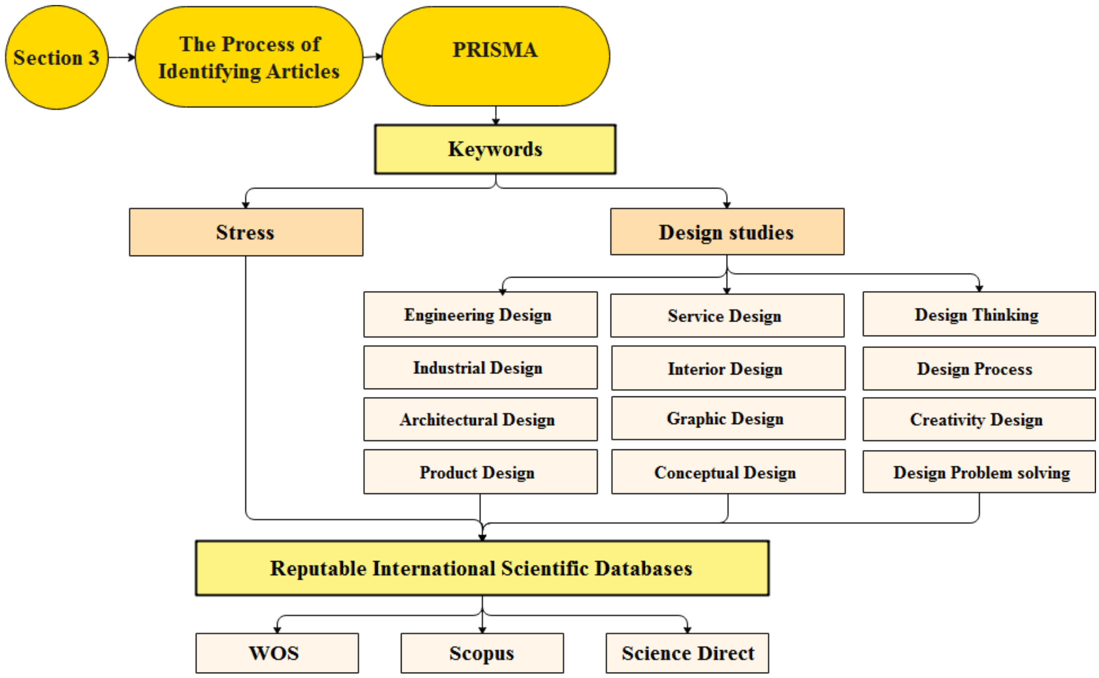

Figure 2-3: Research Methodology Section 3: Article Identification Process According to PRISMA Protocol

2-4- Article Identification Process According to PRISMA Protocol

Based on the selected protocol and its flowchart (Figure 2-3), the first step in identifying articles related to stress in the field of design involved searching reputable scientific databases. For this purpose, relevant keywords were first determined. These keywords were chosen based on a preliminary review of existing literature in the field of design studies and considering related disciplines and concepts. They were used in combination with the keyword "stress" for searching in reputable scientific databases. The keywords included were: (Engineering* and Design* and Stress*), (Industrial* and Design* and Stress*), (Architectural* and Design* and Stress*), (Product* and Design* and Stress*), (Service* and Design* and Stress*), (Interior* and Design* and Stress*), (Graphic* and Design* and Stress*), (Conceptual* and Design* and Stress*), (Design* and Thinking* and Stress*), (Design* and Process* and Stress*), (Design* and Creativity* and Stress*), (Design* and Problem-solving* and Stress*). The selection of these keywords was conducted with precision, aiming to obtain content closely related to the subject under investigation and to facilitate more effective searches. After selecting the keywords, searches were performed for articles published in English across reputable scientific databases without any temporal restrictions from 1975 to 2024. The top article search databases were reviewed, and among them, WOS (Web of Science), ScienceDirect, and Scopus were chosen for keyword searches (Figure 2-4). Searches were conducted on 06th of April 2023 to 15/04/2023, and to update and access new articles, the search was repeated on 1st of February 2024 to 05/02/2024[1].

[1] Detailed tables (Tables 1–4) are included in the Appendix section

Through the search of these twelve keywords in each of the three scientific databases, 201 articles were retrieved from the WOS database, 193 articles from the Scopus database, and 56 articles from the ScienceDirect database. In the initial screening phase, duplicate articles were identified and removed by searching for common keywords in the titles (searching four keywords together) within each database. This step was taken to avoid data repetition in the research. After the initial screening, the number of registered articles was 192 from the WOS database, 185 from the Scopus database, and 56 from the ScienceDirect database (Diagram 2). In the second screening stage, duplicate articles obtained from all scientific databases were removed. The number of articles remaining after the second screening was 201. At this stage of the research, the suitability of the remaining articles for quantitative and qualitative analysis was assessed.

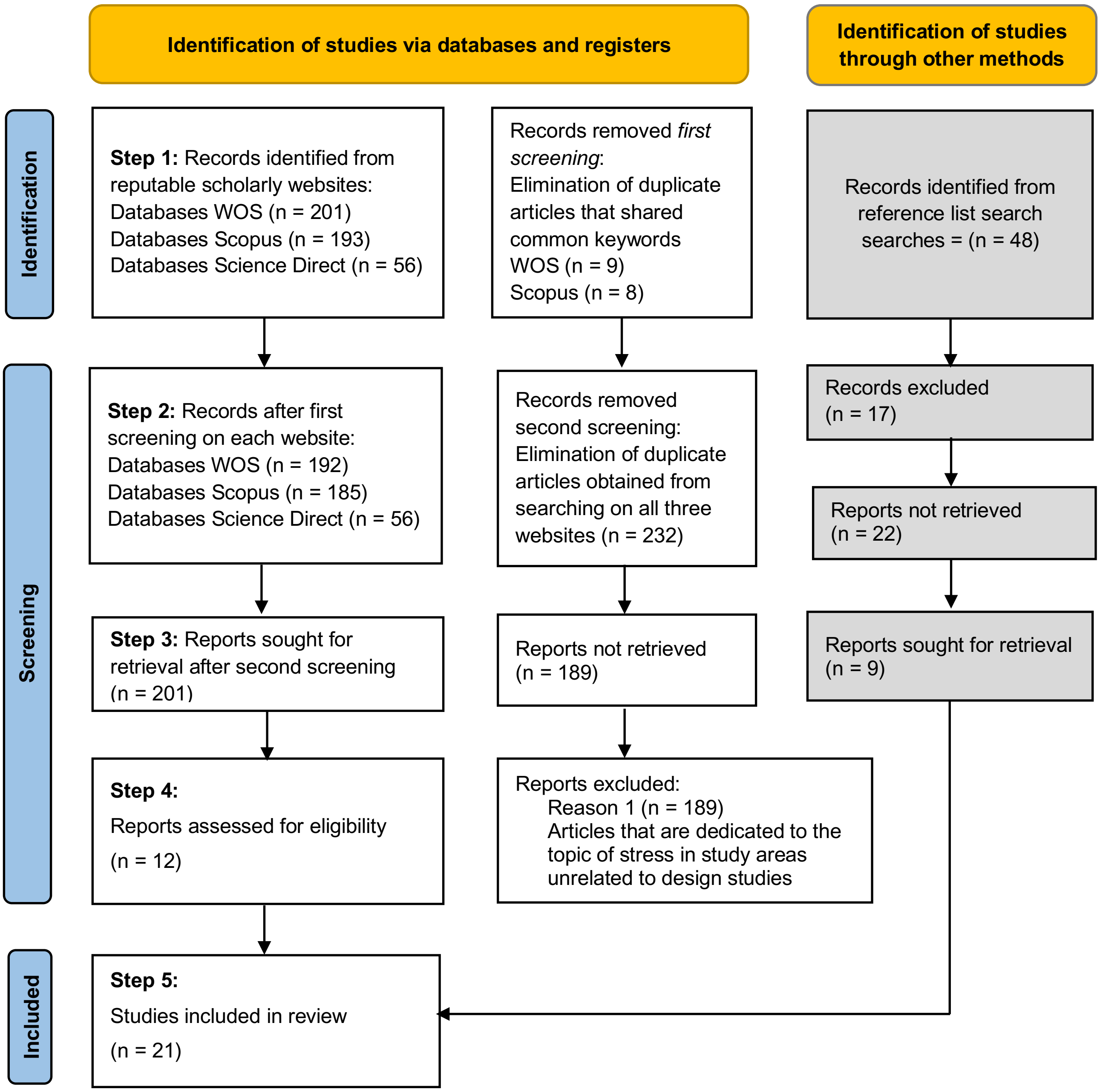

Figure 2-4: PRISMA Flow Diagram

To this end, the main inclusion criteria for the review were established, and articles were evaluated based on these criteria. The texts of the articles registered after the second screening were thoroughly reviewed, and articles that met the inclusion criteria were selected. Other articles were excluded with specified reasons (exclusion criteria). In this phase, 189 articles were removed, leaving only 12 articles. One of the main reasons for the high number of excluded articles was the use of the keyword "design" in its general sense in many articles. This research aimed to obtain articles that used the term "design" specifically and professionally in the context of design studies. Additionally, many of the identified articles dealt with topics in cognitive sciences, psychology, management, and business, with only a few of them being relevant to the focus of this research. Therefore, articles related to design studies, fields, and concepts pertinent to the topic of stress were considered as inclusion criteria for eligible articles, while articles focusing on stress in unrelated study areas were considered exclusion criteria and were removed from the study. To identify all relevant articles for the current research and improve accuracy, additional study records were also reviewed. This review was conducted by examining the reference lists of the identified articles. At this stage, 48 articles were identified, of which 17 articles, previously identified through keyword searches and deemed duplicates, were removed during the initial screening. Subsequently, the full texts of the remaining 22 articles were carefully reviewed, and based on the inclusion and exclusion criteria outlined, 13 articles were excluded, leaving only 9 articles deemed suitable for evaluation. Ultimately, the number of articles deemed eligible for final evaluation and analysis, which were identified through keyword searches in academic databases and additional record reviews, totals 21 articles. These articles fall within the scope of design studies and address the topic of stress and its impact on designers, the design profession, design products, and design creativity in the areas of product design, engineering design, interior design, and architectural design (Figure 2-4).

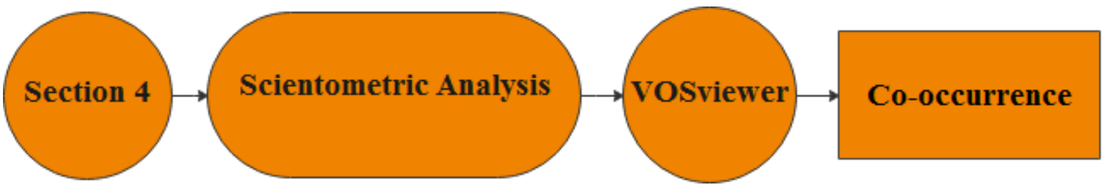

Figure 2-5: Research Methodology Section 4: Co-occurrence Analysis of Design Studies on Stress Using Bibliometric Analysis Methods

2-5- Bibliometric Analysis of Design Studies on Stress Using VOSviewer

In the initial step of this research, previous studies in the field of design related to stress were identified through reputable scientific databases. This process began with the search and screening of keywords related to the subject area and led to the identification of 21 qualified articles suitable for evaluation. In the continuation of this research, this section will focus on bibliometric analysis, where these articles will be quantitatively analyzed using the VOSviewer tool. This will involve the co-occurrence analysis of the selected articles to provide an overview of the primary keywords in these studies. Using this software, three types of mapping visualizations can be created: network visualization maps, overlap network maps, and data density maps (Kuzior & Sira, 2022).

In the network visualization view, nodes are represented with labels, which are by default displayed as circles. The larger the weight of an item (such as keywords), the larger the label appears. The color of an item is determined by the cluster to which it belongs. Lines between items indicate the connections between them. In these maps, the distance between two items reflects the strength of the connections between them. A smaller distance signifies a stronger connection, meaning that the two items frequently appear together in a paper, and there is a higher likelihood of these two items appearing in the same paper. In the overlap network visualization view, the functionality is similar to the network visualization, with the distinction that the display of items is based on their coloring. The color of each item is determined by the average publication year score. Additionally, data density mapping is more useful for illustrating the overall structure of the map and highlighting the most important areas of the map. The color of the points on the map is determined by the density of the item in question. The density of an item at a point on the map depends on the number of neighboring items and the weight of these items (Fallah Barzeghar & Khalili, 2022). The diagram above illustrates the methodology for this phase of the research (Figure 2-5).

2-5-1- Co-occurrence Analysis

In this analysis, the 21 identified articles in the field of design related to stress were obtained in Excel format from scientific databases and uploaded into the VOSviewer software. This analysis is of the co-occurrence type, which examines the simultaneous occurrence of three keywords among all keywords in the identified articles in this research area. According to the results of this analysis, 12 keywords were identified in the fields of design and stress, with the co-occurrence links between these keywords calculated. 25% of the total keywords (3 keywords), namely "stress," "mental stress," and "cognitive stress experience," pertain to the field of stress, while 75% of the total keywords (9 keywords), including "design," "design activity," "engineering design," "product design," "conceptual design," "design process," "design creativity," "conceptual ideation," and "conceptual selection," belong to the field of design.

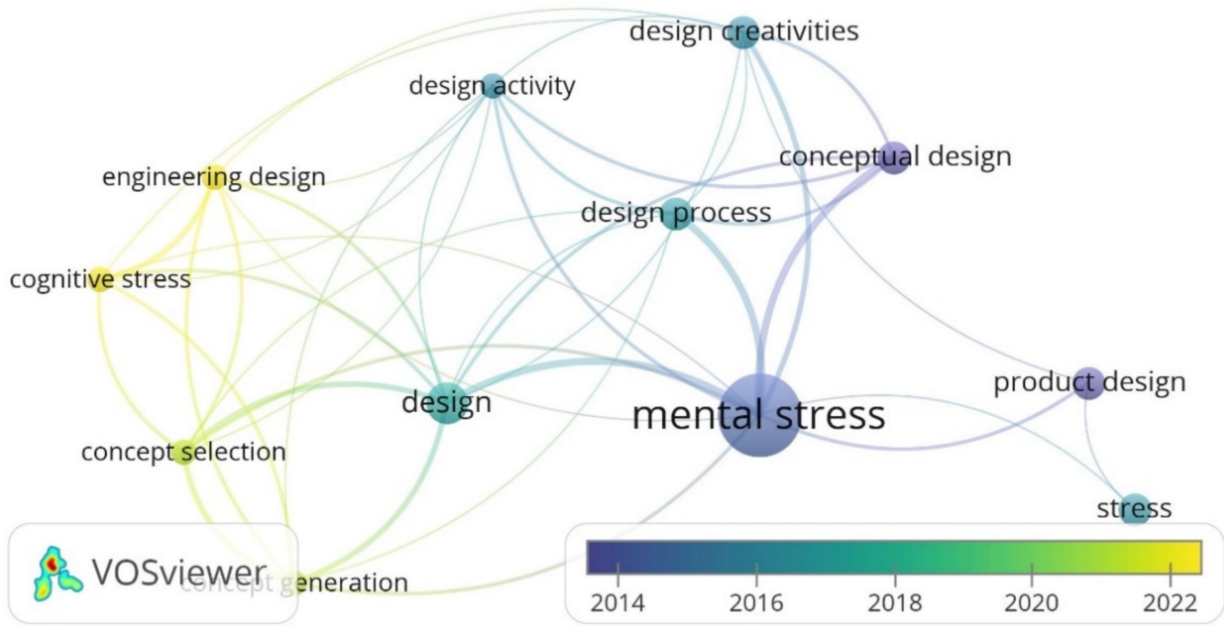

Figure 2-6: Visualization of the Co-occurrence Network Analysis in the Field of Design Related to Stress

The keyword "mental stress" has the highest link strength of 30 and a co-occurrence frequency of 10, ranking first in the studies. Following this, the keywords "design" with a link strength of 21 and a co-occurrence frequency of 5 are ranked second, while "conceptual ideation" and "conceptual selection," with a link strength of 16 and a co-occurrence frequency of 3, are ranked third. The figure below shows an overview of the co-occurrence network visualization, based on the simultaneous occurrence of three items (co-occurrence) and all keywords. It illustrates that, in the field of design, researchers' focus up until 2015 was primarily on mental stress, but in recent years, there has been increased attention to cognitive stress experience and its related concepts within this field (Figure 2-6).

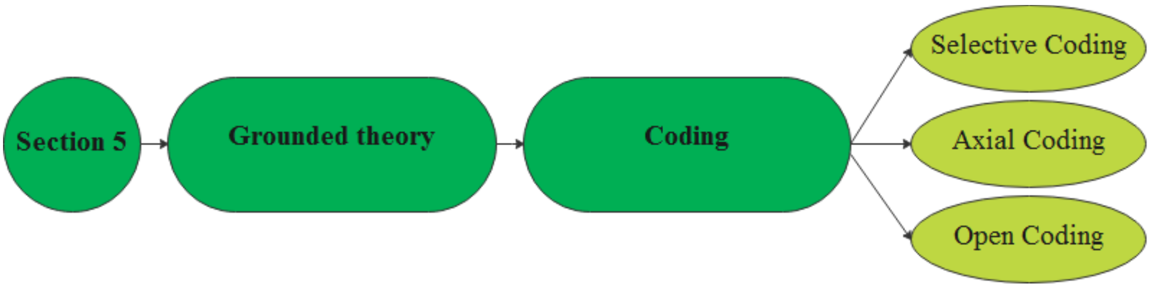

Figure 2-7: Research Methodology, Section 5: Subject Analysis of Articles in the Field of Design Related to Stress Using Grounded Theory

2-6- Analysis of Design-Related Studies on Stress Using Grounded Theory

Following the identification of relevant articles using the PRISMA protocol and their quantitative analysis through bibliometric analysis and co-occurrence analysis with the VOSviewer tool, this section of the research employs grounded theory to qualitatively analyze these articles. The analysis is conducted in three main stages: open coding, axial coding, and selective coding. This process examines and analyzes the subject content of the qualified articles to address the research questions. The strategy aims to develop a comprehensive understanding of stress within the design studies domain (Figure 2-7). Table 5 consolidates all identified articles related to design and stress that meet the criteria for final evaluation and analysis, providing a comprehensive overview. This table categorizes key information about each article into separate columns. The essential details recorded in this table include article codes, titles, the journals that published the articles, the authors and researchers involved, the study areas and objectives, the results of these studies, and the publication years (Table 2-1).

Table 2-1: Qualified Articles for Evaluation in the Field of Design Studies on Stress

Code	Title of Article	Journal Name	Authors	Research Area	Objectives	conclusion	Year
A1	No time for that? An investigation of mindfulness and stress in first-year engineering design	Design Science	Nolte, H., Huff, J. & McComb, C.	Engineering design	The Impact of Mindfulness on the Cognitive Stress of Novice Engineering Design Students	A slight increase in one aspect of mindfulness	2022
A2	The cognitive experience of engineering design: an examination of first-year student stress across principal activities of the engineering design process	Design Science	Nolte, H. & McComb, C.	Engineering design	A study of the cognitive experience of novice engineering design students during concept generation, concept selection, and physical modeling	The presence of cognitive experiences and varying effects of stress throughout the design activity	2021
A3	Identifying Stress Signatures Across the Engineering Design Process: Perceived Stress During Concept Generation, Concept Selection, and Prototyping	IDC	Nolte, H. & McComb, C.	Engineering design	An exploration of the designer's cognitive experience, physiological response, and perceived stressors during concept generation, concept selection, and physical modeling	The presence of mental stress in design	2020
A4	Investigating the relationship between mindfulness, stress and creativity in introductory engineering design	Design Science	Nolte, H. & McComb, C	Engineering design	The impact of an MBA on cognitive stress and design creativity	No impact on stress and design creativity in engineering design	2023
A5	A pilot Study to assess designer' mental Stress and electroencephalogram	IDET/CIE	Petkar, H., Dande, Sh., Yadav, R., Zeng, Y. & Nguyen, Th. A	Design	Evaluation of cognitive stress based on EEG signal analysis and eye-tracking data	A strong correlation exists between recorded physiological signals and the emotional state of designers	2009
A6	Influence of Information Collection Strategy on Designer's Mental Stress	ICED	Zhao, M. & Zeng, Y	Engineering design	Investigating the Quantitative Relationship Between Information Gathering Strategies and Designers' Mental Stress	The Impact of Information Gathering Strategies on Designers' Mental Stress	2019
A7	A novel approach to quantifying designer's mental stress in the conceptual design process	IDET/CIE	Zhu, Sh., Yao, Sh & Zeng, Y	Engineering design	Mitigating Designers' Mental Stress During the Conceptual Design Process	Providing a Formal Definition of Mental Stress Using ROM: Displaying the Dynamic, Nonlinear, and Complex Nature of Designers' Mental Stress	2007
A8	Distribution of mental stresses during conceptual design activities	ICED13	Nguyen, TH. A. & Zeng, Y.	Engineering design	Distribution of Mental Stress Levels in a Conceptual Design Process	Decrease in Design Activity with Increased Levels of Mental Stress and Lack of Correlation between Design Activities and Mental Stress	2013
A9	A physiological study of relationship between	Computer-Aided	Nguyen, TH. A. & Zeng,	Engineering design	Providing a Method for the Relationship	Minimal Cognitive Effort at High Levels of Mental	2014

Code	Title of Article	Journal Name	Authors	Research Area	Objectives	conclusion	Year
	designer's mental effort and mental stress during conceptual design	Design	Y.		between Designers' Mental Stress and Cognitive Effort	Stress	
A10	Stress assessment based on Ergonomics coupled with image-processing tools and techniques for lean product design and development	J. Chin. Inst. Eng.	Wasim, A., Siddique, M. R., Sajid, M., Hussain, S., Jahanzaib, M.& Muhammad Khan, A.	Engineering design	Identifying Facial Stress Levels by Integrating Image Processing Tools and Ergonomics for Lean Product Design and Development	Providing LET for Measuring Mental Stress Using Ergonomic Principles	2019
A11	Design for relaxation: a model for understanding stress for designers	ICED17	Stoop, M. & Snelders, D	Industrial Design	Creating a Model Named "Design for Calmness"	Presenting a Model with 5 Potential Strategies for Designers to Use in Designing Stress-Related Products	2017
A12	Critical stress factors influencing architecture students in Turkey: a structural equation modelling approach	Open House International	Ayalp, G. G. & Çivici, T	Architecture design	Identifying Stress Factors Affecting Architecture Students	Identifying 11 Critical Factors Affecting Stress Levels in Architecture Students	2021
A13	Can architectural design alter the physiological reaction to psychosocial stress? A virtual TSST experiment	Physiology & Behavior	Lars Brorson Fich., & et. all	Architecture design	Physiological Stress Response Differentiates with Specific Design Tasks	Impact of Architectural Space Design on Stress Response	2014
A14	The New Architectural Ethics: Responding to Ethical Stress from Changing Roles in Practice	J. Archit. Plan. Res.	Daniel Leo Faoro & Sarah A. Merrill	Architecture design	Exploring Professional Ethics Issues in Architecture	The Direct Link Between Professional Ethics and Philosophical Principles and Ethical Theories: Enhancing Performance and Upholding Ethical Values in Architecture	1990
A15	Mind the T-Square: Mindfulness-Based stress reduction for design students and its modes of action on studio performance and critique anxiety	Int. J. Des. Educ.	Ceylanlı, Z., Engin, E. & Bengü, M	Interior Architectural Design	Examining the Effects of Mindfulness-Based Stress Reduction in Design Workshops and the Reduction of Anxiety from Critique Discussions	Improving Performance and Reducing Anxiety in Design Students through Mindfulness-Based Training	2020
A16	Design Thinking for Innovation. Stress Testing Human Factors in Ideation Sessions	The Design Journal	Knight e, J., e& t al	Architecture design	Understanding the Factors Influencing Successful Team Ideation	Strong Impact of Factors Such as Physiological Conditions and Professional Background on the Quantity and Quality of Ideas Generated	2019
A17	Understanding Student Perceptions of Stress in Creativity-Based Higher Education Programs: A Case Study in Interior Architecture	J. Inter. Des.	Dianne Smith., & Linda Lilly	Interior Architectural Design	How Stress and Experience are Articulated During Professional Creativity Courses in Interior Architecture	Tension as a Contextual Factor for Stress Induction in Students	2016
A18	Influence of information collection strategy in problem formulation on design creativity through mental stress: a theoretical analysis	ICED15	Wang, X., Nguyen, TH. A. & Zeng, Y	Engineering design	The Impact of Information Gathering Strategies on Creativity through Designer's Mental Stress	Identifying Three Strategies for Information Gathering in the Problem Formulation Process	2015
A19	Effects of acute stress on divergent and convergent problem-solving	Thinking & Reasoning	Duan, H., & et. al	Creativity	Examining the Effects of Acute Stress on Creative Problem-Solving	Reducing Stress to Enhance Problem-Solving Flexibility	2019
A20	Team intuition as a continuum construct and new product creativity: The role of environmental turbulence, team experience, and stress	Research Policy	Dayana, M, & Di Benedetto, C., A.	Creativity	Presenting a Conceptual Model of Team Intuition and Its Impact on Generating New Creative Products	The positive relationship between team intuition and new product creativity, particularly in experienced teams with low stress levels	2011
A21	A Theoretical Model of Design Creativity: Nonlinear Design Dynamics and Mental Stress-Creativity Relation	JIDPS	Nguyen, TH. A. & Zeng, Y.	Engineering design	Designing a theoretical model for creative design	The relationship between design creativity and mental stress of the designer follows an inverted U-shape	2012

In this stage of the current research, the focus is on coding the articles and classifying the concepts directly extracted from the data. These codes are organized in a table, which consists of four sections. After repeatedly studying the text of all eligible and suitable articles with a high degree of precision, and based on their titles, objectives, and results, the main themes were identified and listed as open coding in the second column of Table 6. In the second phase of coding, related topics were grouped around a common axis to identify the main themes of the articles and to clarify the relationships between the topics. This phase of coding is represented as axial coding in the third column of the table. Finally, in the last column, the core themes of the articles were identified and listed based on the main axes (Table 2-2).

Table 2-2: Coding of Eligible and Suitable Articles Using Grounded Theory Method

Article codes	Open coding	Axial coding	Selective coding
	Main topic of the articles	Key themes of the articles	Core essence of the articles
A1-A4-A5-A10	The Impact of Mindfulness on Mental Stress Among Designers in the Engineering Design Process	Mental stress caused by engineering design process	Design process stress
			Mental stress
		Stress reduction through mindfulness	Mindfulness
A2-A3	An Examination of Mental Stress Among Designers in Core Activities of the Engineering Design Process	Mental stress caused by engineering design process	Design process stress
			Mental stress
A6	Investigating the Impact of Information-Gathering Strategies on the Mental Stress of Engineering Designers	Mental stress caused by engineering design process	Design process stress
			Mental stress
A7-A8-A9	Examining Mental Stress in Designers During the Conceptual Design Process	Mental stress caused by conceptual design process	Design process stress
			Mental stress
A11	Proposing a Model for Designers to Create Stress-Inducing Products	Product -induced stress	Product stress
A12	Identifying Stress-Inducing Factors Affecting Architecture Design Students	stress caused by architectural design	Architectural design stress
A13	Examining the Impact of Architectural Space Design on the Physiological Stress Response	Physiological stress caused by architectural design	Architectural design stress
			Physiological stress
A14	Investigating Moral Stress Arising from Role Changes in Architectural Practice	Moral stress caused by architectural design	Architectural design stress
			Moral stress
A15	Reducing Stress Through Mindfulness-Based Techniques for Interior Designers	Mental stress caused by interior architectural design	Interior architectural design stress
			Mental stress
		Stress reduction through mindfulness	Mindfulness
A16	Examining Human Factors-Related Stress in Brainstorming Sessions for Interior Designers	Mental stress caused by interior design	Interior architectural design stress
			Mental stress
A17	Exploring the Expression of Stress During Professional Creativity Training in Interior Architecture	Stress caused by interior architectural design	Interior architectural design stress
		Stress caused by design creativity	Design creativity stress
A18	The Impact of Information Gathering Strategies on Creativity Through Designer's Mental Stress	Mental stress caused by engineering design process	Design process stress
			Mental stress
		Stress related to engineering design creativity	Stress and design creativity
A19	Examining the Effects of Acute Stress on Creative Problem-Solving	Stress related to engineering design creativity	Design creativity stress
		Stress related to design issues	Design problem-solving stress
A20	Examining the Relationship Between Team Intuition and New Product Creativity in Experienced Teams with Low Stress	Stress related to product design creativity	Product design stress
			Design creativity stress
A21	Exploring the Relationship Between Design Creativity and Designer's Mental Stress	Mental stress related to engineering design creativity	Design creativity stress
			Mental stress

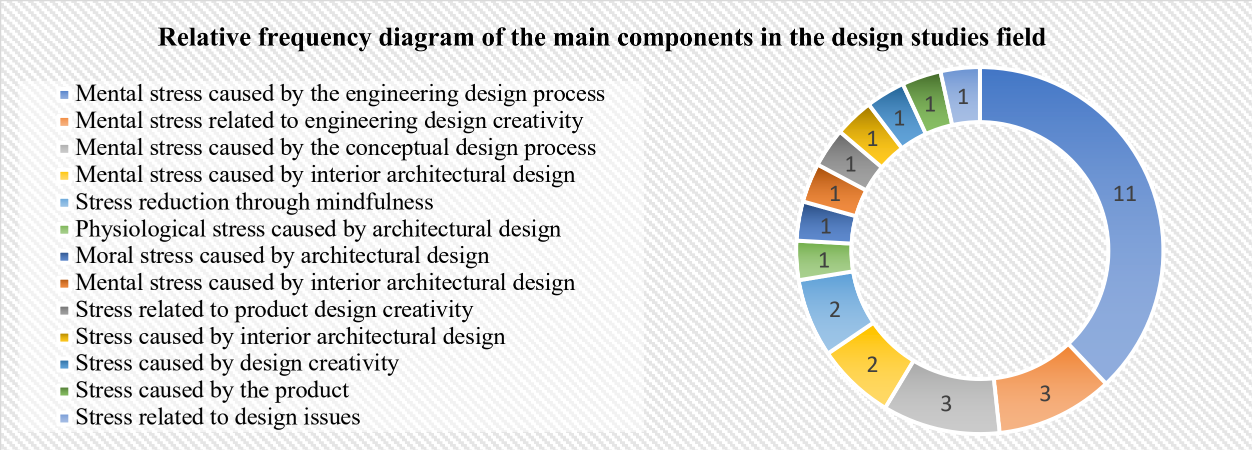

Figure 2-8: Main Themes of Articles in the Design Study Area on Stress

With a detailed analysis of the data extracted from the relevant table in the second coding phase, a visual and comprehensible chart illustrating the relative frequency distribution of the main themes derived from the articles can be presented. This visual representation clearly illustrates the distribution of studies, emphasizing that stress related to the engineering design process, with eight studies, has garnered the most research attention. This highlights the critical role of stress in the engineering design process and underscores the need for further investigation into its effects on designers and the design process as a whole (Figure 2-8). During the coding stages of this research, 15 main topics from articles in the field of design studies on stress were identified through open coding. These were categorized into 14 main themes through axial coding, and finally, distilled into 11 core categories through selective coding (Table 2-2). The final stage of the coding process involves synthesizing and explaining the relationships between these concepts to develop a new theory. In this final stage, after analyzing the focus of the research on these core categories, they were matched based on similarity and connections, and classified into three main subject categories: "Design Studies Focused on the Topic of Stress," "Design Studies Focused on Types of Stress," and "Design Studies Focused on Stress Coping Strategies". Table 2-3 analyzes the first category: "Design Studies Focused on the Topic of Stress." These studies investigate various types of stress in different design fields, such as engineering design, architectural design, interior architecture, and product design. All eligible articles for evaluation fall into this category. The stress examined in these studies is primarily related to the design process, creativity, and problem-solving, with a reciprocal influence on each other. These studies can be categorized based on their primary research focus into a single Subject area named "Design (Table 2-3).

Table 2-3: Design Studies Focused on the Topic of Stress and Their Main Subject Areas

Article codes	Stress-focused design studies	Articles number	Subject area	Total articles number
A1-A2-A3-A4-A5-A6-A7-A8-A9-A10-A18	Design process stress	11	Design stress	21
A17-A18-A19-A20-A21	Design creativity stress	5		
A15-A16-A17	Interior design stress	3		

A12-A13-A14	Architectural design stress	3		
A19	Design problem-solving stress	1		
A20	Product -induced stress	1		
A11	Product stress	1		

Based on the data provided in Table 2-3 the relative frequency distribution is presented in the following chart. This chart specifically highlights those studies focusing on stress related to the design process constitute the largest portion of the research, with eleven studies. Studies addressing creativity in design follow, with five studies. Research on stress related to interior and architectural design includes three studies, reflecting notable interest among scholars. Conversely, studies related to stress in problem-solving within design, product design, and products represent the smallest portion, with only one study each. This analysis underscores the significant emphasis placed on stress within the design process. (Figure 2-9).

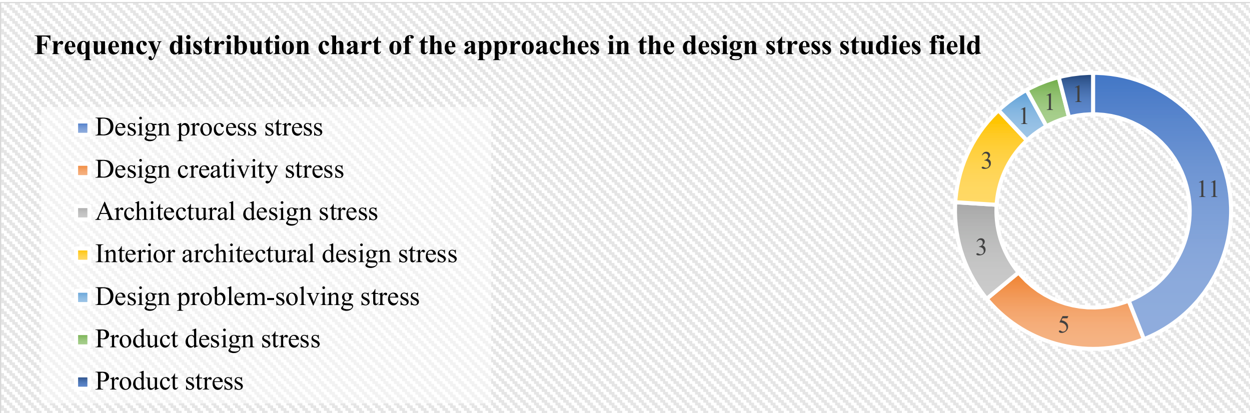

Figure 2-9: Relative Frequency Distribution of Design Studies Focused on Stress

Table 8 provides an in-depth analysis of the second category, "Design Studies Focused on Types of Stress," which investigates the types of stress discussed across various branches of design studies, and the third category, "Design Studies Focused on Stress Coping Strategies," which refers to studies examining strategies to mitigate the effects of stress. This table categorizes studies based on their focus on different types of stress within specialized design fields and the strategies employed to alleviate it. It highlights how research in various design fields has addressed specific types of stress, the proportion of total research dedicated to these areas, and the strategies explored for managing stress in design.

Table 2-4: Studies Focused on Types of Stress and Coping Strategies

Article codes	Core essence of articles based on stress types and coping strategies	Number of articles
A1-A2-A3-A4-A5-A6-A7-A8-A9-A10-A15-A16-A18-A21	Mental stress	14
A11-A12-A17-A19-A20	Stress[2]	5
A13	Physiological stress	1
A14	Ethics-related stress	1
A1-A4-A5-A10-A15	Reducing design stress through mindfulness	5

Using the data from Table 2-4 and focusing on "Design Studies Concentrated on Types of Stress," a chart has been created to illustrate the distribution of research based on the category of stress investigated across various design fields. According to the analysis presented in the chart, the majority of the research has concentrated on mental stress, which frequently emerges during the design process across domains such as engineering design, interior architectural design, architectural design, and product design. In contrast, only a small number of studies have explored other types of stress, such as physiological and ethical stress, experienced by designers (Figure 2-10)(Table 2-4).

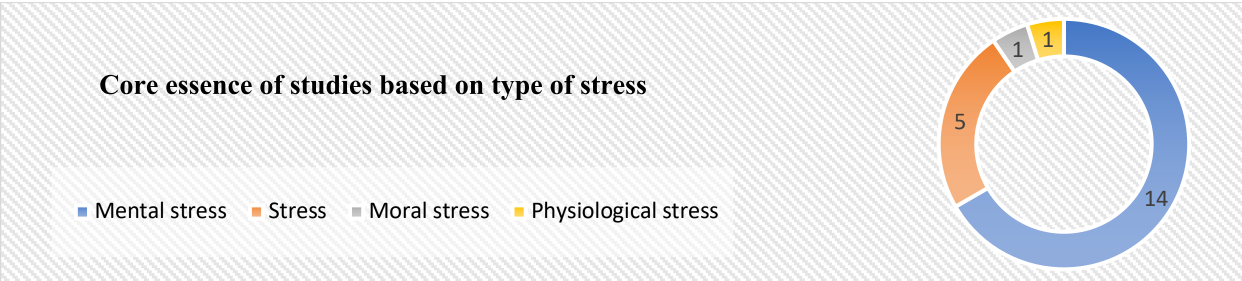

Figure 2-10: Distribution of Frequency of Studies Concentrated on Types of Stress in Design Research

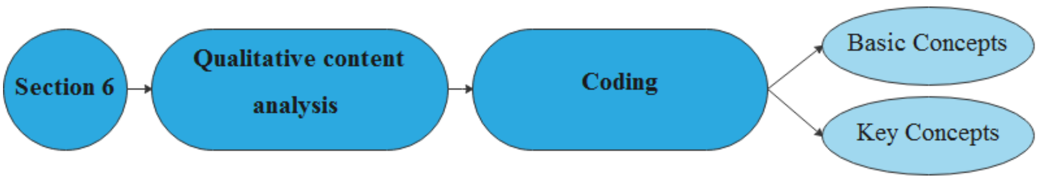

Figure 2-11: Research Methodology Section 6: Analysis of Existing Researchers' perspectives in the Field of Design Studies on Stress Using Qualitative Content Analysis

2-7- Analysis of Design Studies on Stress Using Qualitative Content Analysis

Following the quantitative analysis of eligible articles for final evaluation using bibliometric analysis and co-occurrence analysis via VOSviewer, the qualitative analysis of these articles' topics was conducted using grounded theory through three stages of coding. Concepts extracted from the data were categorized, and related topics were grouped into a common Subject classification. In this phase

2 Five of the cited studies address the concept of stress in a general and non-specific manner, providing an overarching perspective rather than focusing on particular types or contexts of stress.

of the research, the content of these articles and existing researchers' perspectives in the literature will be analyzed using qualitative content analysis. This comprehensive analysis will reveal the viewpoints and theories present in this field and will contribute to a deeper understanding of the subject (Figure 2-11). To achieve this, the texts of all eligible articles were repeatedly studied through line-by-line analysis to extract and organize researchers' perspectives on the study area, as described below.

2-7-1- Existing **researchers' perspectives** in the field of design stress studies

Stress is recognized as a common and impactful phenomenon among design professions, with its effects on designers' health and the understanding of stress experiences related to the design process being critically important, especially given the high frequency of the design process (Nolte & McComb, 2020). If not managed properly, stress has the potential to become chronic (Nguyen & Zeng, 2017) and can have serious long-term consequences for designers' health (Nolte & McComb, 2020). Thus, research on mental stress and its impacts in the design process is crucial, and accurately measuring these mental stresses in designers is vital for constructing a design model. According to the Yerkes-Dodson law, the relationship between performance and mental stress is described as an inverted U-shaped curve, illustrating how the design process can impact stress levels. A well-structured and appropriate design process can help reduce cognitive workload and thereby increase the designer's mental well-being. However, if this process does not align with designers' usual cognitive and work methods, it might lead to increased stress. Therefore, it is essential to maintain mental stress within an optimal level during the design process to enhance designer performance. This underscores the importance of accurately modeling the relationship between mental stress and designer performance (Petkar, Dande, & Zeng, 2009).

In previous studies, researchers have found that design is a highly cognitive activity characterized by mental stress (Dym et al., 2005; Zhu, Yao & Zeng, 2007; Petkar et al., 2009; Nguyen, Xu & Zeng, 2013; Nolte & McComb, 2020, 2021, 2022). This stress is induced throughout the engineering design process (Zhu et al., 2007; Petkar et al., 2009; Nguyen et al., 2013; Nguyen & Zeng, 2014, 2017; Nolte & McComb, 2020, 2021; Nolte, Huff & McComb, 2022; Tang & Zeng, 2009), and various aspects of the process often lead to stress (Tang & Zeng, 2009; Nguyen & Zeng, 2014, 2017; Nolte & McComb, 2020, 2021). Excessive stress during engineering design problem-solving tasks results in decreased designer performance (Nolte & McComb, 2020, 2021; Nolte, Huff & McComb, 2022; Lyle & Bourne, 2003; Zhu et al., 2007; Dyregrov, 2000) and reduces their creativity (Shanteau & Zhu, 2007; Håkansson & Törlind, 2014; Nguyen & Zeng, 2012, 2014, 2017; Nolte & McComb, 2020; Sandi, 2013; Nolte, Huff & McComb, 2022; Nguyen & Zeng, 2012; Nolte et al., 2023). It also affects their motivation and cognition and disrupts their ability to complete tasks requiring complex reasoning and flexibility—skills essential for successful design (Sandi, 2013; Nolte, Huff & McComb, 2022). While moderate levels of stress can potentially enhance designer performance, leading to increased motivation, creativity, and focus (Gutnick et al., 2012; Nguyen & Zeng, 2014; Degroote et al., 2020), other studies have shown that the relationship between stress and creativity is influenced by factors such as the type of stress experienced, its intensity, and individual differences (Byron et al., 2010; Knight, Fitton, Phillips, & Price, 2019). These studies present a complex picture of how stress affects creative cognition (Duan, Wang, et al., 2019). A review study (Byron et al., 2010) discussed three types of outcomes: (1) sometimes stressors decrease creative performance (Beversdorf et al., 1999; Lovelace & Hunter, 2013; Probst et al., 2007); (2) sometimes stressors increase creative performance (Baas et al., 2008; Ohly & Fritz, 2009); and (3) sometimes stressors are related to creative performance in a manner represented by an inverted U function (Baer & Oldham, 2006; Suedfeld & Vernon, 1965).

Quantitative analysis of the relationship between information-gathering strategies and designers' cognitive stress has demonstrated that quantifying cognitive stress contributes to a better understanding of creative and design processes (Zhao & Zeng, 2019; Zhu et al., 2007). Therefore, understanding designers' cognitive stress is crucial for developing a more effective design process (Lyle & Bourne, 2003; Zhu et al., 2007). In this context, using the Recurrent Object Modeling (ROM) approach as a tool to represent designers' mental states at each stage of the conceptual design process facilitates the examination of how different information-gathering strategies impact design creativity. These studies illustrate how these strategies, by affecting cognitive stress, can influence design creativity. These findings are based on theoretical analyses that explore the recursive relationship between the design process and the interplay between creativity and cognitive stress (Wang, Nguyen, & Zeng, 2015). On the other hand, research has shown that acute stress can negatively impact two types of creative problem-solving strategies, namely convergent and divergent, leading to reduced flexibility in problem-solving. Stress, especially in convergent problem-solving, generates quick but less accurate responses, and in divergent problem-solving, it reduces flexibility in generating solutions, which in turn decreases the variety of proposed solutions (Duan, Wang, et al., 2019).

Since design activities are primarily based on cognitive processes, understanding the impact of stress on the design process and finding effective methods to reduce stress in workplace, educational, and academic environments is crucial. To date, there has been limited research on identifying cognitive stress within design teams (Wasim et al., 2019). However, the productivity of design teams is significantly affected by cognitive stress (Wasim et al., 2019), which may negatively impact intuitive decision-making, creativity, and ultimately their performance (Dayan & Di Benedetto, 2011). The role of team experience and stress as moderating factors in the impact of team intuition on product creativity in new product development (NPD) processes has been examined. The results indicate that team intuition positively affects product creativity, but this effect is moderated by team experience and stress (Dayan & Di Benedetto, 2011). Designers experience high levels of stress due to their intense focus on their work (Dym et al., 2005; Nolte & McComb, 2020). The inherent complexity of design issues, such as poorly defined or constantly evolving problems (Dym et al., 2005), extended brainstorming session durations (Tsenn et al., 2014), and the multiple skills designers must employ to solve design problems, including analytical skills, decision-making, and creativity (Dym et al., 2005), contribute to this stress. Additionally, the methods used for problem-solving (Nolte, Huff & McComb, 2022; Wang, Nguyen & Zeng, 2015; Zhao & Zeng, 2019), various additional factors such as design requests (Nguyen & Zeng, 2012), problem-solving strategies (Wang et al., 2015; Zhao & Zeng, 2019), individual differences (Nolte et al., 2023), and time constraints on design activities (Nolte, Huff & McComb, 2022) all contribute to the increased cognitive load and stress experienced by designers (Nolte, Huff & McComb, 2022; Nolte & McComb, 2021). Furthermore, intensive schedules, complex tasks, or other severe stressors may cause designers to experience stress, potentially leading to reduced performance or even failure (Lyle, 2003 & Bourne; Zhu et al., 2007; Dyregrov, 2000).

Past research has observed an increase in stress among professionals and students in the fields of engineering and architectural design. Various studies have indicated that designers experience significant levels of stress (Nolte & McComb, 2020; Foster and Spencer, 2003; Ipsen and Jensen, 2012; Anthony, 1991; Kirkpatrick, 2018; Xie et al., 2019). Consequently, research emphasizes the necessity of finding methods to improve mental conditions, reduce stress, and enhance the quality of students' educational experiences (Gümüşburun Ayalp & Çivici, 2020). Furthermore, other studies have examined stress in creative educational programs, especially in the context of interior architectural design, and have shown that stress can impact students' performance and well-being (Smith & Lilly, 2016). Stress at a low to moderate level is experienced during most stages of conceptual design (Nguyen et al., 2013; Nguyen & Zeng, 2014; Nolte et al., 2023). Acute stress, resulting from involvement in engineering design, also fluctuates throughout the design process (Zhu et al., 2007; Nguyen et al., 2013; Nguyen & Zeng, 2014; Nolte & McComb, 2021; Nolte et al., 2022; Nolte et al., 2023) and contributes to design stabilization (Nguyen & Zeng, 2017).

Additionally, some studies have indicated that physical modeling is one of the most stressful stages in the design process, whereas activities such as concept generation and concept selection have similar levels of stress (Nolte & McComb, 2021; Nolte, Huff & McComb, 2022). These findings emphasize that cognitive stress is related to the design activity itself, rather than the design subject (Nolte & McComb, 2021; Nolte, Huff & McComb, 2022). Similarly, a few studies have shown how certain aspects of engineering design contribute to increased stress, while stress among professionals and students can also be influenced by various contextual factors (Nolte & McComb, 2020; Lobel and

Dunkel-Schetter, 1990). Other research suggests that mental stress is positively associated with cognitive workload and negatively associated with cognitive capacity (Tang & Zeng, 2009; Nguyen & Zeng, 2012), which is a combination of the designer's knowledge and skills (Nolte & McComb, 2023; Nguyen & Zeng, 2012).

Other studies have shown that each design activity creates a unique cognitive experience, with stress levels present and consistent across design activities (Nolte & McComb, 2021). It should be noted that differences in design experience do not contribute to variations in cognitive stress experience, as each design activity has its own distinct stressors, which are generally different from those of other activities, and the ranking of perceived stressors varies for each design activity (Nolte, Huff & McComb, 2022; Nolte & McComb, 2021). Additionally, different levels of stress can affect the cognitive experience of the designer during the design process and the quality of design outcomes (Nolte et al., 2023). Therefore, managing long-term stress in designers and mitigating its negative effects is crucial (Nolte & McComb, 2021). Recognizing the characteristics of stress throughout the design process allows for appropriate training to reduce designers' stress and improve the quality of final products (Nolte & McComb, 2020). Studies have shown that mindfulness-based stress reduction (MBSR) approaches not only decrease stress and anxiety levels in design students but also improve focus, motivation, reduce perfectionism, enhance sleep patterns, and decrease chronic fatigue and pain (Ceylanlı, Engin & Bengü, 2020). From another perspective, stress is recognized not only as an individual issue but also as a social challenge with widespread negative impacts on individuals and communities. Researchers have proposed strategies to assist designers in creating products and services that help alleviate stress. These strategies include identifying sources of stress, adopting coping approaches, assessing stress levels, and enhancing individual capabilities (Stoop & Snelders, 2017). Designers can utilize these existing stress management strategies to transform them into useful products and services that can support individuals affected by stress. Based on the existing literature in this field, a model called "Design for Serenity" has been developed. This model can be used by designers to develop future products and services aimed at addressing excessive stress levels (Stoop & Snelders, 2017).

2-7-2- Analysis of Theoretical Perspectives in the Field of Design Studies on Stress

After collecting all the theories in the current research area, the next step involved extracting and coding the primary concepts using qualitative content analysis methods. In this section, through a multi-step process, semantic units, sentences, and phrases related to the research area presented by researchers in the studies of this field were identified, extracted, and coded (Table 9). The focus was on identifying patterns and underlying meanings, which required multiple readings of the articles. In qualitative content analysis, after data extraction, the data were transformed into primary concepts, which were then further refined into main concepts. Thus, by coding the content of research related to the study area, the researcher refined these concepts to extract the relationships among them. Through coding, analysis, matching, combining, and classifying these concepts, a comprehensive theoretical framework and a new structure for future studies were provided. The following table presents the semantic units embedded in the theories of researchers in the field of design studies on stress (primary concepts) extracted from sources, coded, and presented. After analyzing them, these units were grouped into larger categories termed main concepts (Table 2-5). Figure 2-12 presents the number of articles encompassing these core concepts (Figure 2-12).

Table 2-5: Semantic Units Embedded in researchers' perspectives in the field of design studies on sress

Code	References	Basic concepts	Key concepts
B1	Nolte & McComb, 2020	Stress in design professions	Stress from design professions
B2	Nolte & McComb, 2020; Nolte & McComb, 2021	Impact of design stress on designers' health	Impact of design stress on designers' health
B3	Nolte & McComb, 2020; Nolte & McComb, 2021	Experience of design process stress	Stress caused by the design process
B4	Nguyen & Zeng, 2017	Chronic stress resulting from stress in the design profession	Chronic stress from design professions
B5	Petkar., Dande, & Zeng, 2009	Impact of mental stress on the design process	Impact of stress on the design process—mental stress
B6	Nolte & McComb, 2021; Nolte & McComb, 2020	Managing stress caused by design	Design stress—stress management
B7	Petkar., Dande, & Zeng, 2009	Impact of mental stress on designers' performance	Impact of stress on designers' performance—mental stress
B8	Petkar., Dande, & Zeng, 2009	Impact of mental stress on the creative design process	Impact of stress on the design process and creativity—mental stress
B9	Petkar., Dande, & Zeng, 2009	Impact of the design process on mental stress	Stress caused by the design process—mental stress
B10	Wasim et al, 2019	Impact of stress on the design process	Impact of stress on the design process
B11	Petkar, Dande, & Zeng, 2009	Role of the design process on mental stress and designer performance	Stress from the design process—mental stress—impact on designers' performance
B12	Petkar, Dande, & Zeng, 2009	Relationship between mental stress and designer performance	Relationship between stress and designers' performance—mental stress
B13	Zhu, Yao & Zeng, 2007; Petkar et al, 2009; Nguyen, Xu & Zeng, 2013; Nolte & McComb, 2020; 2021; 2022	Mental stress caused by design	Stress from design—mental stress
B14	Zhu et al, 2007; Petkar et al, 2009; Nguyen et al, 2013; Nguyen & Zeng, 2014, 2017; Nolte & McComb 2020, 2021; Nolte, Huff & McComb, 2022	Mental stress caused by engineering design	Stress from engineering design—mental stress
B15	Nolte et al, 2023; Nolte & McComb, 2020	Impact of stress on design quality	Impact of stress on design quality
B16	Tang & Zeng, 2009; Nguyen & Zeng, 2014; 2017; Nolte & McComb, 2020; 2021	Mental stress from different stages of the design process	Stress caused by the design process—mental stress
B17	Beilock et al, 2004; lte & McComb 2020, 2021; Nolte, Huff & McComb, 2022; Bourne & Lyle, 2003; Zhu et al, 2007; Dyregrov, 2000	Reduced performance of designers experiencing high stress in problem-solving	Stress from design problem-solving—acute stress—impact on designers' performance
B18	Dino & Shanteau, 1993	Reduced creativity of designers experiencing high stress in problem-solving	Stress from design problem-solving—acute stress—impact on designers' creativity
B19	Håkansson and Törlind, 2014 ؛Nguyen and Zeng, 2012; 2014; 2017; Nolte & McComb, 2020; Sandi, 2013; Nolte, Huff & McComb, 2022; Nguyen & Zeng, 2012 ؛Nolte et al, 2023; Gutnick et al, 2012; Nguyen & Zeng, 2014; Degroote et al, 2020	Positive and negative effects of stress on designer motivation	Impact of stress on designers' motivation
B20	Håkansson and Törlind, 2014; Nguyen and Zeng, 2012; 2014; 2017; Nolte & McComb,2020; Sandi, 2013; Nolte, Huff & McComb, 2022; Nguyen & Zeng, 2012 Nolte et al, 2023	Impact of stress on designers' cognition	Impact of stress on designers' cognition
B21	Sandi, 2013; Nolte, Huff & McComb, 2022	Impact of stress on designers' reasoning ability	Impact of stress on designers' reasoning
B22	Sandi, 2013; Nolte, Huff & McComb, 2022	Impact of stress on designers' flexibility	Impact of stress on designers' flexibility
B23	Gutnick et al, 2012; Nguyen & Zeng, 2014; Degroote et al, 2020; Dayan & Di Benedetto,	Positive and negative effects of stress on designers' performance	Impact of stress on designers' performance

Code	References	Basic concepts	Key concepts
	2011; Bourne & Lyle, 2003; Zhu et al, 2007; Dyregrov, 2000; Smith & Lilly, 2016		
B24	Wasim et al, 2019	Impact of mental stress on design team performance	Impact of stress on designers' performance—mental stress
B25	Gutnick et al, 2012; Nguyen & Zeng, 2014; Degroote et al, 2020; Dym et al, 2005; Nolte & McComb; 2020	Positive and negative effects of low and acute stress on designers' focus	Impact of stress on designers' focus—acute stress—low stress
B26	Gutnick et al, 2012; Nguyen & Zeng, 2014; Degroote et al, 2020; Duan, Wang, et al, 2019	Positive and negative effects of stress on designers' creativity	Impact of stress on designers' creativity
B27	Byron et al, 2010; Knight, Fitton, Phillips, & Price, 2019	Relationship between stress and creativity	Relationship between stress and creativity
B28	Byron et al, 2010; Knight, Fitton, Phillips, & Price, 2019	Impact of stress type and intensity on creativity	Impact of stress on creativity—chronic stress
B29	Zhu et al, 2007; Nguyen et al, 2013; Nguyen & Zeng 2014; Nolte & McComb, 2021; Nolte et al, 2022; Nolte et al, 2023	Stress caused by the design process	Stress caused by the design process
B30	Baas, De Dreu, & Nijstad, 2008; Ohly & Fritz, 2009; Beversdorf et al, 1999; Lovelace & Hunter, 2013; Probst et al, 2007	Increase and decrease in creative performance due to stress-inducing factors	Impact of stress on designers' performance—impact of stress on design creativity
B31	Bourne & Lyle, 2003; Zhu et al, 2007; Dyregrov, 2000	Relationship between stress and the design process	Relationship between stress and the design process
B32	Petkar, Dande, & Zeng, 2009; Baer & Oldham, 2006; Suedfeld & Vernon, 1965; Yeh et al, 2015	U-shaped relationship between stress and creative performance	Relationship between stress and creativity
B33	Zhao & Zeng, 2019; Zhu et al, 2007	Relationship between information gathering strategies in the design process and mental stress	Relationship between stress and information gathering strategies in the design process—mental stress
B34	Wang, Nguyen, & Zeng, 2015	Impact of information gathering strategies on mental stress	Stress caused by information gathering strategies—mental stress
B35	Wang, Nguyen, & Zeng, 2015	Reciprocal relationship between the design process and the interplay of creativity and mental stress	Relationship between stress and creativity in the design process—mental stress
B36	Duan, Wang, et al, 2019	Impact of acute stress on convergent and divergent problem-solving	Impact of stress on design problem-solving—acute stress
B37	Duan, Wang, et al, 2019	Impact of stress on reduced flexibility in design problem-solving	Impact of stress on design problem-solving—flexibility
B38	Duan, Wang, et al, 2019	Impact of stress on design problem solutions	Impact of stress on design problem-solving
B39	Duan, Wang, et al, 2019	Rapid and less accurate responses in convergent problem-solving due to stress	Impact of stress on design problem-solving
B40	Duan, Wang, et al, 2019	Decreased production of convergent problem solutions due to stress	Impact of stress on generating design problem solutions
B41	Dayan & Di Benedetto, 2011	Impact of stress on intuitive and creative design decisions	Impact of stress on designers' reasoning
B42	Nolte & McComb, 2021	Physiological changes resulting from design stress	Impact of stress on designers' flexibility
B43	Dayan & Di Benedetto, 2011	Role of stress experience in the impact of team intuition on product creativity	Impact of stress on designers' performance
B44	Dayan & Di Benedetto, 2011	Relationship between stress experience, team intuition, and product creativity	Impact of stress on designers' performance—mental stress
B45	Dym et al, 2005	Stress caused by analysis in design	Impact of stress on designers' focus—acute stress—low stress
B46	Dym et al, 2005	High stress due to the inherent complexity of design issues	Impact of stress on designers' creativity
B47	Dym et al, 2005	High stress resulting from poorly defined and evolving design problems	Relationship between stress and creativity
B48	Tsenn et al, 2014	Stress caused by increased idea generation time	Impact of stress on creativity—chronic stress
B49	Dym et al, 2005	Stress from design creativity	Stress caused by the design process
B50	Wang, Nguyen &Zeng, 2015; Zhao& Zeng, 2019; Nolte, Huff & McComb, 2022	Stress resulting from design problem-solving strategies	Impact of stress on designers' performance—impact of stress on design creativity
B51	Nolte, Huff & McComb, 2022; Yerkes & Dodson 1908	Stress caused by time constraints	Relationship between stress and the design process
B52	García et al, 2019; Nolte et al, 2023	Stress caused by individual differences	Relationship between stress and creativity
B53	Nolte, Huff & McComb, 2022; Nolte & McComb, 2021	Stress caused by cognitive workload in design	Relationship between stress and information gathering strategies in the design process—mental stress
B54	Dym et al, 2005	Stress caused by decision-making in design	Stress caused by information gathering strategies—mental stress
B55	Nguyen et al, 2013; Nguyen & Zeng, 2014; Nolte et al, 2023	Different levels of stress at various stages of the conceptual design process	Relationship between stress and creativity in the design process—mental stress

Code	References	Basic concepts	Key concepts
B56	Zhu et al, 2007; Nguyen et al, 2013; Nguyen & Zeng, 2014; Nolte & McComb, 2021; Nolte et al, 2022; Nolte et al, 2023; Nolte & McComb, 2020; Foster and Spencer, 2003; Ipsen and Jensen, 2012	Acute stress resulting from engineering design	Impact of stress on design problem-solving—acute stress
B57	Nguyen & Zeng 2017	Design fixation caused by acute stress	Impact of stress on design problem-solving—flexibility
B58	Nolte & McComb, 2021; Nolte, Huff & McComb; 2022	Physical modeling as the most stressful stage of the design process	Impact of stress on design problem-solving
B59	Nolte & McComb, 2021; Nolte, Huff & McComb; 2022	Stress caused by concept generation in the design process	Impact of stress on design problem-solving
B60	Nolte & McComb; 2021; Nolte, Huff & McComb; 2022	Stress caused by concept selection in the design process	Impact of stress on generating design problem solutions
B61	Nolte & McComb; 2020; Gee et al., 1987; Dunkel-Schetter and Lobel, 1990	Stress caused by various aspects of engineering design	Impact of stress on designers' reasoning
B62	Wasim et al: 2019; Gümüşburun Ayalp & Çivici: 2020	Reducing stress in design work, educational, and academic environments	Stress from work, educational, and academic environments—stress management
B63	Tang & Zeng 2009; Nguyen & Zeng 2012; Nolte & McComb; 2023; Nguyen & Zeng 2012	Positive and negative relationship between mental stress and design knowledge and skills	Relationship between stress and design skills
B64	Wasim et al, 2019	Impact of mental stress on the productivity of design teams	Impact of stress on design—mental stress
B65	Wasim et al, 2019	Mental stress in design teams	Stress caused by design—mental stress
B66	Anthony, 1991; Kirkpatrick, 2018; Xie et al., 2019	Acute stress resulting from architectural design	Stress caused by architectural design—acute stress
B67	Nolte & McComb, 2021; Nolte, Huff & McComb, 2022	Differences in perceived stress for each design activity	Types of design stress
B68	Nolte & McComb, 2020	Impact of chronic stress on designers' health	Impact of stress on designers' health—chronic stress
B69	Nolte et al, 2023	Impact of stress on designers' cognitive experience in the design process	Impact of stress on the design process—designers' cognitive experience
B70	Nolte & McComb, 2021; Nolte, Huff & McComb, 2022	Stress caused by design activities	Stress caused by design
B71	Nolte & McComb, 2020	Stress caused by various aspects of engineering design	Stress caused by the design process
B72	Nolte & McComb, 2020; Ceylanlı, Engin & Bengü, 2020	Identifying features resulting from design process stress	Stress management
B73	Nolte et al, 2023	Reducing designer stress	Stress caused by design—impact on design quality
B74	Stoop & Snelders, 2017	Impact of reducing design stress on design quality	Stress caused by design—stress management
B75	Stoop & Snelders, 2017	Coping with design stress	Impact of stress on designers
B76	Stoop & Snelders, 2017	Negative effects of stress on designers	Stress management with products
B77	Stoop & Snelders, 2017	Stress-reducing products and services	Stress management—mindfulness

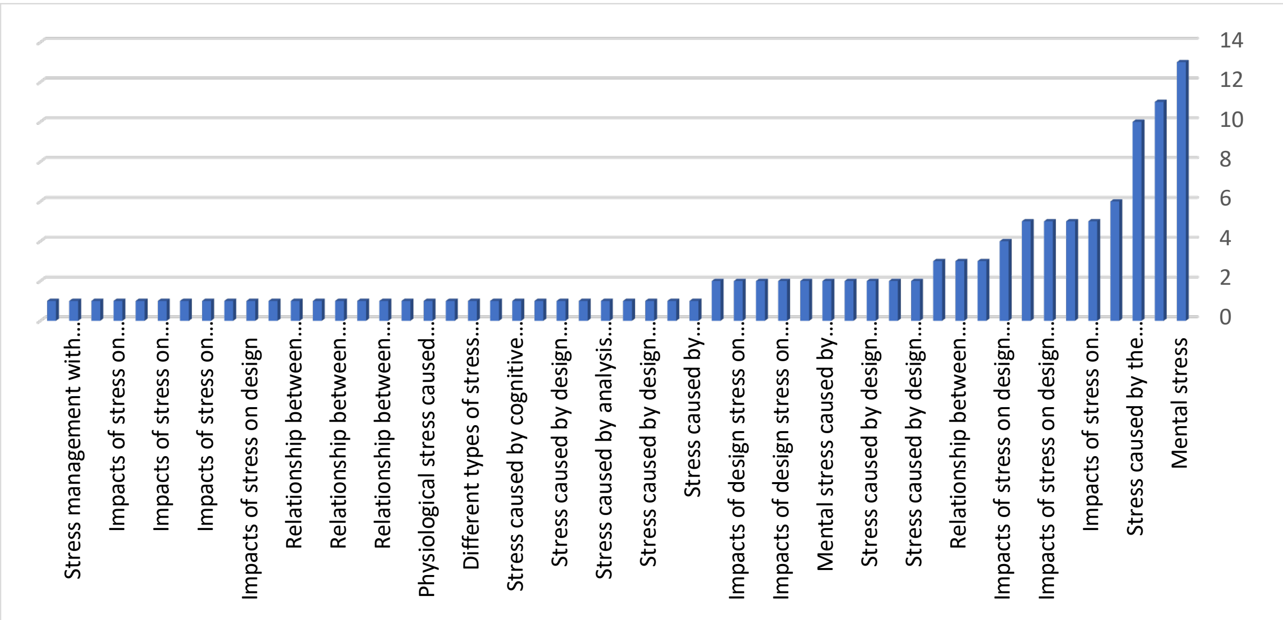

Figure 2-12: Frequency distribution of key concepts underlying Design Research

In the initial phase of this section of the study, primary concepts were extracted from the theories of various researchers. In the subsequent phase, after analyzing the approach and main orientation of these theories, they were categorized, and a common title (main concepts) was assigned to them. These main concepts were then compared to identify the central focus and core themes within the existing literature of the present study, leading to their classification into seven categories (Table 2-6). In this stage, codes were grouped into these categories based on their similarities and differences. This categorization facilitates the identification of hidden connections between the concepts. The categories are as follows: design stress, types and intensity of design stress, the bidirectional relationship between stress and design, the effects of design-induced stress, the positive and negative impacts of stress on design, and coping with design stress. According to the data presented in Table 10, the primary focus of these theories is on concepts such as mental stress, acute and chronic stress resulting from design, the design process, its various stages, and problem-solving in design. Researchers have predominantly examined the effects of these types of stress on the health, performance, focus, creativity, and cognition of designers.

Table 2-6: Classification of Key Concepts Extracted from researchers' perspectives in the field of design studies

Article codes	Key concepts	Core essence of theories
B6-B13-B65-B70-B73-B74	Stress caused by design	Design stress
B1-B4	Stress caused by design professions	
B3-B9-B16-B29-B55-B58-B59-B60-B69-B71	Stress caused by the design process and its various stages	
B34	Stress caused by information gathering strategies in the design process	
B14-B56-B61	Stress caused by engineering design	
B66-	Stress caused by architectural design	
B17-B18	Stress caused by design problem-solving	
B46-B47	Stress caused by design issues	
B49	Stress caused by design creativity	
B48	Stress caused by increased idea generation time	
B45	Stress caused by analysis in design	
B54	Stress caused by decision-making in design	
B50	Stress caused by design problem-solving strategies	
B51	Stress caused by time constraints in design	
B53	Stress caused by cognitive workload in design	
B67	Types of design stress	Types and intensity of stress in design
B52	Different types of stress arising from each design activity	
B4-B17-B18-B25-B36-B46-B47-B56-B57-B66-B68	Acute and chronic stress in design	
B25- B28	Different levels of stress in design	
B52	Stress caused by individual differences among designers	
B5-B9-	Mental stress caused by design and its process	
B7-B8-B11-B12-B13- B14-B16-B24- B33-B34-B35-B64-B65	Mental stress	
B42	Physiological stress caused by design	
B62	Stress caused by work, educational, and academic environments in design	
B27-B32-B35-	Relationship between stress and design creativity	Bidirectional relationship between stress and design
B31	Relationship between stress and the design process	
B33	Relationship between stress and information gathering strategies in the design process	
B44	Relationship between stress and intuition in design	
B63	Relationship between stress and design skills	
B12	Relationship between stress and design performance	

Article codes	Key concepts	Core essence of theories
B2-B68	Impacts of design stress on designers' health	Impacts of stress caused by design
B17-	Impacts of design stress on designers' performance	
B8-B18	Impacts of design stress on design creativity	
B8-B11-	Impacts of design stress on the design process and its various stages	
B15-B73	Impacts of design stress on design quality	
B64	Impacts of stress on design	Impacts of stress on design
B5-B10-	Impacts of stress on the design process	
B7-B11-B23-B24-B30	Impacts of stress on designers' performance	
B19-B20-B21-B22-B37	Impacts of stress on designers' motivation, cognition, focus, reasoning, decision-making, and flexibility	
B41	Impacts of stress on decision-making in design	
B26-B28-B30-B41-B43	Impacts of stress on design creativity	
B36-B37-B38-B39	Impacts of stress on design problem-solving	
B40	Impacts of stress on generating solutions in design	
B57	Impacts of stress on fixation in design	
B75	Impacts of stress on designers	
B68	Impacts of stress on designers' health	
B69	Impacts of stress on designers' cognitive experience	
B19-B23-B25-B26-B30	Positive impacts of stress on designers' performance, focus, motivation, and creativity	Positive impacts of stress on design
B6-B72-B74	Design stress management	Coping with design stress
B77	Solutions and strategies for reducing designers' stress	
B76	Stress management with products	
B76	Stress reduction through mindfulness	

The pie chart below examines the frequency distribution of various researchers' perspectives on the topic of stress in design studies. The chart highlights that the highest research focus, with 34 perspectives, is dedicated to "design stress." This is followed by significant emphasis, with 33 perspectives on "types and intensity of stress in design" and 28 perspectives on "impacts of stress on design," underscoring the importance of addressing these topics in research. The distribution reveals a predominant focus on broader themes such as design stress and its intensity, while more specific aspects, such as the effects of stress and the mechanisms of its impact, require greater attention in future studies (Figure 13).

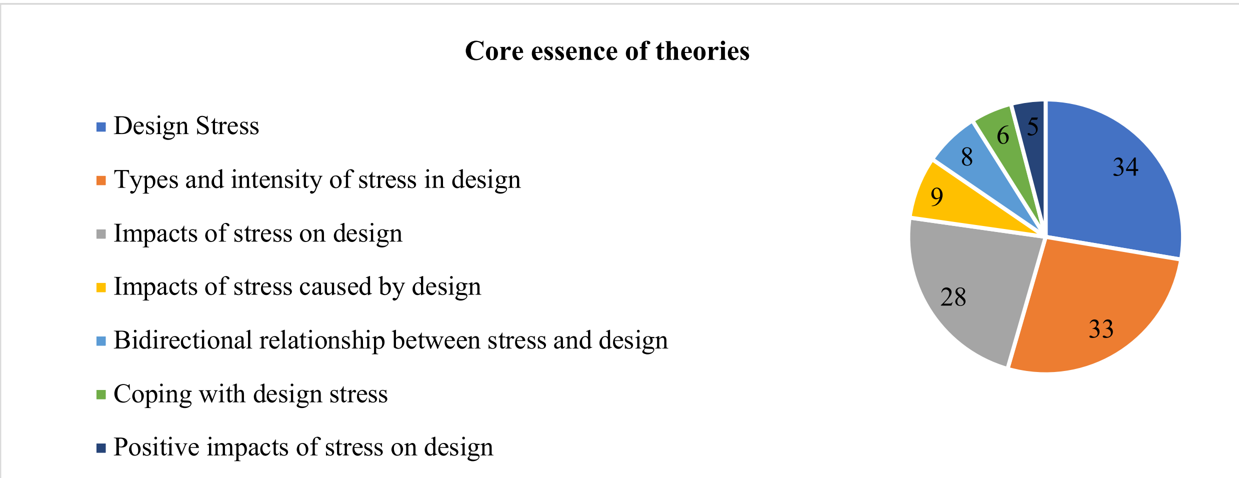

Figure 2-13: Frequency distribution Core essence of Researchers' perspectives of Design Research

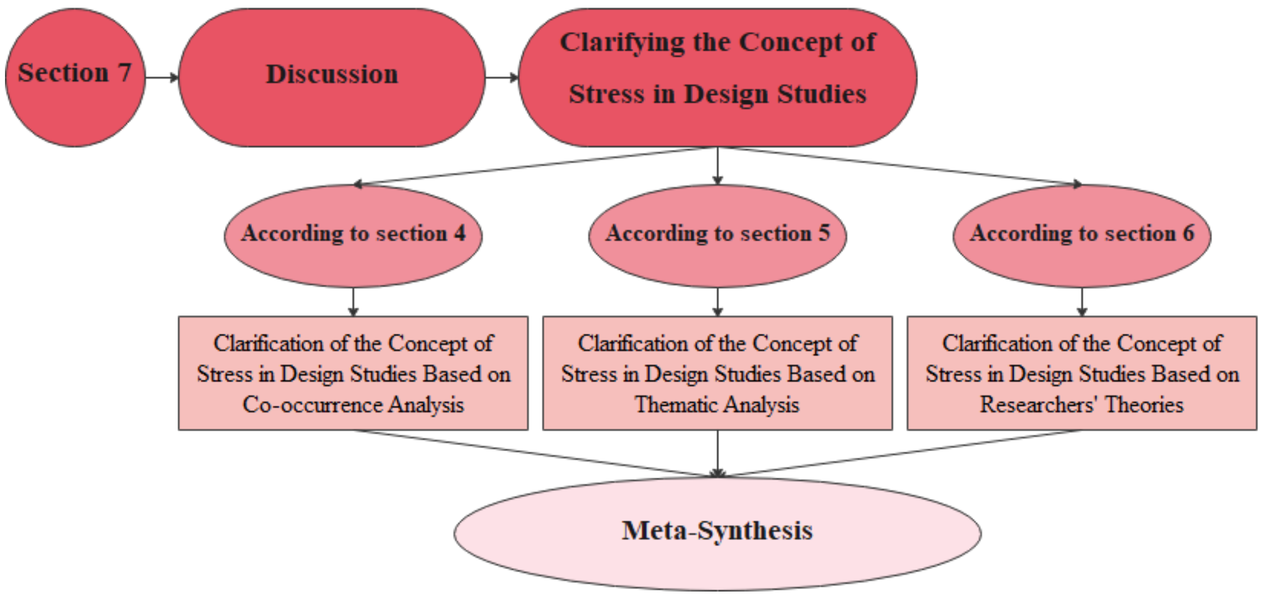

Figure 2-14: Research Methodology of Section 7: Clarification of the Concept of Stress in Design Studies

2-8- Summary of Chapter Two: Literature Review

This study represents a systematic review and meta-synthesis that, through a multi-step process using various quantitative and qualitative methods, seeks to synthesize, categorize, and integrate existing information in order to identify a novel area of study and propose a comprehensive conceptual and theoretical framework. To achieve the research objectives, the first step involved systematically reviewing studies in the field of design that addressed stress, using the PRISMA protocol and its flowchart to identify relevant articles from reputable scientific databases. Based on inclusion and exclusion criteria, qualified articles were selected for evaluation in this domain. These articles were then analyzed in three phases using both quantitative and qualitative methods. The quantitative analysis employed Scientometric methods using co-occurrence analysis in VOSviewer to identify key terms. The qualitative analysis was conducted using grounded theory through three stages of coding: open coding, axial coding, and selective coding, with the goal of identifying the main themes within these studies. Content analysis and the extraction of semantic units from research texts were also utilized to uncover researchers' perspectives and existing researchers' perspectives in this field. In the final stage, the findings were synthesized and presented as a novel and comprehensive conceptual and theoretical framework that defines a new area of study. This section will now integrate and interpret these analyses (Figure 2-14).

2-8-1- Disambiguation of the Concept of Stress in Design Studies Based on Bibliometric Analysis

In the initial phase of analysis, the research articles within the scope of this study were examined using bibliometric analysis through the VOSviewer tool. This process involved categorizing information based on co-occurrence of three-keyword combinations, co-authorship networks by authors and countries, bibliographic coupling, and research methodologies. The aim was to identify and classify keywords, determine collaboration patterns among researchers, analyze the research methods employed in studies, and investigate temporal publication trends.

Findings from this phase revealed that studies in this domain predominantly focus on two primary areas: "stress" and "design." Particular emphasis is placed on keywords such as mental stress, design, and cognitive experience of stress in design, highlighting a significant concentration of research on the impact of mental stress on designers, the design process, activities, and various stages such as ideation and concept selection—particularly in engineering and product design. While earlier research primarily focused on mental stress in design studies, more recent investigations have shifted toward the cognitive experience of stress and its underlying concepts. Co-occurrence analysis within this field clearly illustrates how stress and design, as two distinct research domains, share a reciprocal relationship, wherein both positive and negative mutual influences can emerge. This finding underscores the interdisciplinary depth and complexity of interactions between these fields. Prominent figures in this domain include Jung Zeng and Tang An Nyong, along with emerging scholars such as Hannah Nolte and Christopher McCamp from Canada and the United States. These researchers have played a significant role in advancing knowledge in this area through the establishment of international collaboration networks.

Regarding research methodologies, various approaches have been utilized, with survey-based studies being the most frequently applied method. In terms of publication trends, an increase in research activity observed in 2019 signifies a shift in focus from mental stress to the cognitive experience of stress in design. Additionally, Design Science Journal and the International Design Conference have been identified as the leading publication venues contributing to this field.

2-8-2- Clarifying the Concept of Stress in Design Studies Based on Subject Analysis

In the second stage of the analysis, a qualitative examination of the articles within the research domain was conducted using grounded theory. This process involved extracting 15 primary research topics through open coding based on the text, titles, objectives, and results of the studies. These topics were then organized into 14 main themes during axial coding. Subsequently, during selective coding, these themes were consolidated into 11 central categories, which were further grouped into three main

Subject categories based on their research focus: (1) "Design Studies Focused on Stress as a Subject," which examines various types of stress across different design fields such as engineering design, architectural design, interior architecture, and product design; (2) "Design Studies Focused on Types of Stress," which investigates specific types of stress within various branches of design studies; and (3) "Design Studies Focused on Stress Management Strategies," which refers to studies exploring strategies to manage stress and mitigate its adverse effects. The results indicate that the focus of all studies is on the unified concept of "design stress," with the majority (68%) concentrating on cognitive stress, while less than half (24%) address mindfulness-based approaches to stress management. The relative frequency distribution charts further show that cognitive stress related to the design process and creativity, particularly in engineering design, are the primary areas of research focus.

2-8-3- Clarifying the Concept of Stress in Design Studies Based on Researchers' Perspectives

In the third phase of the analysis, researchers' opinions were extracted from the texts of articles within the study's research domain as primary concepts. After analyzing the approach and main trends of these theories, they were categorized under principal concepts. In the final stage, these concepts were aligned to identify their approach, main trend, and core essence, and were grouped into seven categories. These categories are: Design Stress, Types and Intensity of Design Stress, Bidirectional Relationship between Stress and Design, Effects of Stress Resulting from Design, Positive and Negative Effects of Stress on Design, and Stress Management in Design. This categorization aids in a better understanding of how stress interacts with design and its impacts on both design and designers. According to the results from this section of the analysis, researchers' primary focus has been on concepts such as mental stress, acute and chronic stress resulting from design, the design process and its various stages, and problem-solving in design. Researchers have primarily examined the effects of these types of stress on designers' health, performance, concentration, creativity, and cognition.

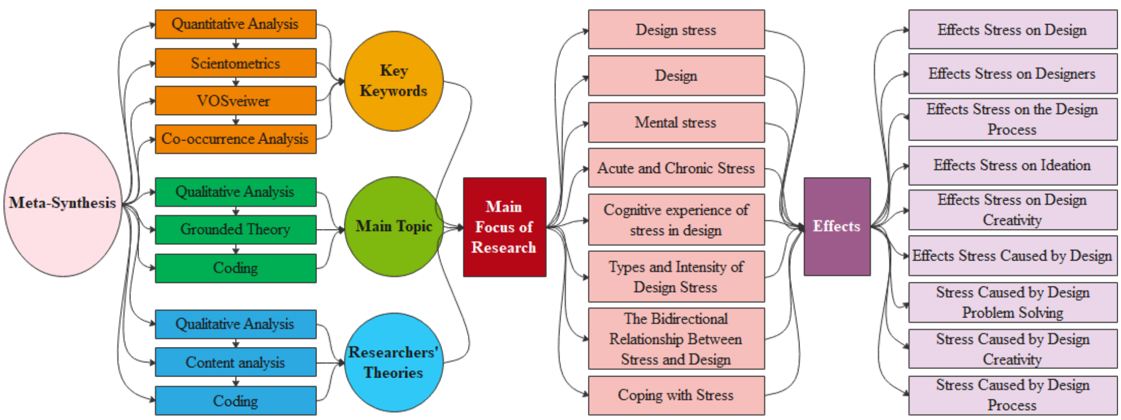

Figure 2-15: Disambiguation of the Concept of Design Stress

2-8-4- Disambiguation of the Concept of Design Stress

In the final stage of the multi-phase meta-synthesis process, the findings from this research section will be integrated to establish a comprehensive theoretical and conceptual framework that defines a novel research domain. This integration process involves synthesizing and aligning the results to create a structured foundation for future studies. The diagram below (Figure 2-15) illustrates the outcomes of this analysis.

According to this diagram, the primary focus of research-based on all three levels of analysis (keyword analysis, thematic analysis, and expert opinions)-centers on design stress, its types and intensities, coping mechanisms, and cognitive experience in designers, as well as mental, acute, and chronic stress as some of the most significant and prevalent forms of stress among designers, along with the mutual impact between stress and design. Based on the findings of the present study, research on design that addresses stress can be divided into three general categories: "studies focused on stress induced by the design process," "studies focused on the impact of stress on design," and "studies focused on the bidirectional relationship between stress and design," which ultimately provide a theoretical and conceptual framework derived from previous studies.

2-8-4-1- Studies Focusing on the Effects of Stress on Design

Many researchers have concentrated on the impact of stress on design, creativity, and various stages of the design process, such as brainstorming and problem-solving. They have examined not only the effects of stress on design itself but also its impact on designers, particularly concerning their health, performance, concentration, cognition, motivation, decision-making, and flexibility. While some researchers have demonstrated that these effects can be positive, they have not clarified whether these stresses arise from personal factors, external factors such as lifestyle, job-related stress, or environmental conditions, or from internal factors related to the design process itself. This lack of clarity represents one of the main challenges in studies within this category.

2-8-4-2- Studies Focusing on the Bidirectional Relationship Between Stress and Design

Another group of researchers has solely focused on the relationship between stress and design, creativity, various stages of the design process, and designers' performance. They argue that a bidirectional relationship exists between stress and design, where both influence each other, leading to both positive and negative effects on the design process and designers. The primary focus of this category of studies has been on the interplay between creativity and stress and their mutual impact, while other related topics have been addressed in a more fragmented and limited manner.

In general, design is constantly exposed to stress due to its inherent complexities and the need for extensive skills. This stress, whether stemming from external factors or from the design process itself, can manifest in various forms and impact the design, its process, and the designers. Therefore, studying this area, systematically reviewing the research literature, providing a comprehensive content and theoretical framework, and introducing a new research domain for future studies aimed at identifying these stresses, their causes, types, impacts, and coping strategies is of immense importance. To achieve this goal, this section of the present research analyzes the existing knowledge in this field, and through a meta-synthesis study, seeks to develop an understanding and knowledge that is not only peripheral to existing theories but establishes a new and expansive research area for future studies. The results from this section of the research show that through meta-analysis and synthesis in multiple stages of quantitative and qualitative analysis of the studies conducted, a comprehensive content and theoretical framework for the new research domain of "design stress" can be clearly defined and introduced. Design stress, which is categorized into various types and levels, has numerous and diverse impacts and appears in various forms, requiring a multifaceted approach to identify, analyze, and offer solutions for managing it in order to enhance designers' productivity, improve the design experience, and achieve higher design quality. The findings of this research provide valuable insights into the area of design stress, enabling researchers to better understand and develop innovative strategies and approaches for future research in this domain. By filling existing research gaps, it will contribute to advancing our understanding of this subject and provide a foundation for developing practical solutions in this field.

Chapter 3
Research Methodology

3-1- Introduction

Design thinking is recognized as a complex cognitive process that encompasses various stages, including problem definition and structuring, analysis, decision-making, evaluation, ideation, creativity, and problem-solving. Each of these stages inherently induces specific types of stress, necessitating thorough research and systematic investigation. Although recent years have seen a limited and fragmented body of research in this domain, the emerging field of "design stress" requires a more structured, comprehensive, and extensive examination.

To address this gap, the present study conducted a meta-synthesis in Chapter 2, integrating existing research through multiple analytical methods, including data collection, analysis, comparison, and synthesis. This approach aimed to identify a novel research domain and establish a comprehensive theoretical and conceptual framework for understanding design stress. Based on the findings from the literature review, the study introduced and delineated the concept of "design stress" as an emerging research area. Design stress manifests in various forms and intensities, exerting significant and diverse effects on the design process and practitioners. Given its multifaceted nature, a multidimensional approach is essential for identifying, analyzing, and proposing solutions to manage design stress effectively. Such an approach is crucial for enhancing designers' productivity, optimizing their performance, and fostering an improved design experience and higher-quality outcomes. Building upon the previous chapter, this section aims to identify and introduce appropriate methodologies from the fields of design and cognitive sciences for measuring design stress. Additionally, a novel method for assessing stress in designers will be proposed. The integration of advanced knowledge from both design research and cognitive sciences is crucial, as it provides a structured research trajectory, guiding the study toward meaningful and reliable outcomes. Moreover, this interdisciplinary approach presents an opportunity to develop and implement innovative techniques that enhance design thinking, improve designers' performance, elevate design quality, and ultimately contribute to better products and a healthier life for both designers and users. Recent advancements in design research highlight two key considerations: first, the necessity for more precise and rigorous investigations in this field compared to previous studies; and second, the availability of advanced tools that enable collaboration with disciplines such as cognitive science and psychology to facilitate these studies. Traditionally, design research has relied on techniques such as protocol analysis and interviews, which may be susceptible to bias. The significance of employing novel methodologies lies in the ability of experimental approaches, neuroimaging tools, and physiological measurements to minimize these biases and provide deeper insights into cognitive processes that cannot be fully captured through behavioral metrics (Chrysikou & Gero, 2020, p. 320).

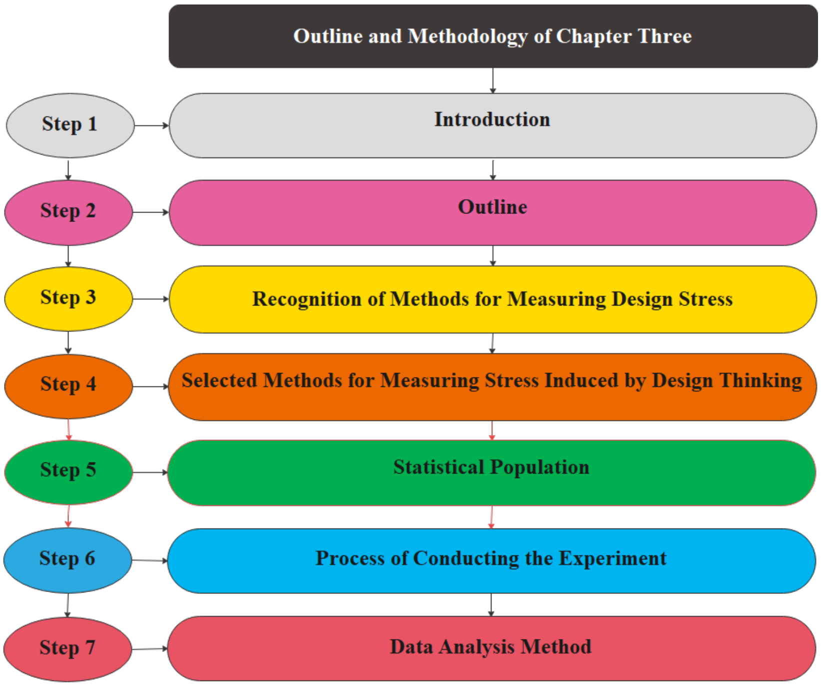

Figure 3-1: An Overview of the Research Methodology in Chapter Three

3-2- Outline and Methodology of Chapter Three

Chapter Three of this research is dedicated to examining and explaining various methods for measuring design stress. As a complex and multidimensional subject, design stress requires a precise and comprehensive evaluation encompassing physiological, emotional, cognitive, and behavioral aspects. Due to its vast scope and complexity, this study exclusively focuses on stress arising from the design thinking process. The primary objective of this chapter is to provide a clear and detailed roadmap for understanding how the research findings are derived. By reading this chapter, the audience will gain a full understanding of the research process and ensure the validity and reliability of the presented results. This chapter begins with a general introduction that highlights the significance and necessity of identifying, measuring, and assessing design stress (Section 1). Following this, an overview of the chapter's structure and research methodology is presented in Section 2. In Section 3, appropriate methods from the fields of design and cognitive sciences will be identified and analyzed for measuring design stress among designers. To identify and analyze design stress more accurately, including its causes and effects, using selected methods, design stress will be measured across four research phases among design students and designers. These phases include Phase One: assessment of designers' mental health and status using the Structured Clinical Interview for DSM-5 (SCID-5) and the Positive and Negative Affect Schedule (PANAS) questionnaire, Phase Two: stress measurement using Electroencephalography (EEG) tools, Phase Three: implementation of the MetaCogno software, a cognitive meta-analysis tool for design thinking, and Phase Four: using the Perceived Stress Scale (PSS), the Physiological Arousal Questionnaire (PAQ), and the Coping Strategies Inventory (CSI). Next, the study population will be described, the inclusion criteria and sampling method will be explained, followed by the experimental process and data recording. The methods of data analysis for each research phase and ethical considerations will be introduced. Finally, a summary of the results obtained from this section of the study will be presented (Figure 3-1).

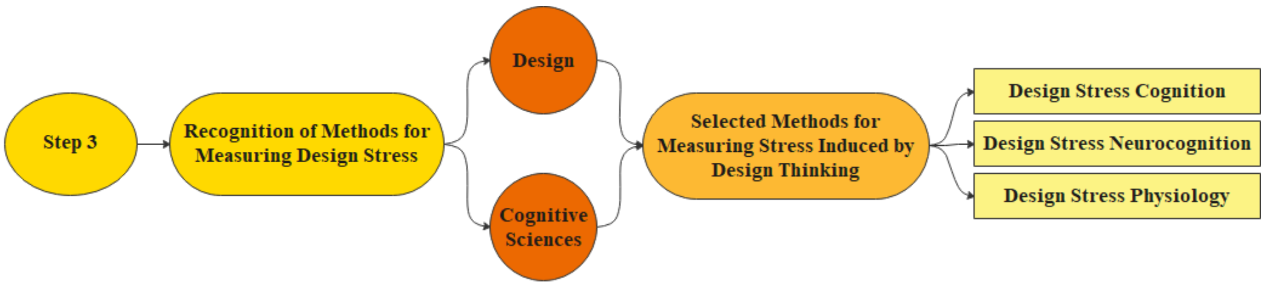

Figure 3-2: Research Methodology for Phase 3 of Chapter 3: Identification of Suitable Methods for Measuring Design Stress

3-3- Identification of Existing Methods for Measuring Design Stress

For conducting this research, an effort was made to consider research methods from both the fields of cognitive science and design studies (Figure 2-3). In the field of cognitive science, reference was made to the research methods presented in Sternberg's Cognitive Psychology textbook (Sternberg, 2011: 30), as well as modern neuropsychological and physiological methods, and techniques used for measuring stress. After reviewing various research methods in the fields of cognitive sciences, stress, and design, it appears that the most suitable methods for measuring, evaluating, and analyzing design stress are a combination of several different approaches, each with its own characteristics and limitations. These methods can be categorized into three main groups within the field of design stress studies: Design Stress Cognition (DSC), Design Stress Neurocognition (DSNC), and Design Stress Physiology (DSPH)(Figure 3-3).

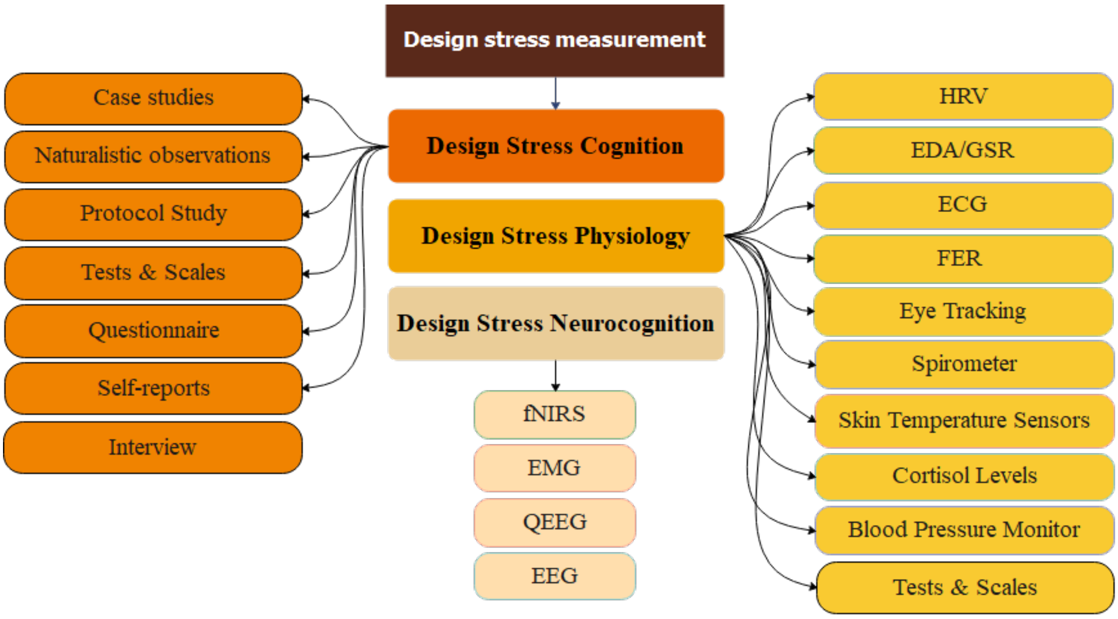

Figure 3-3: Suitable Methods for Measuring Design Stress

- **Design Stress Cognition (DSC)** focuses on the mental processes and strategies of designers in stressful conditions and uses tools such as case studies and natural observations to gain a deeper understanding of design challenges.
- **Design Stress Neurocognition (DSNC)** studies brain activity related to stress and, by using advanced technologies like fNIRS and EEG, helps identify neurocognitive correlations.
- **Design Stress Physiology (DSPH)** measures the physiological responses of designers to stress, utilizing tools such as cortisol measurement and heart rate analysis.

The combination of these three categories of tools and methods allows for a more comprehensive and accurate analysis of the various dimensions of design stress and can help develop effective strategies for managing stress in designers.

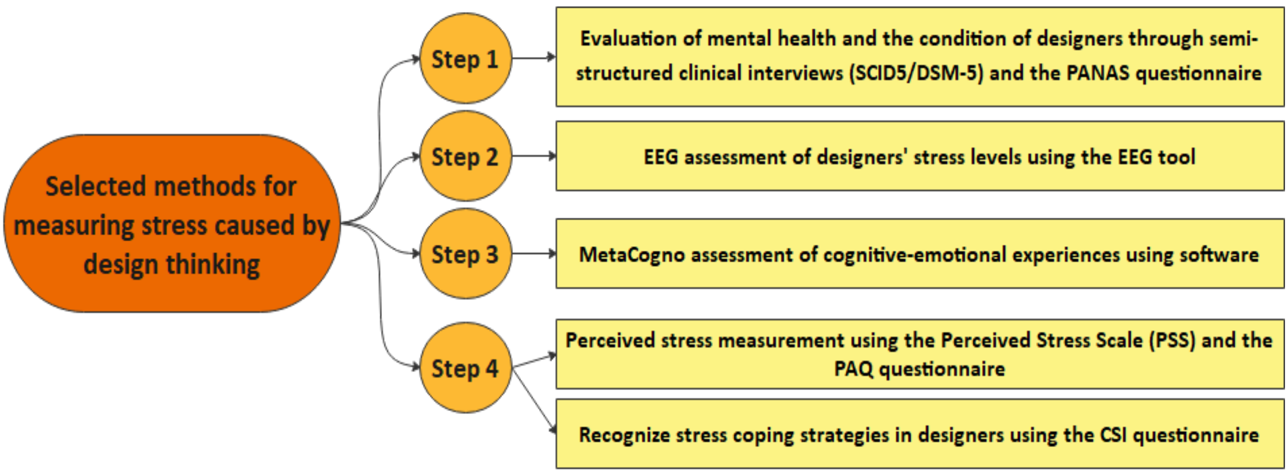

Figure 3-4: Selected Methods for Measuring Stress Caused by the Design Thinking Process

3-4- Methods for Measuring Stress Caused by the Design Thinking Process

In this section of the research, a combination of cognitive design stress, neurocognitive design stress, and physiological design stress methods is introduced to measure the stress caused by the design thinking process. The methods presented for measuring design stress in the four main phases of the research include the following:

- **Semi-structured Clinical Interviews (SCID5/DSM-5)** and the **Positive and Negative Affect Schedule (PANAS)** questionnaire are used for initial assessment of the psychological and emotional state of the designers.
- **Electroencephalography (EEG)** is employed to record and analyze brain waves of designers during various phases of the design thinking process
- The **MetaCogno tool**, a novel innovation, is used to capture and analyze real-time emotional-cognitive experiences in conjunction with neural and physiological responses of designers throughout the design thinking process.
- Finally, the **Perceived Stress Scale (PSS)**, the **Physiological Arousal Questionnaire (PAQ)**, and **Coping Strategies Inventory (CSI)** are used to assess the perceived stress levels of designers and their awareness of coping strategies in response to stress.

The combination of these tools and diverse analytical methods allows for a comprehensive and multifaceted analysis of the stress induced by the design thinking process (Figure 3-4).

3-5- Phase one of the Research: Mental Health Assessment of Designers

3-5-1- Structured Clinical Interview SCID-5/ DSM-5

The Structured Clinical Interview based on DSM-5 (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition) is a standardized tool used by mental health professionals to diagnose mental disorders. It provides a systematic framework for accurate diagnosis according to DSM-5 criteria (First et al., 2016). A key change in DSM-5 is its focus on dimensional diagnoses, allowing for more flexible and precise assessments (Hyman, 2010).

The interview is intended for individuals over 18, particularly those not seeking treatment or perceiving themselves as ill. While it is generally understandable, it may not be suitable for individuals with severe cognitive impairments or acute distress. DSM-5 is widely accepted and facilitates consistent diagnoses and communication among mental health professionals (First et al., 2016). This interview is useful for diagnosing not only mental disorders but also for treatment planning and evaluating outcomes. It is particularly effective in identifying stress-related disorders and assessing their impact on daily life (American Psychiatric Association, 2013). Additionally, it helps in identifying internal and external factors contributing to stress, such as job issues, interpersonal relationships, and major life events (Lazarus & Folkman, 1984).

3-5-2- Positive and Negative Affect Schedule (PANAS)

The Positive and Negative Affect Schedule (PANAS) is a 20-item self-report questionnaire designed to independently assess two mood dimensions: positive affect and negative affect. The PANAS consists of two subscales, each with 10 items, with each item representing a single trait. Respondents rate each item on a five-point Likert scale, and the score range for each subscale is from 10 to 50. Completing the questionnaire typically takes only a few minutes. PANAS has been widely used in numerous studies and is highly regarded for its clinical utility. This tool is particularly valuable when there is a need to measure both affects independently. PANAS exhibits strong psychometric properties. It demonstrates high convergent validity, with internal consistency for the positive affect subscale reported at 0.88 and for the negative affect subscale at 0.87. Test-retest reliability over an eight-week period is 0.68 for positive affect and 0.71 for negative affect (Watson, Clark, & Tellegen, 1988).

3-6- Phase two of the Research: Stress Measurement Using Electroencephalography

In 1875, Richard Caton discovered electrical activity in the brains of monkeys and rabbits, and in 1924, Hans Berger recorded the first human EEG (Bronzino, 1999). By 1936, the first EEG laboratory was established at Massachusetts General Hospital for diagnosing brain disorders. EEG records brain waves and electrical activity from the scalp, showing voltage fluctuations caused by ionic currents between neurons. It is used in clinical diagnoses to analyze the frequency and spectrum of brain waves, focusing on changes in recorded signals (Niedermeyer & da Silva, 2005). EEG waves are classified into delta, theta, alpha, beta, and gamma waves, with delta having the largest amplitude and lowest frequency (Niedermeyer, 2017). Various factors, such as eye movements and muscle activity, can create artifacts in EEG signals, affecting data interpretation. Controlling these artifacts is essential for accurate results in EEG analysis (Karami Herastani, 2020). EEG has various applications in stress assessment in research. The main advantage of EEG is its non-invasive nature and relative ease of use. The information transmitted through EEG signals can provide valuable insights into the underlying functional networks. Moreover, an important advantage of EEG is its excellent temporal resolution, which offers an unmatched opportunity to track brain networks in a large-scale manner over very short time periods, such as during many cognitive tasks (Hassan et al., 2015). Another key application of EEG is examining changes in brain activity in response to stress-inducing situations. Using EEG, researchers can identify changes in different brain waves, such as beta and gamma waves, which are typically associated with stress. This feature allows researchers to closely examine the brain's real-time responses to stress. Additionally, EEG can aid in identifying specific patterns of brain activity associated with stress responses or stress-related disorders.

3-7- Phase three of the Research: Stress Measurement with the MetaCogno Tool

In this test, four main stages of the design thinking process (Problem Analysis, Ideation, Evaluation and Selection of Ideas, and Sketching) have been designed based on Nigel Cross's design thinking model and the set of skills needed for the design thinking process, as outlined in previous studies. The significance and reason for creating the MetaCogno tool stem from the limitations found in previous methods for assessing the emotional-cognitive experiences of designers. In past studies, cognitive design methods such as protocol analysis, think-aloud, retrospective sessions, interviews, questionnaires, or surveys conducted during and after the design process were used. Although these methods provide useful information, their reflective and retrospective nature may not effectively capture the immediate and rapid emotional and cognitive changes that designers experience during the process. Additionally, these methods can be influenced by various biases. For example, designers might unintentionally alter or report their emotional-cognitive experiences with delays and lower accuracy, or fail to report them altogether. Furthermore, many times, designers are not fully aware of the stages they go through during the design thinking process and may unconsciously mention things they haven't done or fail to reflect on their actions. In think-aloud, designers report on their design process during the thinking phase, which can disrupt their focus and may lead them to forget or fail to mention some emotional-cognitive experiences. Given these limitations, the MetaCogno tool was designed as a study beyond cognitive design. The main goal of this tool is to provide real-time and precise evaluation of the emotional-cognitive experiences of designers while engaging in the design thinking process, enabling an understanding of their cognitive mechanisms and experiences at each stage. In essence, MetaCogno aims to record the emotions and cognitive experiences of designers immediately after they experience and perceive them at any stage of the design thinking process. This approach, due to its high temporal clarity and accuracy in evaluating emotional-cognitive experiences, offers more precise data and helps gain a better understanding of the impact of the design thinking process on the mental and psychological state of designers. Therefore, this tool not only complements previous methods but also serves as an innovation in the precise and scientific evaluation of emotional-cognitive experiences, design experiences, and cognitive mechanisms of designers in cognitive design.

3-7-1- Innovation of the MetaCogno Tool

The MetaCogno tool is introduced as an innovative method in this section of the research.

Specifically designed to capture real-time emotional-cognitive experiences of designers during various stages of the design thinking process (Figure 3-5), the tool brings several key innovations and features, including:

- **Real-Time Emotional-Cognitive Experience Evaluation**: Designers immediately record their emotional-cognitive experiences after each stage of the design process. This approach enhances the accuracy of data capture and reduces cognitive biases, providing a more authentic representation of the designer's mental state during the process.
- **Segmentation of Emotional-Cognitive Experiences by Design Stages**: The tool records specific emotional-cognitive experiences that designers perceive during each stage of the design thinking process separately, allowing for a detailed analysis of how these experiences evolve throughout the process.
- **Integration with Recording Systems**: MetaCogno can connect with EEG systems. This integration enables the synchronization of emotional, cognitive, and neural data, providing a comprehensive analysis of the effects of stress on the neural status and emotional-cognitive experiences of designers at different stages.
- **Ongoing Data Support and Storage for Future Analysis**: The tool records and stores data related to the emotional-cognitive experiences of designers at each stage. This stored data is available for future analysis, offering valuable insights for further research on design stress and the cognitive processes involved.

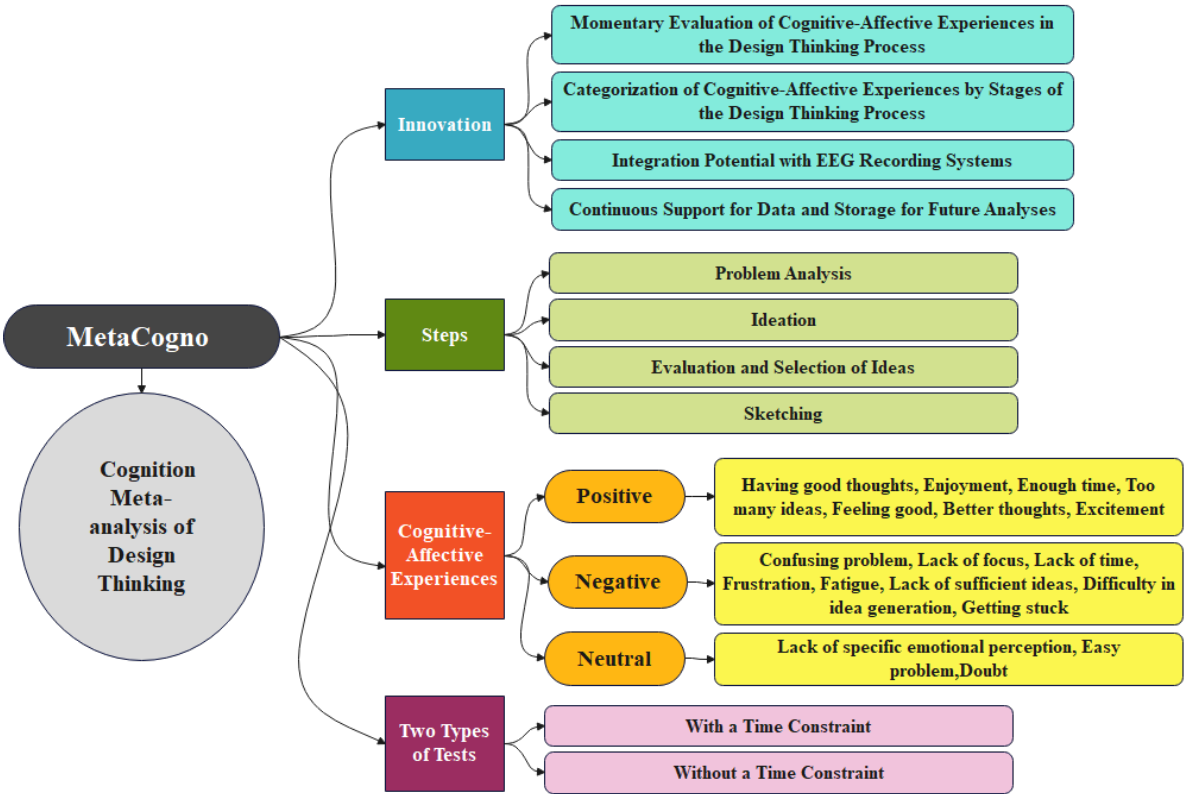

Figure 3-5: An Overview of the MetaCogno

3-8- Phase Four of the Research: Stress Measurement Using Questionnaires

3-8-1- Perceived Stress Scale (PSS)

The Perceived Stress Scale (PSS) was developed to measure stress levels in individuals. It was first developed by Sheldon Cohen and his colleagues in 1983 and has since become one of the most commonly used tools in stress and occupational stress studies. This scale consists of 14 items with a four-point Likert scale (ranging from "never" to "very often"), and each item is scored from 0 to 4. It assesses perceived stress and is a unidimensional scale (Safaee & Shakouri, 2014). Cohen and colleagues calculated the test-retest reliability at 0.85, and the Cronbach's alpha coefficient for this scale was found to be 0.85 (Cohen et al., 1983).

3-8-2- Physiological Arousal Questionnaire (PAQ)

The Physiological Arousal Questionnaire (PAQ) is designed to assess individuals' physiological arousal in response to stress or various environmental stimuli. This questionnaire measures physiological changes such as increased heart rate, sweating, muscle tension, and other physical symptoms that occur as a response to stress-inducing or threatening stimuli. In this study, it is used as a metric for assessing the experiential stress related to the design process. The PAQ typically consists of a series of questions that individuals respond to, reporting their level of physiological arousal in different situations. Responses are usually provided on a 5-point or 7-point Likert scale, ranging from "not at all" to "very much" (Smith & Jones, 2010).

3-8-3- Coping Strategy Inventory (CSI)

As mentioned, the relationship between personality, stress, and coping styles has been examined and validated in numerous studies (Panelli & Tomaka, 2002; Sallis, David, & Harvey, 1996; Ferguson, 2001; Watson & Hubbard, 1996; Wollert & Torgersen, 2000). The Coping with Stressful Situations Questionnaire (CSI) is designed to assess the various coping strategies individuals employ in stressful situations. It evaluates four types of coping strategies: problem-focused coping, emotion-focused coping, problem-avoidant coping, and emotion-avoidant coping (Endler & Parker, 1990). This questionnaire consists of 72 items, and each question is answered using a 5-point Likert scale ranging from "never" (1) to "very often" (5). The CSI is generally divided into two main categories:

- **Problem-focused coping strategies**: These strategies aim to address or reduce the root problem, where the individual attempts to identify and manage the source of stress.
- **Emotion focused coping strategies**: These strategies focus on managing and reducing the negative emotions caused by stress, without directly solving the problem (Marzabadi & Nik Nafas, 2016).

3-9- Statistical Population

The target population consists of designers selected from the field of industrial design. This choice is made due to the limited comprehensive studies in industrial design, as most research to date has focused on engineering design, architectural design, and interior design. The statistical population studied in this research possesses diverse characteristics, enabling researchers to conduct a more detailed examination and analysis of stress induced by the design thinking process and evaluate its impacts among designers with varying profiles. These characteristics are as follows:

- **Age**: The statistical population includes designers aged 18 to 33 years, who face stress challenges related to design thinking. These designers are familiar with design activities and design thinking processes both professionally and at the academic level.
- **Gender**: The statistical population is equally divided between male and female designers.
- **Academic Education Level**: The population includes designers with varying levels of academic education, from students to graduates holding bachelor's and master's degrees.
- **Professional Experience and Expertise**: This population includes designers with varying levels of professional experience and expertise, ranging from beginners to experienced professionals.
- **Industrial Design Field**: The statistical population exclusively consists of designers from the industrial design field.
- **Handedness**: The statistical population of this study includes both left-handed and right-handed designers.

3-9-1- Sample Size

The target statistical population consists of 107 expert and beginner designers, as well as students from the bachelor's and master's degree programs in industrial design at the University of Islamic Arts in Tabriz, who were selected through purposive sampling. After the announcement and registration of students willing to participate in the experiment, seven pretests were conducted to ensure the experimental procedures, timing, and stages of the design thinking process were appropriate, along with other aspects related to the experiment. Based on the adjustments made following the preliminary trials, these designers were excluded from the data analysis. In the first phase of the study, the statistical population was assessed using a structured clinical interview based on DSM-5. According to the inclusion criteria, 100 designer students and professional designers were selected as the final sample.

3-9-2- Inclusion Criteria for the Study Sample

- **Physical and Mental Health**: Only designers who were in full mental and physical health were selected. This was determined by ensuring the absence of any major psychological disorders following the structured DSM-5 clinical interview, as well as no history of neurological disorders, head trauma, or surgeries.
- **No Medication Use**: Participants who had not taken any medication that could potentially affect stress levels, anxiety, or brain activity were included.
- **No Drug Use**: Designers who had never used any illicit substances and had refrained from consuming alcoholic beverages, hookah, or cigarettes at least one month and one day, respectively, prior to the experiment were selected.
- **No Caffeine Consumption**: Designers who had not consumed any food or drink containing caffeine, such as tea, coffee, instant coffee, chocolate, or cocoa, in the hours preceding the experiment were included.

3-9-3- Sampling Method

The statistical population studied in this research was selected using a purposive sampling method. This method ensures that only individuals with desirable conditions, full mental and psychological health, and no external interventions such as medications and caffeine participate in the experiments. This approach helps enhance the accuracy and reliability of the obtained results, as external factors that could influence the EEG results were eliminated. Therefore, the sampling method in this section of the research is based on a precise and controlled process, carried out from the beginning to the end with the goal of ensuring the selection of the best samples for achieving valid results. Table 3-3 presents the key characteristics of the target population in phases two and three of the research, including gender, age, education level, field of study, etc. (Table 3-1).

Table 3-1: Demographic Information of the Study Population

Variable	Category	Number
Gender	Female	51
	Male	49
Age	18 to 20 (Adult)	23
	21 to 25 (Adult)	68
	26 to 30 (Adult)	7
	31 to 35 (Adult)	2
Field of Study	Industrial Design	100
Level of Academic Education	Bachelor's	84
	Master's	14
Experience and Expertise	Expert	25
	Novice	75
Dominant Hand	Right-Handed	83
	Left-Handed	17

The design thinking process test, which is part of the MetaCogno software, has been presented in two versions: one with no time constraints and one with time constraints. The number of student designers and professional designers in these two groups is outlined in the table below (Table 3-2).

Table 3-2: Statistical Population Information for the Two Design Process Tests: Stress Measurement Using 32-Channel EEG Tool and MetaCogno

	Design Process Test	Number	Dominant Hand	Number	Gender	Number
100 Designers	**Without Time Constraints**	59	Right-Handed	42	Female	21
					Male	21
			Left-Handed	17	Female	9
					Male	8
	With Time Constraints	41	Right-Handed	41	Female	19
					Male	22

3-10- Experiment Process

This research was conducted in five phases with the aim of identifying, understanding, and comprehending the stress induced by the design thinking process and the designers' cognitive processes throughout the design phase. After explaining the methods used, we now describe the process of conducting the experiment. The experiment process is as follows:

3-10-1- Request for Collaboration and Initial Selection of Volunteers

For the laboratory portion of the study, an academic competition titled "Neuro Idea" was organized. The purpose of this competition was to create conditions where student designers and professionals could engage in the design process within a real competition framework, thereby increasing motivation and commitment. This approach was chosen because, without this setup, participants might have viewed the test merely as a class assignment, and due to a lack of sufficient motivation, the perceived stress levels might have been significantly lower than those in real-world situations. The "Neuro Idea" competition received significant interest from student designers and professionals, with approximately 150 participants. Although there was an intention to use EEG/ECG tools for recording, this was not feasible due to time constraints. (Figures 3-6 and 3-7).

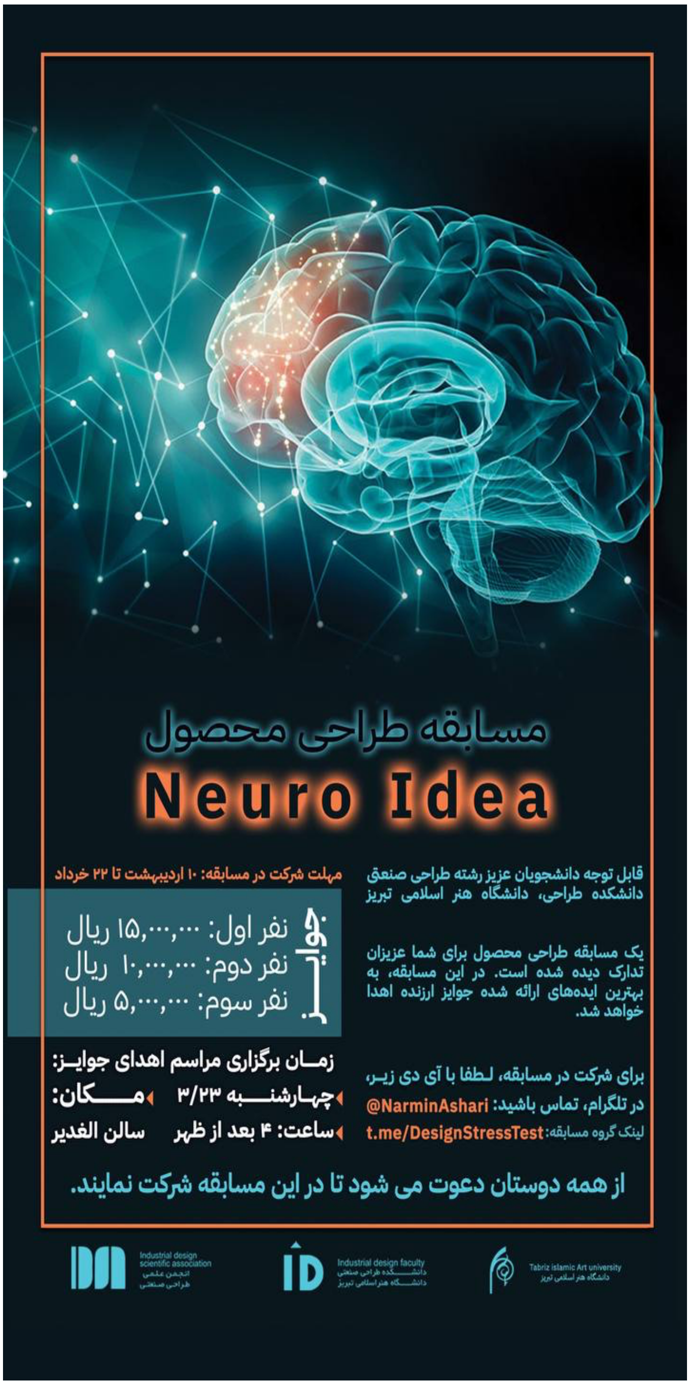

Figure 3-6: The Neuro Idea competition announcement Poster

Figure 3-7: Ceremony for selecting the best idea, award presentation, and competition closure

3-10-2- Design and Implementation Phases of the Experiment

In this study, following the structured clinical interviews and the psychological and emotional evaluations of the designers, the **MetaCogno** software was utilized to collect data on the emotional and cognitive experiences of designers. Additionally, EEG tools and questionnaires were employed to measure the levels and intensity of stress among designers. These methods aimed to enhance understanding of stress experienced throughout the design thinking process, explore the coping strategies employed by designers, and assess the impact of stress on their performance.

3-10-2-1- Design Thinking Process Test

The Design Thinking Process Test, integrated into the MetaCogno software, was implemented in two formats:

- **Test without Time Constraints**: In this group, no time restrictions were imposed on the designers. Participants progressed to the next stage by pressing the spacebar on the keyboard upon completing each phase.
- **Test with Time Constraints**: In this group, specific time limits were applied. A duration of 2 minutes was allocated for each of the Problem Analysis, Ideation, and Evaluation and Selection of Ideas stages, while 5 minutes were designated for the Sketching stage.

3-10-2-2- Selected Design Problem for the Study

The design problem presented in this study is as follows:

"Design an intelligent waste disposal system for motorcycles, scooters, and bicycles."

Participants were instructed to consider the following criteria:

- Minimize production costs.
- Ensure the system can separate wet and dry waste effectively.
- Make the system easy and efficient for users to operate.
- Incorporate additional functions beyond waste disposal.
- Address aesthetic considerations, functionality, material selection, manufacturing methods, innovation, originality, hygiene, odorlessness, technology integration, and portability across different vehicle types.

3-10-2-3- Duration of the Experiment

Based on preliminary studies and considering the length of the preparation process for the designers, to prevent fatigue, the duration allocated for this experiment was set at 35 minutes, which includes 7 stages. This duration was adjusted after conducting 7 initial trials, and ultimately, this time frame was finalized for the main experiment (Figure 3-8).

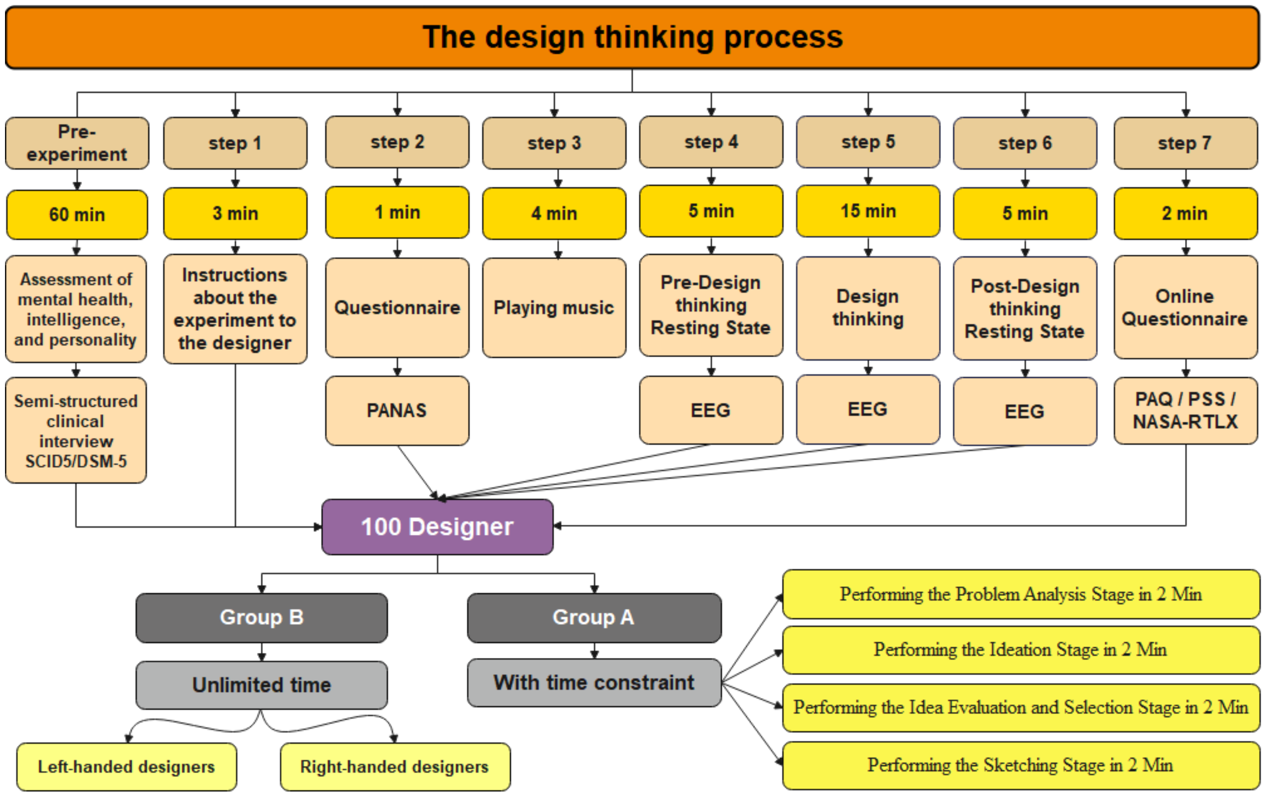

Figure 3-8: Stages of the Experiment

3-10-2-4- Implementation of Phase one of the Research: Mental Health Assessment of Designers

After registering the student designers and designers for participation in the test, Dr. Saba Mousavi-Nejad conducted a semi-structured clinical interview (SCID5/DSM-5) with them. Based on the entry criteria for the statistical population, eligible student designers and designers were selected for participation in the experiment.

3-10-2-5- Implementation of Phases Two, Three, and Four of the Research: Stress Measurement Using EEG, MetaCogno, and Questionnaires

This study was conducted in the laboratory of Tabriz Islamic Art University using a 64-channel electroencephalography (EEG) device from Negarandishgan Company, equipped with 32 electrodes uniformly distributed across the scalp's surface for recording and sampling. Initial explanations about the experiment and its procedures were provided to the student designers and professional designers. Then, a consent form was given to them to read and sign. The consent form contained comprehensive details about the test, the research objectives, and the ethical considerations of the study.

- **PANAS Questionnaire**: The student designers and professional designers were asked to complete the Positive and Negative Affect Schedule (PANAS) questionnaire at the beginning. This was done to assess their current emotions and feelings before the experiment, taking less than a minute to complete.
- **Explanations to the Student Designers and Designers**: Explanations were provided regarding

how the test would be conducted, the questionnaires, the MetaCogno software, and the EEG device. The four stages—problem analysis, idea generation, evaluation and selection of ideas, and implementation—were explained to the students and designers, along with an example to ensure they fully understood the design thinking process. This stage took approximately three minutes.

- **Music Playback**: After preparing and providing explanations to the student designers and professional designers, they were seated in a quiet and peaceful space and listened to instrumental, calming music for four minutes. The same music was played for all participants. This section aimed to help the designers relax after the preparation process for the test, which took about half an hour.
- **Resting State Before the Design Thinking Process**: In a quiet space, the designers sat comfortably in chairs, while their stress levels were measured using EEG. They were instructed to do nothing, simply close their eyes for 2:30 minutes. Then, they were asked to open their eyes for 2:30 minutes. During this phase, their brainwaves and heart rate were measured in a resting state for a total of 5 minutes (2:30 minutes with eyes closed and 2:30 minutes with eyes open in a quiet environment).
- **Design Thinking Process**: In this stage, which is the main part of the experiment, the designers began the design thinking process using the MetaCogno software, while their brainwaves and heart rate were measured and recorded using EEG. Since designers were instructed not to move during the EEG brainwave measurements, the EEG recording was paused during the section that displayed the designers' emotional-cognitive experiences after each stage of the design process. This allowed the student designers and professional designers to think freely without time constraints and move freely during this period to avoid fatigue.

Figure 3-9: Images of the experimental process, implementation of ideas during the experiment, and the final design presentation by designers for the Neuro Aidea competition

- **Resting State After the Design Thinking Process**: After completing this stage, the designers were again asked to sit calmly on a chair. While their stress levels were measured using EEG, they were instructed to do nothing, simply close their eyes for 2:30 minutes. They were then asked to open their eyes for 2:30 minutes. During this phase, their brainwaves and heart rate were measured in a resting state for a total of 5 minutes (2:30 minutes with eyes closed and 2:30 minutes with eyes open in a quiet environment).
- **Post-Experiment Questionnaires**: In the final stage, the designers were asked to complete three questionnaires: CSI/PAQ/PSS. Images from the experiment process, the implementation of ideas during the experiment, and the presentation of the final designs by the designers and student designers for the Noor Idea competition are shown below (Figures 3-9).

3-10-3- EEG Signal Recording

Data recording was performed using 32 electrodes based on the standard 10-20 system. The selected channels for recording brain electrical activity included FPZ, FP1, F3, FZ, F4, FP2, FC5, FC1, FC2, FC6, T7, C3, C4, Cz, T8, CP5, CP1, CP2, CP6, P7, P3, PZ, P4, P8, PO7, PO3, POZ, PO4, PO8, O1, OZ, and O2. The electrode names and their locations on the scalp are shown in the figure below (Figure 3-10).

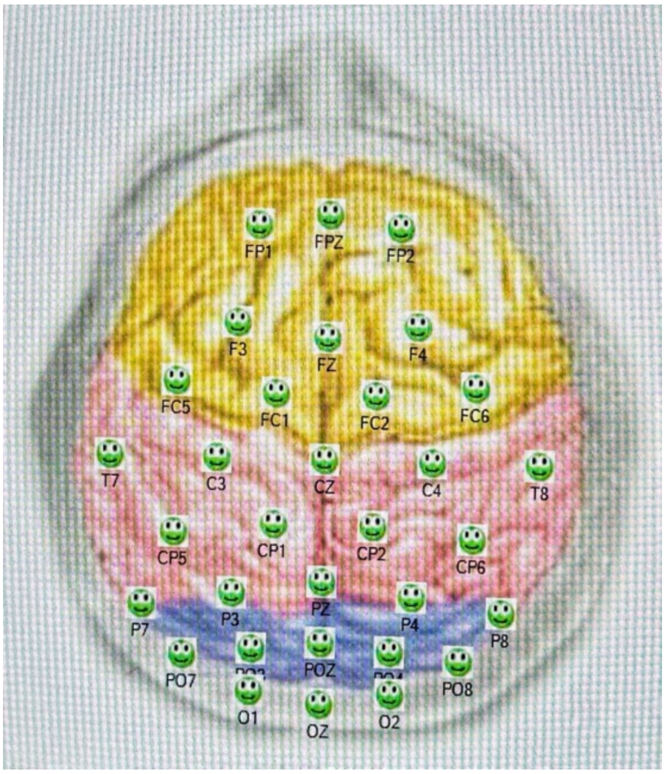

Figure 3-10: 2D schematic of the electrode placement layout on the scalp.

The FCZ channel was used as the reference channel (Ref). The left hand of right-handed design students and designers, and the right hand of left-handed design students and designers were connected to the Grand. Additionally, the electrodes used were active (Active) electrodes. All electrodes were connected to the scalp using electrode gel, which establishes the connection between the scalp and the electrode. Once the electrodes were set up, the EEG device recorded the brain's electrical activity by detecting very weak electrical waves originating from the brain's neurons. The EEG device captures the signals in short time intervals (milliseconds), and these data are displayed momentarily (Figure 3-11). It is worth noting that the quality of the data collected was quality-controlled according to EEG standards. The signals were recorded at a rate of 500 Hz, and the electrode impedance was kept below 5 kΩ. This level of impedance is necessary to ensure high-quality signals and reduce noise in the recorded data.

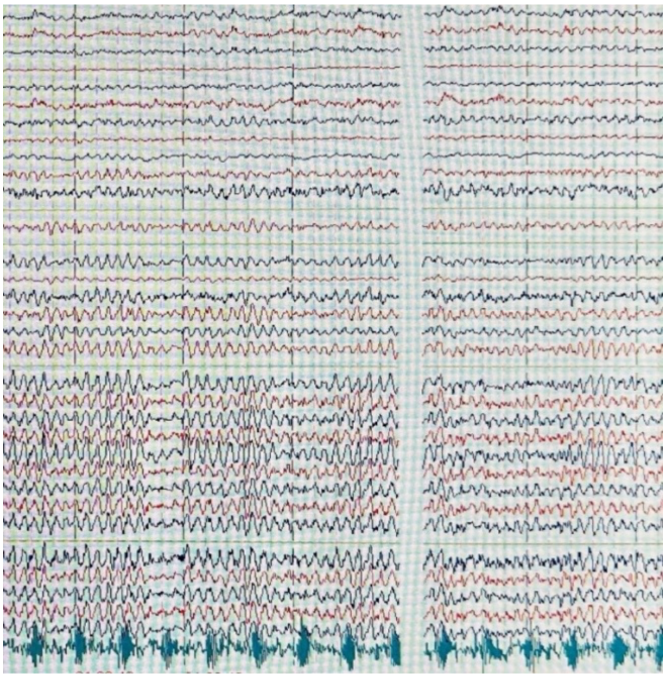

Figure 3-11: Image of the signals received from designers during the design thinking process.

3-11- Data Analysis Methodology

In this research, two types of comparisons will be conducted to examine the impact of stress induced by the design thinking process on designers: **within-group** and **between-group** comparisons. These comparisons aim to assess and evaluate the **perceived stress levels** and **emotional-cognitive experiences** of designers across the four key stages of the design thinking process, considering the variables of **time constraints** and **handedness**.

These methods have been widely employed in previous studies to measure stress levels and emotional-cognitive experiences during various task performances. The following sections provide a detailed explanation of these methods and their application in this study.

- **Within-Group Comparison**: The within-group comparison aims to evaluate the perceived stress levels and emotional-cognitive experiences of designers by examining differences between their resting state and the four key stages of the design thinking process. In this approach, a designer's stress levels and emotional-cognitive responses in different stages of the process are compared to their own baseline and other stages. This allows for identifying which stage of the design thinking process induces the highest level of stress and emotional-cognitive engagement among designers. This method has been previously utilized in research assessing stress in creative environments and is aligned with studies employing within-group analysis to investigate cognitive and emotional changes during task performance (Smith & Gevins, 2004). Moreover, prior research has demonstrated that fluctuations in EEG frequency bands (e.g., alpha and beta) can serve as reliable indicators of how tasks influence mental states (Klimesch, 1999).
- **Between-Group Comparison**: The between-group comparison aims to evaluate perceived stress levels and emotional-cognitive experiences by analyzing differences between distinct groups of designers. This comparison examines variations based on the following variables:
  - **Handedness Variable**: Designers with different individual characteristics may exhibit varied emotional-cognitive experiences and stress levels. In this study, the perceived stress levels and emotional-cognitive experiences of left-handed and right-handed designers during the design thinking process will be compared to assess the influence of dominant hand preference. This method aligns with previous research exploring individual differences in cognitive and emotional processing (Michel & Murray, 2012; Coren, 1993). Studies have shown that handedness can significantly impact emotional experiences and stress responses (Porac & Coren, 1981).
  - **Time Constraint Variable**: This analysis compares designers who complete the design thinking process without time constraints with those working under strict time limitations. Investigating these differences helps determine whether time pressure significantly increases designers' stress levels. This approach is consistent with prior research examining the impact of time constraints on stress and cognitive performance (Lin et al., 2010; Eysenck & Calvo, 1992; Salthouse, 1996).

3-11-1- Data Analysis Methods of the First Phase of Research: Structured Clinical Interview SCID5/ DSM-5

Clinical interviews, as one of the qualitative data collection methods, require precise techniques for recording and analyzing information, helping researchers to systematically and reliably analyze the rich and complex data collected through interviews. One of the most basic and common methods for recording interview data is note-taking during the interview. In this method, the researcher simultaneously notes key points, important phrases, and non-verbal reactions while conducting the questioning and answering. This method is simple and quick but may not capture all the important details and could compromise the accuracy of the analysis (Kvale & Brinkmann, 2009). The researcher then proceeds to analyze the collected data.

3-11-2- Data Analysis Methods of the Second Phase of Research: Electroencephalography

In this study, electroencephalography (EEG) was employed within the framework of the design thinking process to identify and quantify stress levels and their distribution across different stages of design thinking. This approach is based on standard EEG analysis methods and aims to provide objective assessments of designers' mental states and stress responses throughout the design process. Machine learning algorithms were utilized to analyze EEG data, identify stress-related patterns, and extract features associated with brain activity at each stage of design thinking. This method establishes a quantitative framework for examining designers' perceived stress across the four key stages of the design thinking process.

To ensure the accuracy and reliability of data acquisition and processing, two five-minute Resting State periods were included—one before and one after the design thinking process. These periods served as baseline conditions, allowing for direct comparison with EEG data recorded during the design thinking process. This approach facilitated the identification of any changes in EEG signals specifically associated with design-related cognitive activity. Additionally, to validate the integrity and reliability of the data acquisition system, seven pre-tests were designed and conducted. These pre-tests aimed to assess the proper functioning of the EEG system and to verify the accuracy of the data processing pipeline, particularly under controlled conditions without external interference. The results of these pre-tests were meticulously analyzed to ensure that the recorded signals aligned with expected benchmarks under each experimental condition.

Following this validation process and confirmation of data integrity, the main experiment was conducted with confidence in the precision and reliability of the recorded data. This phase was specifically designed to minimize the presence of artifacts and signal disturbances in the final dataset while ensuring the reproducibility of the main experiment. Therefore, the comprehensive validation measures—including rigorous analysis of pre-test results and the comparison of resting-state data with design process data—effectively ensured the accuracy and reliability of the collected data and subsequent analyses in the main study.

3-11-2-1- Feature Extraction and Signal Preprocessing

The chart presented in this study is derived from EEG data recorded during different stages of the design thinking process. One of the key challenges in analyzing EEG data for stress evaluation in the design thinking process is the removal of artifacts from EEG signals. Artifacts are typically caused by body movements, eye blinks, and other non-neural activities that can significantly impact the accuracy of analyses and machine learning models. To address this issue, several advanced techniques were employed, as detailed below:

1. **Independent Component Analysis (ICA):** One of the most advanced and widely used methods for artifact removal in EEG data is Independent Component Analysis (ICA). This technique helps decompose EEG signals into independent components, enabling the identification and separation of artifacts such as eye blinks and ocular movements, which predominantly appear in low-frequency bands. In this study, ICA was applied to detect and eliminate non-neural components, ensuring that the extracted EEG data remained accurate and meaningful for further analysis.
2. **Bandpass Filters:** To eliminate unwanted frequencies that may result from artifacts, bandpass filters were applied. These filters constrained the EEG signal within the frequency range of 1 to 40 Hz, encompassing essential brainwave frequency bands while reducing artifacts caused by high- and low-frequency noise.
3. **Machine Learning Models for Artifact Detection:** In addition to traditional methods, machine learning models were employed to enhance artifact detection accuracy. Specifically, models such as Support Vector Machines (SVM) and Random Forest were utilized to identify and remove motion artifacts and other non-neural contaminants based on their distinct characteristics. These models leveraged features extracted from the EEG signals, such as signal energy and complexity, to effectively distinguish between neural and non-neural components.
4. **Adaptive Filters for Real-Time Artifact Removal:** In certain cases, adaptive filters were also implemented for real-time artifact removal. These filters dynamically identified and eliminated artifacts as they occurred, particularly in scenarios where artifact signals exhibited continuous variation over time.

These advanced approaches significantly improved the accuracy and reliability of EEG data, mitigating the impact of artifacts on the analysis outcomes. Following the preprocessing stage, a sliding window technique (4-second windows with a 2-second overlap) was applied to extract a comprehensive set of features, including the following:

1. **Estimation of Power in Various Brain Bands:** Using the Welch method, the power in different brain bands was calculated, including:
    - **Delta Band Power (0.5–4 Hz):** Associated with deep sleep and brain recovery.

- **Theta Band Power (4–8 Hz):** Associated with drowsiness, creativity, meditation, daydreaming, and imagination.
- **Alpha Band Power (8–13 Hz):** Indicative of relaxation and resting states.
- **Beta Band Power (13–30 Hz):** Associated with active thinking, problem-solving, decision-making, and concentration.
- **Gamma Band Power (30–50 Hz):** Associated with high-level information processing, conscious perception, learning, solving complex problems, deep thinking, and working memory.

2. **Brain Band Ratios:** The theta/beta and alpha/beta ratios were calculated to assess mental relaxation and engagement in design activities throughout the design thinking process.
3. **Statistical and Signal Complexity Features:** To analyze the complex dynamics of brain activity, statistical features such as mean, standard deviation, skewness, and kurtosis, as well as Hurst features (movement and complexity), were also calculated.
4. **Data Segmentation:** The data were divided into different epochs based on the stages of the experiment. This segmentation includes the resting state before and after the design task and the four main stages of the design thinking process.

3-11-2-2- Stress Algorithm Identification in the Design Thinking Process

The obtained features were classified into five different stress levels using the K-means clustering method: very high stress, high stress, normal state, low stress, and very low stress. This approach was chosen without relying on pre-established stress thresholds to reflect the diversity of stress responses throughout the four stages of the design thinking process. The clustering steps included:

- **Feature Standardization:** Ensuring equal weighting of all features to maintain fairness across the data.
- **Clustering:** K-means was used with the k-means++ initialization method, where k=3.
- **Cluster Interpretation:** Based on the characteristics of the cluster centers, where high power in the beta and gamma bands indicates stress states, often related to solving complex problems or dissatisfaction in design activities.

3-11-2-3- Temporal Analysis in the Design Processes

In this phase of the study, statistical methods and algorithms for identifying temporal changes in EEG data were utilized to analyze the patterns of stress variations over time. The primary goal of this analysis was to identify the stress changes over time and determine the duration of each stress period. The employed methods included the following:

1. **EEG Data Extraction and Segmentation:** After initial preprocessing and noise removal, the EEG data were divided into time segments (epochs). This segmentation allowed for the identification and analysis of stress variations over both short-term and long-term time intervals.
2. **Temporal Change Analysis and Data Smoothing:** A moving average filter was applied to smooth the stress variations over time, separating transient changes from stable fluctuations. This method enabled the calculation of the number of state transitions (e.g., from low stress to high stress) and their temporal distribution.
3. **Analysis of Short-term and Long-term Stress Period Patterns:** Different stress periods were categorized based on the duration of each episode. A time threshold (e.g., 0.1 and 0.9 time units) was applied to differentiate between short-term and long-term stress periods.
4. **K-means Clustering Algorithms:** K-means clustering was used to identify temporal patterns and classify the duration of stress periods based on different stress levels.
5. **Statistical Indices Usage:** To determine the average number of state changes and analyze stress periods, statistical indicators such as the mean and relative frequency were used. These indices assist in understanding the number and distribution of stress periods among the designers.

3-11-2-4- Quantitative Evaluation of Stress Caused by Design Thinking

Various criteria were calculated for each designer and stage of the design thinking process:

- Percentage of Time Spent in Each State (High Stress, Low Stress, Normal State)
- Maximum Continuous Duration in High Stress State
- Frequency of State Transitions
- Perceived Stress Level in the Four Main Stages of the Design Thinking Process
- Impact of Stress on Designers' Performance

To ensure the reproducibility of the study’s findings, the entire data processing pipeline—including EEG signal recording, preprocessing steps, feature extraction, clustering methodology, and temporal analysis—was comprehensively documented. This level of detail is essential for other researchers to replicate the study in different experimental settings or populations and validate the results. The thorough documentation provided above guarantees transparency and replicability of the process. This methodology establishes a reliable framework for analyzing stress induced by the design thinking process using EEG data.

3-11-2-5- Classification Models

This section discusses the classification models and their evaluation metrics used to identify and assess stress levels during the design thinking process. Depending on the research objectives and the level of accuracy and detail required, either binary classification or multi-class classification can be employed. The classification technique proposed in this study is a commonly used method in the field of machine learning, specifically applied for analyzing stress levels across various contexts (Nirabi et al., 2022). These models and evaluation metrics can be utilized to analyze and assess the levels, extent, and intensity of stress during the design thinking process in designers. The evaluation metrics further assist in the precise assessment of the model's performance.

1. **Binary Classification**:
   - **Proposed Models**: Use of models such as Support Vector Machines (SVM) and Random Forest.
   - **Support Vector Machines (SVM)**: One of the most widely used classification models that divides data into two categories using linear and non-linear decision boundaries. SVM performs well in high-dimensional spaces, but it may be slow for large datasets.
   - **Random Forests**: This classification model uses multiple decision trees and determines the final result through voting. It is particularly suitable for complex data, provides high accuracy, and is less prone to overfitting, though it may be more complex to interpret.
2. **Multi-class Classification**: Multi-class classification can assist in identifying and assessing the level, extent, and intensity of stress during different stages of the design thinking process. It categorizes stress into low, medium, and high levels.
   - **Proposed Models**: The same binary classification models (SVM and Random Forest) can be used, with modifications for multi-class classification.

3-11-2-6- Evaluation Metrics

1. **Binary Classification Metrics**:
   - **Accuracy**: The ratio of correct predictions to the total instances.
   - **Precision**: The ratio of true positive observations predicted correctly to the total predicted positives.
   - **Recall**: The ratio of true positive observations predicted correctly to the total observations in the actual class.
   - **Confusion Matrix**: The harmonic means of precision and recall.
   - **ROC Curve and AUC**: Represents the model's ability to distinguish between classes. The Receiver Operating Characteristic (ROC) curve shows the model’s performance in binary classification. The Area Under the Curve (AUC) is a metric of the model’s ability to distinguish between positive and negative classes; an AUC close to 1 indicates good model performance.

2. **Multi-class Classification Metrics**:
   - **Accuracy**: Similar to the accuracy metric in binary classification, it shows the percentage of correct predictions across all classes (low, medium, high).
   - **Precision, Recall, and F1 Score for Each Class**: Calculated separately for each stress class (low, medium, and high) to determine the model's performance in each class.
   - **Confusion Matrix**: This matrix is used to assess the model's performance in multi-class classification. It includes information such as true positives, true negatives, false positives, and false negatives for each class.

3-11-2-7- Application of SVM and Random Forest for Stress Detection in the Design Thinking Process with EEG Data

Support Vector Machines (SVM) and Random Forest methods are suitable for detecting stress in EEG data for the following reasons: their ability to handle complex, multidimensional data, resistance to noise, capacity to detect nonlinear patterns, good performance with limited sample sizes, interpretability of results, flexibility across individual differences, efficient processing speed, ability to address class imbalance, capability to combine information from multiple sources, and proven success in previous studies. Given these reasons, the use of Support Vector Machines and Random Forest for stress detection in EEG data is a logical and evidence-based choice. These methods are capable of handling the complexities of EEG data and delivering reliable results.

3-11-3- Data Analysis Method for Phase Three of the Research: MetaCogno

The statistical data in this section of the thesis were analyzed using Excel and SPSS version 26. The results are presented in two sections: descriptive statistics and inferential statistics. In the descriptive statistics section, statistical parameters such as relative frequency, highest frequency, and tables describing related variables are provided. These analyses will specifically focus on time variables and handedness in relation to the emotional-cognitive experiences experienced by designers during different stages of the design thinking process, and will ultimately examine the entire design process. The inferential statistics section examines the significant relationships between the research variables, including the time variable between the two groups of designers with and without time constraints, and the handedness variable between left-handed and right-handed designers.

3-11-4- Data Analysis Method for Phase Four of the Research: Questionnaires

In this research, the data obtained from the questionnaires were analyzed using descriptive statistical indicators such as the mean and standard deviation of the test. The mean, as an indicator of data centrality, reflects the general tendency or focal point of the data, while the standard deviation measures the dispersion of the data relative to the mean, evaluating the variability in responses. These indicators enable the researcher to gain a comprehensive understanding of the data distribution and response patterns. In the inferential statistics section, the significant relationships between the questionnaire data and the results obtained from the EEG tool were examined using statistical tests such as Pearson Correlation, Spearman's Rank-Order Correlation Test, One-Way ANOVA, and the Kolmogorov-Smirnov Test, depending on the type of questionnaire.

Chapter 4
Research Findings

4-1- Introduction

Stress is recognized as one of the factors threatening both the mental and physical health of individuals. This issue not only affects individual well-being but also influences the quality and effectiveness of performance in professional environments, including design. In the field of design, stress can seriously disrupt the design process and its activities, leading to a decline in the quality of final products and negatively impacting the user experience. Therefore, addressing stress within design studies and exploring management and coping strategies is essential. This focus can contribute to improving the quality of design, enhancing designers' performance, and promoting the mental well-being of designers. On the other hand, contemporary psychological and cognitive design studies are increasingly focusing on identifying stress-inducing factors and examining their impact on designers' performance in decision-making, creativity, and design processes. In this context, the concept of "design stress" was introduced as a new field of study in Chapter 2, and efforts were made to clarify the ambiguities related to this concept based on existing theories. In Chapter 3, appropriate methods for measuring studies in the field of design stress were collected and systematically categorized. Due to the broad scope of design stress studies, this research specifically focused on stress arising from the design thinking process. Among the various methods suitable for studies in this field, several combined approaches, including the novel MetaCogno tool, were selected to examine the emotional-cognitive experiences of designers and assess stress resulting from the design thinking process. Furthermore, the process of conducting the experiment, the tools used in the four research phases (questionnaires, semi-structured clinical interviews, electroencephalography (EEG), and the MetaCogno tool), and the methods for analyzing their data were explained in detail. The remainder of this chapter focuses on the analysis of the research data, the findings, the designers' cognitive patterns, the differences related to time and hand dominance variables, and the evaluation of the performance of classification models in identifying stress levels and intensities.

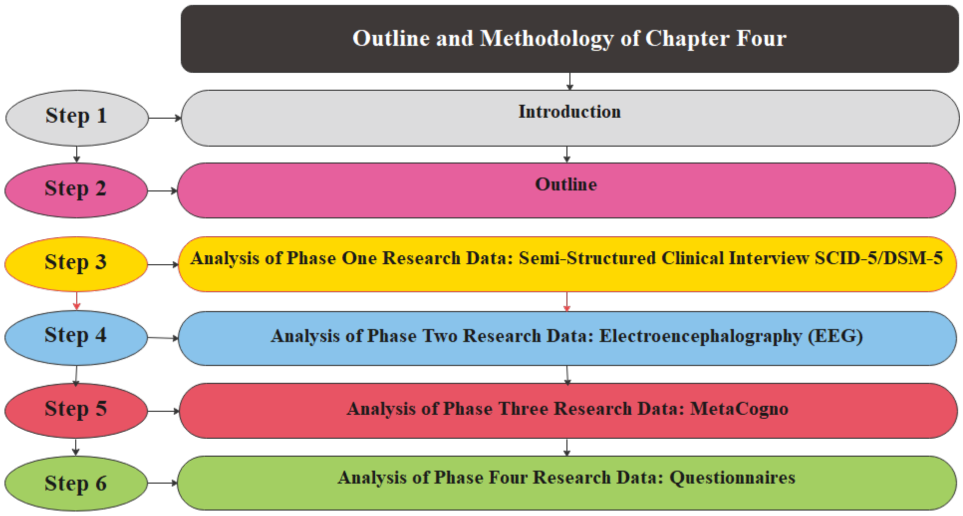

Figure 4-1: An Overview of the Research Phases in Chapter Four: Research Findings

4-2- Overview and Methodology of Chapter Four

Chapter Four is dedicated to presenting the findings of the research, with the aim of answering the research questions through the analysis of the data collected in the previous chapters. The structure of this chapter is designed based on the research phases and data analysis, ensuring that the research findings are categorized and presented in an organized and scientific manner. After the introduction and the overview and methodology of Chapter Four in Section 3, the analysis of the collected data from various research phases will be discussed. In Phase One, the data obtained from the semi-structured clinical interviews using SCID5/DSM-5 and the PANAS questionnaire will be analyzed. In Phase Two, the electroencephalography (EEG) data will be examined and analyzed using machine learning tools, and the performance of classification models in assessing and detecting stress states resulting from the design thinking process, temporal patterns, and various stress levels, as well as the impact of stress from different stages of the design thinking process on designers and their performance, will be explored in Section 4. Phase Three of the research, focusing on the data from the MetaCogno tool, will provide valuable findings centered on the emotional-cognitive experiences of designers during the design thinking process in Section 5. A comparative analysis of designers based on the variables of time and hand dominance will also be conducted using EEG and MetaCogno data. Section 6, representing Phase Four of the research, will analyze the results of the PSS/PAQ/CSI questionnaires, and finally, in Section 7, a discussion of the findings of Chapter Four will be presented. Figure 4-1 provides an overview of the research methodology (Figure 4-1).

4-3- Analysis of Phase One Data: Assessing Designers' Mental Health

In the first phase of the study, a total of 145 design students and professional designers were enrolled. Semi-structured clinical interviews (SCID-5) were conducted by Dr. Saba Mousavinejad, a psychologist, based on DSM-5 criteria. The primary objective of these interviews was to assess the participants' psychological health and determine their eligibility for inclusion in the study sample. The results of these assessments led to the identification of individuals who, due to psychological issues such as high levels of stress, severe anxiety, or other psychiatric disorders, were excluded from further participation. Consequently, only those designers who demonstrated relatively stable and normal psychological conditions were included in the study to ensure the accuracy and validity of the experimental data.

A thematic analysis of the interview data revealed two main groups: (1) design students and designers with relatively stable psychological conditions and (2) individuals exhibiting significant psychological issues, including high levels of anxiety, stress, or diagnosed psychiatric disorders. Out of the 145 participants, 45 individuals (31%) were excluded from the study due to severe psychological distress, high anxiety levels, or the use of anti-anxiety medication. This exclusion highlights the relatively high prevalence of anxiety and stress among design students and professionals in the field of industrial design. A significant portion of these individuals were undergoing specialized treatment and psychiatric supervision. This categorization facilitated the selection of designers with comparable and stable psychological conditions, enhancing the homogeneity of the study sample and increasing the reliability of the research findings. The prevalence of stress and anxiety as widespread and structural issues among design students and professionals underscores the importance of a deeper understanding of this aspect of mental health. The high levels of stress and anxiety observed among designers may stem from the inherently demanding nature of the design profession, workplace and academic pressures, societal conditions, or lifestyle factors. These findings emphasize the necessity of developing effective strategies for stress management and improving the psychological well-being of designers.

4-3-1- Comparative Analysis of PANAS Questionnaire Results

The results of the Positive and Negative Affect Schedule (PANAS) questionnaire, completed by designers one minute before the experiment, provide insights into their emotional and psychological state prior to engaging in the design thinking process. Regarding positive affect, 78% of designers exhibited high levels of positive affect, indicating that they were in a favorable emotional and mental state before beginning the design process. This condition may stem from their motivation, interest, and mental readiness to engage in the task. Additionally, 20% of designers reported a moderate level of positive affect, suggesting a balanced emotional state. Only 2% demonstrated low levels of positive affect, which may reflect concerns or a lack of complete mental preparedness at the outset of the task.

In terms of negative affect, 41% of designers reported low levels of negative affect, indicating a sense of calmness and a relatively positive outlook at the beginning of the design thinking process. Another 42% exhibited moderate levels of negative affect, suggesting that they experienced some degree of worry or stress, albeit at a manageable level. However, 17% of designers reported high levels of negative affect, which may indicate stress or a lack of mental preparedness before initiating the process. Overall, the findings suggest that the majority of designers demonstrated high levels of positive affect before commencing the design thinking process, with only a small subset experiencing heightened levels of negative affect.

4-4- Analysis of Phase Two Data: Electroencephalography (EEG)

This section of the findings is derived from the use of machine learning techniques for extracting and analyzing EEG data. Specifically, these results focus on the evaluation and analysis of the perceived stress levels experienced by designers during the design thinking process, achieved through the extraction of features related to brainwave frequency bands (delta, theta, alpha, beta, and gamma) and the use of frequency band ratios. These analyses enabled the calculation of overall indicators such as average stress, the distribution of different stress levels among designers, temporal patterns, the impact of stress on designer performance, the distribution of mental states, and the correlation between stress and relaxation.

As stated in Chapter 3, the determination of stress levels based on EEG data was carried out through preprocessing, feature extraction, and classification using machine learning techniques. In the preprocessing stage, the EEG signals were filtered, and noise and artifacts caused by movement and blinking were removed using methods such as band-pass filtering and Independent Component Analysis (ICA). Next, key features from various frequency bands and their ratios (such as theta/beta ratio), along with statistical indicators and complexity measures (such as spectral entropy and Hurst parameters), were extracted. In the subsequent stage, machine learning models, including Support Vector Machine (SVM) and Random Forest, were employed to classify stress levels (low, moderate, high). The stress thresholds (red dashed line) and baseline state (green dashed line) were determined by statistical analysis of EEG readings in baseline conditions (pre- and post-test rest) and the observed changes during the design thinking process.

In this study, the perceived stress levels of the designers were assessed both generally across all designers and comparatively based on the variables of time and dominance in the design thinking process. The performance of the classification models was also evaluated using metrics such as accuracy, recall, F1 score, and confusion matrix to confirm the precision and reliability of the proposed method. The results obtained in this section are presented (Figure 4-4). In the first step, after processing the data and extracting the features, graphs were generated for each designer, representing their stress levels over time based on the EEG data (Figure 5-4). The graphs are interpreted as follows:

- **Horizontal Axis (X-axis):** Represents time in seconds.
- **Vertical Axis (Y-axis):** Measures stress levels.
- **Blue Line:** Represents variations in stress levels over time.
- **Red Dashed Line:** Indicates the stress threshold. When the stress level exceeds this threshold, the designer is in a state of stress.
- **Green Dashed Line:** Represents the normal state threshold. Values below this threshold are recognized as periods of rest or relaxation.
- **Stress Periods:** These areas correspond to time intervals where the stress level surpasses the stress threshold (red dashed line), indicating periods of heightened stress for the designer.
- **Potential Rest Periods:** These areas correspond to time intervals where the stress level falls below the normal threshold (green dashed line), indicating periods of rest or relaxation.

4-4-1- Evaluation of Stress Levels in Designers Using EEG during the Design Thinking Process

These charts effectively aid in identifying temporal patterns related to stress, normal states, and relaxation during various activities within the design thinking process. They clearly demonstrate the time intervals when the designer experienced stress, periods of reduced stress leading to relaxation, and phases of normal states. Furthermore, these charts have been utilized to evaluate the impact of stress induced by the design thinking process on the designers' stress levels and performance over time and across different stages of this process (Figure 4-2).

This analysis provides a comprehensive understanding of the dynamic interactions between stress levels and the cognitive and emotional demands of the design thinking process, offering valuable insights for improving stress management and performance optimization in design tasks.

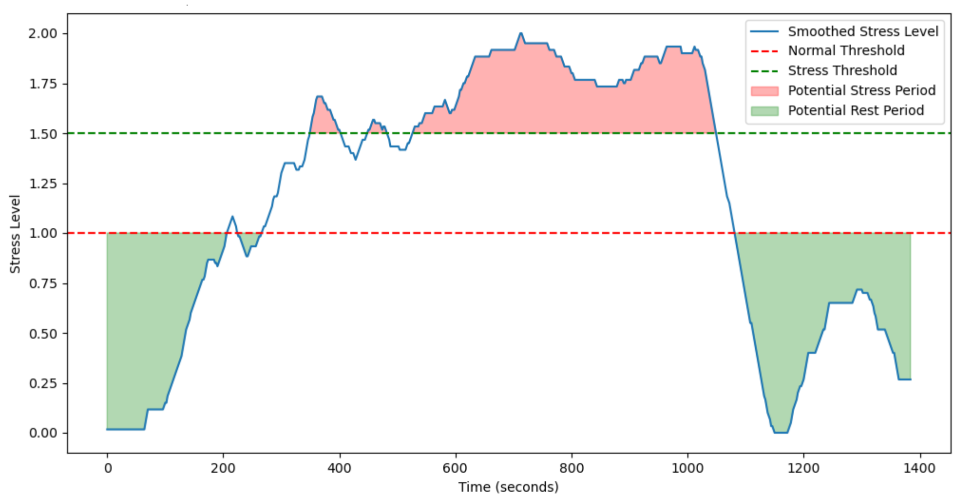

Figure 4-2: Designers' Stress Levels During the Design Thinking Process

4-4-1-1- Comparative Analysis of Classification Models' Performance in Detecting Stress during the Design Thinking Process

As explained in Chapter 3 of the research, two models, Random Forest and SVM (Support Vector Machine), were used to classify different stress levels in the design thinking process. These models aimed to identify stress states (low, medium, and high) by utilizing features extracted from the EEG signals of designers during the design activity. To evaluate the accuracy and efficiency of the classification models, metrics such as accuracy, precision, recall, and F1 score were used. The overall accuracy of the Random Forest and SVM models was calculated to show which model performed better in predicting stress levels during the design thinking process. In the comparison between the two models, it was observed that Random Forest outperformed SVM with an accuracy of 0.98 compared to SVM's accuracy of 0.94, and correctly classified the various stress states during the design thinking process. The high accuracy of this model is due to the multi-layered nature of Random Forest, which uses the combination of several decision trees to predict stress states. In the Random Forest model, multiple decision trees are created based on random sampling of the data, and the results of these trees are combined, enhancing accuracy and robustness against complex and unstable data. Since EEG data under high-stress conditions exhibit more variable frequency and amplitude changes, Random Forest is better suited to handle these data compared to SVM. By combining results from multiple trees, this model demonstrates higher detection power in identifying complex stress states. The 98% accuracy indicates that this model can effectively detect various stress patterns in the complex EEG data and align well with real-world conditions.

Figure 4-3: Comparison of Stress Levels and Performance with SVM and Random Forest Accuracy

A comparative line chart showing the relationship between stress levels and the accuracy of the machine learning models, SVM and Random Forest, is presented above. The horizontal axis represents the percentage of stress, while the vertical axis represents the accuracy of the classification models. The accuracy of the Random Forest model is generally higher than that of the SVM, and it does not show significant changes as the stress level increases. In contrast, the accuracy of SVM decreases. This chart was generated through testing machine learning models on the obtained EEG data to analyze the relationship between stress levels and model performance accuracy (Figure 4-3).

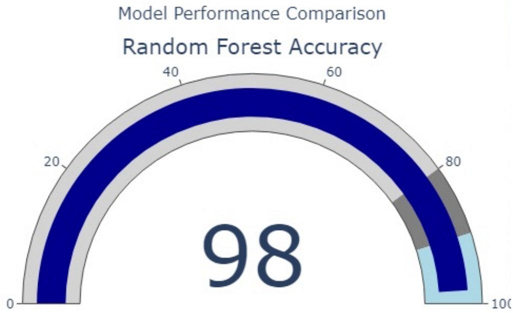

Figure 4-4: Comparison of Classification Model Performance: Accuracy of Random Forest

4-4-1-2- Correlation Analysis of Design Thinking Stress and Classification Model Performance

To examine the relationship between stress levels in the design thinking process and classification accuracy, correlation analysis was conducted. The results indicate an inverse correlation between stress levels and classification accuracy, meaning that as stress levels increase during the design thinking process, the accuracy of the models in classification decreases (Figure 4-4). This may be due to the increased complexity of EEG data under high stress conditions, as high stress directly impacts the quality of the EEG data and the models' ability to predict accurately. At higher stress levels in the design thinking process, the EEG data often contain more fluctuations and complexities due to stronger responses from the nervous system. These conditions make it more difficult for classification models, especially those sensitive to frequency and amplitude variations such as SVM, to detect patterns. Consequently, identifying stress patterns in the design thinking process becomes more challenging at higher levels, and the models are less able to accurately identify the different stress states.

4-4-1-3- Best Classification Model for Detecting Stress Patterns in the Design Thinking Process

The pie chart below illustrates the high accuracy of the Random Forest model, which is 98% (Figure 3). This high accuracy demonstrates the model's ability to reliably detect and classify stress states in the design thinking process. This result was obtained through testing machine learning models, particularly the Random Forest model, on EEG data to detect stress states in the design thinking process, showcasing the strong performance of this classification model. The findings from this part of the research highlight the importance of using more robust models, such as Random Forest, for complex and unstable data obtained in the design thinking process using tools like EEG. It also emphasizes that reducing designers' stress can help improve the accuracy and performance of predictive models, while high stress can diminish model accuracy and performance (Figure 4-4).

4-4-2- Analysis of the Average Stress Level in the Design Thinking Process

The classification of stress levels based on EEG signal monitoring, the distribution ranges of stress levels in the design thinking process, and the determination of the stress level percentage for each designer have been obtained. The bar chart below illustrates the number of designers at various stress levels during the design thinking process (Figure 1). The highest number of designers fall into the moderate stress level category, indicating that most of them experienced a moderate and manageable level of stress during the design process. Therefore, the overall average stress level among the designers in this study is 35%. This average serves as a reference point for categorizing stress levels in the design thinking process and, based on this, the stress levels are divided into five categories: very low stress level (0-5%), low stress level (5-15%), moderate stress level (15-25%), high stress level (25-40%), and very high stress level (>40%) (Figure 4-5).

4-4-3- Analysis of the Distribution of Different Stress Levels in the Design Thinking Process

Based on the average stress levels obtained from the design thinking process, the distribution of stress levels among the designers has been divided into five categories (Figure 4-5):

- **Very Low Stress (0-5%)**: 15% of designers experienced very low stress levels.
- **Low Stress (5-15%)**: 20% of designers experienced low stress levels.
- **Moderate Stress (15-25%)**: The results indicate that approximately 35% of designers in this study experienced moderate stress levels during the design thinking process.
- **High Stress (25-40%)**: 18% of designers experienced high stress levels.
- **Very High Stress (>40%)**: 12% of designers experienced very high stress levels.

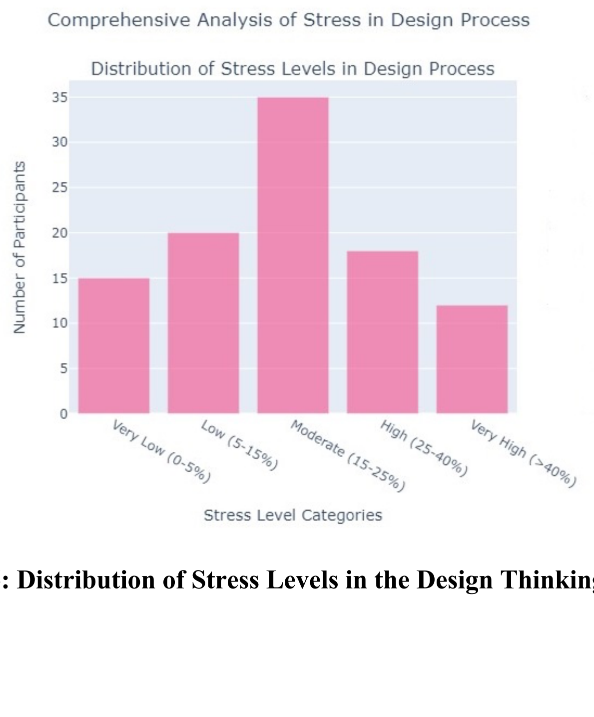

Figure 4-5: Distribution of Stress Levels in the Design Thinking Process

4-4-4- Analysis of Stress Patterns in the Design Thinking Process

As previously mentioned, for analyzing temporal variations, the duration of stress signals in the EEG data was monitored using a moving average filter to group the findings. The goal was to demonstrate the distribution of stress duration in the design process, as it was found that different stages of the design thinking process can involve varying degrees of stress over time. This temporal smoothing helps identify continuous periods of stress or relaxation that represent key experiences of designers while performing design activities. It also aids in identifying temporal stress patterns in the design thinking process and accurately evaluating the relationship between the duration of stress periods and the frequency of state changes. The bar chart below shows the distribution of the frequency of different stress durations in the design thinking process. The horizontal axis represents time intervals (such as 0-0.1, 0.1-0.3, etc.), while the vertical axis shows the frequency of occurrences within each time interval. The most frequent stress durations occurred in shorter intervals (0-0.1) with a frequency of 40%, indicating that shorter periods of stress are more common. The least frequent stress durations occurred in the longest intervals (greater than 0.9) with a frequency of 8%. The stress durations in the time ranges of (0.1-0.3), (0.3-0.6), and (0.6-0.9) occurred with frequencies of 25%, 15%, and 12%, respectively (Figure 4-6).

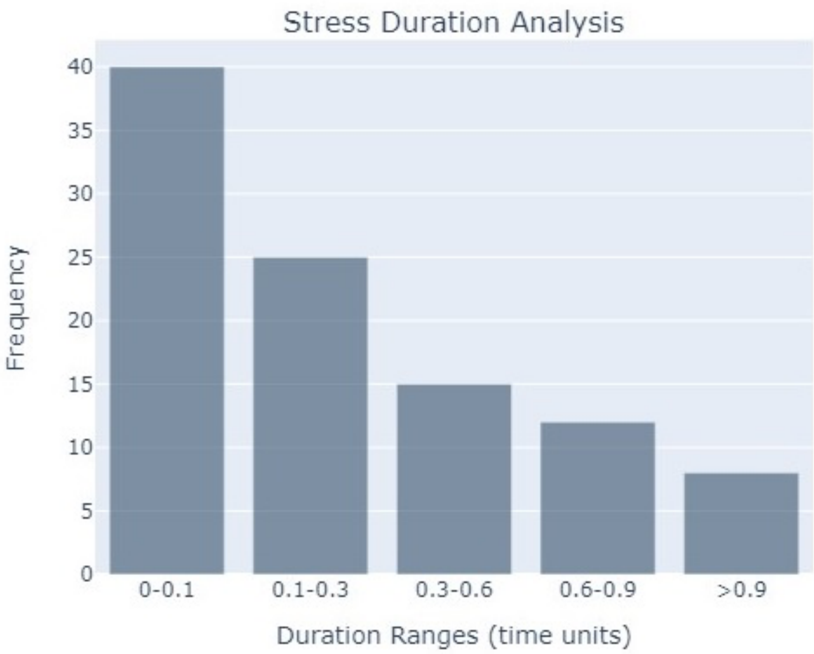

Figure 4-6: Stress Duration Analysis

4-4-4-1- Average State Changes in the Design Thinking Process

On average, designers shifted between different stress states (low, medium, and high) 40 to 60 times during the design process. This indicates that designers are continuously experiencing emotional-cognitive fluctuations and changes in their stress levels in response to challenges, complexities, and various stages of the design thinking process. The high number of state changes in stress may reflect the varied reactions of designers to different stages of the design process and the numerous cognitive activities involved in design.

4-4-4-2- Short-Term Stress Periods in the Design Thinking Process

A significant portion of the designers' stress periods, with a frequency of 40%, are short-term and last less than 0.1 time units. This indicates that designers predominantly experience high levels of stress temporarily during the design thinking process, and then return to lower stress levels or a normal state. The presence of short-term stress periods reflects a natural and adaptive response to the stressors inherent in the design thinking process, where designers react to challenges, different stages, and inherent complexities, but quickly return to a balanced state. This transient pattern helps designers continue their work without experiencing continuous stress and allows them to maintain focus.

4-4-4-3- Long-Term Stress Periods in the Design Thinking Process

Only 8% of the designers' stress periods are long-term (lasting more than 0.9 time units), indicating that very few designers experience prolonged and sustained stress. Long-term stress periods, especially in different stages of the design thinking process, reflect fundamental challenges, inherent complexities, and the poorly structured nature of design issues that designers are unable to overcome in the short term. These prolonged stress periods can impact the mental health and performance of designers, as well as the outcomes and quality of the design. They may require stress management techniques or changes in the stages of the design thinking process to prevent burnout or a decrease in performance.

4-4-4-4- Analysis of the Relationship Between Stress and Rest in the Design Thinking Process

The findings in this section of the research highlight the relationship between stress levels and the duration of rest periods for designers during the design thinking process. This analysis was carried out by converting the EEG time data and identifying shifts between stress and rest states, or vice versa. Techniques such as signal filtering and frequency analysis were applied to detect these changes.

4-4-5- Analysis of the Relationship Between Stress and Rest in the Design Thinking Process

The findings in this section of the research highlight the relationship between stress levels and the duration of rest periods for designers during the design thinking process. This analysis was carried out by converting the EEG time data and identifying shifts between stress and rest states, or vice versa. Techniques such as signal filtering and frequency analysis were applied to detect these changes.

4-4-5-1- Analysis of the Relationship Between Stress and Rest in the Design Thinking Process

The findings indicate an inverse relationship between the percentage of stress in the design thinking process and the duration of rest periods, such that as stress levels increase, rest time decreases, and vice versa. This pattern shows that designers with lower stress levels had more regular rest intervals during the design thinking process. In contrast, designers with higher stress levels had less time for rest and experienced more state changes during the process. Therefore, regular and adequate rest during the design process plays an important role in reducing stress and enhancing designer performance. This inverse relationship between stress and rest in the design thinking process highlights the need for planning regular rest periods throughout the design to prevent mental strain and burnout, which can provide a basis for developing stress management strategies. The following graph illustrates the fluctuations in stress levels, showing the changes between stress and rest states.

4-4-6- Analysis of the Effects of Stress in the Design Thinking Process

To investigate the impact of stress levels on the design thinking process and designer performance, several analytical methods were employed. The data in this section were analyzed using frequency change indicators to determine whether high stress levels lead to more frequent changes in emotional states. Additionally, to assess the performance of designers at different stress levels, EEG data combined with the frequency characteristics of brainwave bands were analyzed. This comparison was performed using statistical analyses and performance metrics to identify the direct impact of varying stress levels on designer performance throughout the design thinking process.

The momentary fluctuations of stress in the design thinking process indicate that high stress levels are associated with greater state changes and mental instability, while designers with moderate stress levels exhibited more stable performance. This highlights the importance of maintaining a balanced stress level throughout the design thinking process, as excessively high stress can reduce focus and the quality of design output.

In contrast, moderate stress levels lead to optimal performance in designers. These analyses demonstrate that stress levels are significantly related to the complexity of design stages and activities, the time spent in the design thinking process, and the cognitive demands of each stage. To achieve optimal performance in the design thinking process, designers need a level of stress that keeps them focused and motivated, but this stress should not exceed a moderate level, as high stress can lead to instability and frequent changes in mental and emotional states.

4-4-7- The Relationship Between Stress and Performance at Different Stages of the Design Thinking Process

This finding examines the relationship between stress and designer performance at different stages of the design thinking process (such as problem analysis, ideation, evaluation and selection of ideas, and implementation). The relationship suggests that at certain stages (problem analysis and evaluation and selection of the final idea), a moderate level of stress may enhance designer performance, as it creates an optimal level of cognitive arousal. Conversely, at more challenging stages (ideation), high stress might reduce performance and creativity, as designers require higher levels of creativity, calmness, and focus during these stages. In other words, this finding indicates that each stage of the design process requires a moderate level of stress for optimal performance, and either excessive or insufficient stress can negatively impact the quality of the design output.

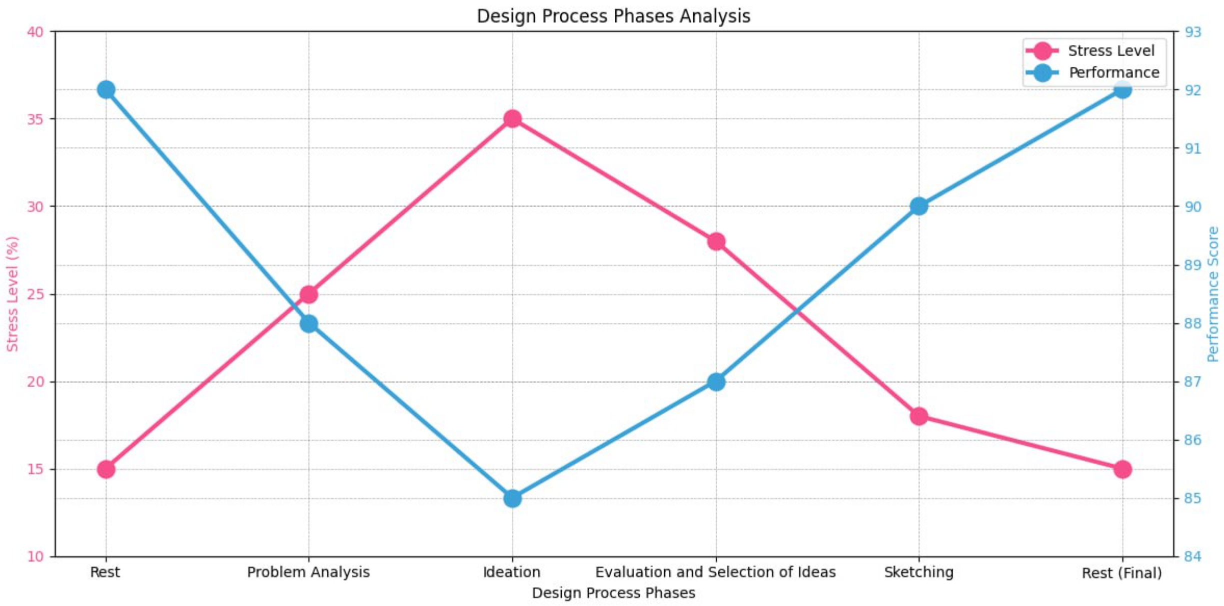

Figure 4-7: The relationship between stress and performance at different stages of the design thinking process.

Different stages of the design thinking process, stress levels, and designer performance. Here, the differences in stress levels and performance across each stage of the design thinking process are identified, and the relationship between them is analyzed in detail for each stage. The following performance matrix illustrates the relationships and performance patterns under various stress conditions. Each cell in the matrix represents a combination of states and different stress levels, with colors indicating the intensity of performance. This matrix was calculated using correlation analysis between performance data and stress states at different stages of the design process. Statistical methods were employed to extract functional relationships and display the associated patterns between stress states and performance (Figure 4-7).

4-4-7-1- Resting State

In the resting state, designers experience a low stress level (15%), and their performance reaches its highest level (92%). These results indicate that rest is effective for recovering both mental and physical energy, helping designers perform at their peak. The low stress level during this phase of the design thinking process indicates the creation of ideal conditions for returning to balance and enhancing performance in subsequent stages.

4-4-7-2- Problem Analysis

In the problem analysis stage, the stress level increases to 25% and is accompanied by a relative decrease in performance (88%). The rise in stress during this stage may be due to the high focus and precision required for understanding and analyzing the problem, while the relative decrease in performance could result from additional cognitive load and mental effort. This level of stress in the design thinking process can be beneficial, as it has helped designers focus more on understanding the problem, its challenges, and potential solutions.

4-4-7-3- Idea Generation

In the idea generation stage, designers experience the highest stress level (35%), and their performance reaches its lowest point at 85%. This high stress level in the design thinking process may stem from the pressure to be creative, innovative, and the challenge of generating new ideas. Idea generation requires creative and innovative thinking, which is often accompanied by uncertainty, stress, and anxiety. The high stress has led to a decrease in performance, as designers struggled to produce creative ideas with focus due to the elevated stress levels.

4-4-7-4- Evaluation and Selection of Final Idea

In this stage, the stress level of designers decreases to 28%, and their performance improves to 87%, compared to the idea generation phase. The relative decrease in stress during this stage has allowed designers to evaluate the existing ideas with more focus and precision, selecting the best option. The improvement in performance indicates that designers have shifted from creativity to logical decision-making, which requires concentration and accurate evaluation.

4-4-7-5- Implementation of Final Idea and Sketching

In this stage, stress levels stabilize, with designers experiencing a balanced stress level of 18% in the design thinking process. Their performance also reaches a high level (good performance at 90%). This balanced stress may be due to the practical nature of the task, where implementing the final idea and sketching by hand reduces stress. The balanced stress in this stage of the design thinking process leads to high performance in executing ideas and final details.

4-4-8- Comparative Analysis of Mental States Distribution Based on Time and Handedness Variables

In this section of the research, the data are categorized based on the variables of time and handedness, dividing them into two groups. The first group is classified according to the time variable, consisting of designers who engaged in the design thinking process with and without time constraints. The second group is classified according to the handedness variable, consisting of left-handed and right-handed designers who participated in the design thinking process without time constraints. The results indicate the distribution of mental states (stress, rest, and normal) over time in each group. The amounts of time assigned to each mental state in each group were calculated as percentages to identify the effects of the time and handedness variables and examine the differences in mental states among the groups. The results of each section are described separately as follows.

4-4-8-1- Comparative Analysis of Stress Distribution

The results of this analysis show the distribution of stress levels in the design thinking process based on the variables of time constraints and handedness (left-handed and right-handed designers without time constraints, and right-handed designers with time constraints). The percentages for each group are as follows:

- **Left-handed designers (without time constraints)**: The stress level in this group is 18.86%.
- **Right-handed designers (without time constraints)**: The stress level in this group is 22.90%. This group experienced higher stress compared to the left-handed designers without time constraints.
- **Right-handed designers (with time constraints)**: The stress level in this group is 17.91%. This value is lower than the other groups, indicating that time constraints, rather than increasing stress in the design thinking process, actually reduce stress.

Figure 4-8: Chart of the relationship between stress and rest

4-4-8-2- Comparative Analysis of Mental Rest

These results show the temporal distribution of mental rest during the design thinking process based on the variables of time and handedness. The percentages for each group are as follows:

- **Left-handed designers (without time constraints):** The percentage of rest in this group (40.34%) is the lowest among the three groups. This could indicate the effect of the dominant hand type (left-handedness) on the distribution of mental rest time.
- **Right-handed designers (without time constraints):** This group, with 43.11% of rest time, experienced a higher percentage of mental rest compared to the left-handed designers. This could suggest that right-handed designers, under natural conditions (without time constraints), have more opportunity for mental restoration and rest compared to left-handed designers.
- **Right-handed designers (with time constraints):** The percentage of mental rest in this group (49.17%) is the highest among the three groups. This shows that the presence of time constraints in the design thinking process surprisingly increased the amount of mental rest time. This point could be important in showing that moderate time pressure helps designers maintain efficiency, improve performance, focus, and avoid mental fatigue by requiring shorter, more frequent rest periods and mental rejuvenation, which is why they experience more rest time. The chart below shows the scatter of the relationship between the percentage of time designers spent in stress and rest during the design thinking process across different groups (Figure 4-8).

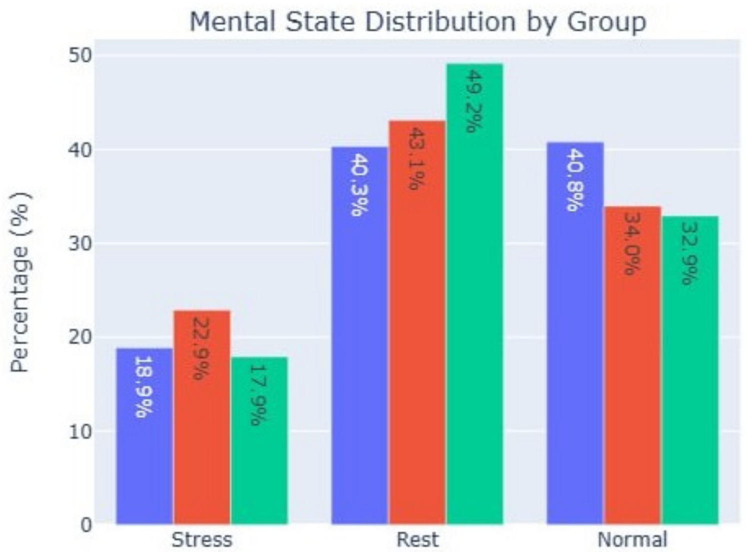

Figure 4-9: Distribution of Mental States Chart

4-4-8-3- Comparative Analysis of Normal State

This section presents the results related to the temporal distribution of the normal mental state during the design thinking process, based on the variables of time and handedness, as follows:

- **Left-handed designers (without time constraints):** The percentage of normal state time in the design thinking process for left-handed designers (40.80%) is the highest among the three groups. This indicates that left-handed designers experienced more time in a normal state without stress during the design thinking process.

- **Right-handed designers (without time constraints):** In the right-handed group without time constraints, the normal mental state percentage decreased to 33.98%. This suggests that right-handed designers, under normal conditions (without time constraints), spent less time in a normal state compared to left-handed designers.
- **Right-handed designers (with time constraints):** The normal state percentage in this group (32.93%) is even lower than the group without time constraints. In other words, the addition of time constraints to the design thinking process led to a further reduction in the time spent in a normal state for right-handed designers.

The bar chart above illustrates the percentage distribution of mental states (stress, rest, and normal state) during the design thinking process, based on the variables of time and handedness among the groups of left-handed designers, right-handed designers without time constraints, and right-handed designers with time constraints. Each color represents a group, differentiated by the variables of time and handedness. This chart shows the extent to which designers in each group experienced each of these mental states during the design thinking process (Figure 4-9).

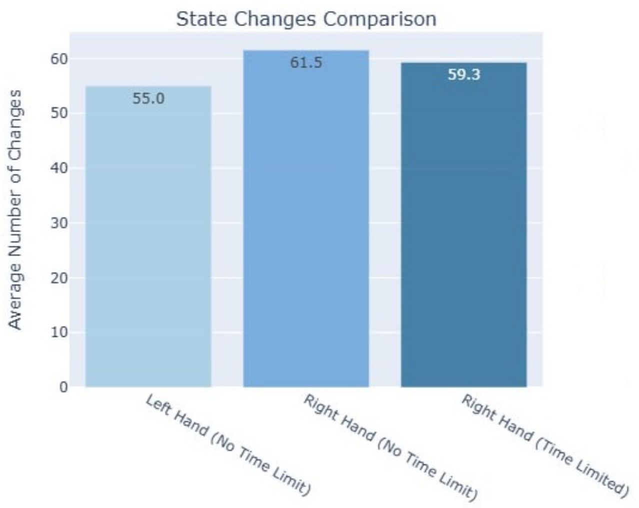

Figure 4-10: Comparison of State Changes Chart

4-4-9- Comparative Analysis of Mental State Changes Based on Time and Handedness Variable

These results represent the extent of mental state changes in the design thinking process based on the time and handedness variables for each of the three groups. The "state changes" number refers to the number of times designers shifted from one mental state (such as stress, rest, or normal state) to another during the design thinking process.

- **Left-handed Designers (Without Time Constraints):** The number of state changes for left-handed designers in the design thinking process is 55 changes, which is the lowest number of changes among the three groups. This indicates that left-handed designers had greater mental stability throughout the design thinking process and experienced fewer mental state changes.
- **Right-handed Designers (Without Time Constraints):** The number of state changes in this group is 61.55, indicating more changes than in the left-handed group. This suggests that right-handed designers without time constraints experienced more diverse mental states during the design thinking process and had less mental stability.
- **Right-handed Designers (With Time Constraints):** The number of state changes in this group is 59.30, which falls between the two other groups. However, the time constraint seems to have caused a relative reduction in state changes and created some mental stability, although this group still experienced more changes than the left-handed designers (Figure 4-10).

4-4-10- Comparative Analysis of the Impact of Stress on Designers and Their Performance Based on Time Variable

The results of the impact of the time variable can be analyzed more comprehensively, as they indicate the direct and indirect effects of time constraints on the mental states of designers in the design thinking process, as follows:

- **Reduction in Stress:** A 5% reduction in stress during the design thinking process with time constraints.
- **Increased Rest:** A 6% increase in mental rest time during the design thinking process.
- **Reduction in State Changes (Improved Mental Stability):** A reduction in the number of state changes during the design thinking process, indicating greater mental stability in the group of designers with time constraints.

4-4-11- Comparative Analysis of the Impact of Stress on Designers and Their Performance Based on Handedness Variable

These results indicate significant differences between designers based on the handedness variable in their mental experiences during the design thinking process, as detailed below:

- **Left-handed Designers**: This finding suggests that left-handed designers experience less stress during the design thinking process. Additionally, the higher percentage of the normal state during the design thinking process in left-handed designers indicates greater mental stability and balance throughout the process.
- **Right-handed Designers**: Right-handed designers experience more frequent changes between stress, normal, and rest states during the design thinking process. This indicates that the minds of

right-handed designers frequently shift from one state to another during the process. Moreover, the increased need for rest in right-handed designers suggests that they require more frequent short breaks and rest periods to mentally recharge. This need is likely due to mental pressures and more frequent state transitions during the design thinking process.

4-5- Analysis of Phase 4 Data in the MetaCogno Research

In this section, a comprehensive and scientific analysis of the emotional-cognitive experiences of designers in the four main stages of the design thinking process is presented. The data, collected with the aim of gaining insights into the emotional and cognitive experiences of designers throughout the design thinking process and its various stages, are compared and aligned with the results obtained from EEG recordings and questionnaires used to assess perceived stress in the design thinking process. This includes an examination of the overall frequency, percentage relative to the total experiences, and percentage relative to the number of designers for each type of emotional experience. The cognitive-emotional experiences of designers throughout the design thinking process are categorized into three groups: positive, negative, and neutral. These experiences include:

- **Positive Experiences**: Such as having good thoughts, enjoyment, enough time, many ideas, excitement, feeling good, and better thoughts, which represent enjoyable design experiences for designers.
- **Negative Experiences**: Including feelings of confusion regarding the problem, lack of concentration, time pressure, frustration, fatigue, lack of ideas, getting stuck, difficulty in ideation, and final idea selection, which reflect the challenges and difficulties designers face during the design thinking process.
- **Neutral Experiences**: Such as a lack of a specific emotional perception, ease of the problem, and doubt, which suggest a different mental experience, potentially indicating a lack of immediate awareness by designers regarding their internal experiences at certain moments.

4-5-1- Analysis of the Emotional-Cognitive Experiences of All Designers in the Design Thinking Process

In this section, a comprehensive and scientific analysis of the cognitive-emotional experiences of designers in the design thinking process is presented. This analysis is based on data collected from one hundred designers and includes an examination of the total frequency, percentage of total experiences, and percentage relative to the number of designers for each type of emotional experience. The table below represents the total cognitive-emotional experiences of designers throughout the entire design thinking process. The various experiences are broken down by frequency and percentages as follows. The results show that the experience of enjoyment, with 12.19% of all perceived experiences, stands as the most dominant emotional experience in the design thinking process. This high percentage indicates the significance of positive design experiences for the designers. Additionally, feelings of having enough time (9.22%) and excitement (8.42%) are other positive experiences that point to success and satisfaction in the design thinking process. In contrast, negative experiences such as having insufficient ideas and lack of time rank fourth and fifth, respectively, highlighting the challenges and psychological pressures encountered by designers during the design thinking process. This is particularly evident during the ideation phase, where these negative experiences may stem from challenges related to creativity and idea generation. Furthermore, the selection of "no specific feeling" at 11.39% could suggest a lack of awareness among designers regarding their emotional experiences (Table 4-1).

Table 4-1: Cognitive-Emotional Experiences of All Designers in the Design Thinking Process

The overall emotional-cognitive experiences of designers in the design thinking process				
	All designers			
Type of Experience	**Total Frequency**	**Rank**	**Percentage of Total Experiences**	**Percentage of Designers**
Enjoyment	152	1	12.19%	800.00%
Lack of specific emotion perception	142	2	11.39%	747.37%
Enough time	115	3	9.22%	605.26%
Excitement	105	4	8.42%	552.63%
Lack of sufficient ideas	105	4	8.42%	552.63%
Lack of time	89	5	7.14%	468.42%
Having good thoughts	62	6	4.97%	326.32%
Too many ideas	57	7	4.57%	300.00%
Lack of focus	49	8	3.93%	257.89%
Doubt	49	8	3.93%	257.89%
Getting stuck	46	9	3.69%	242.11%
Difficulty in selecting the final idea	46	9	3.69%	242.11%
Feeling good	44	10	3.53%	231.58%
Better thoughts	43	11	3.45%	226.32%
Confusing problem	35	12	2.81%	184.21%
Frustration	34	13	2.73%	178.95%
Fatigue	29	14	2.33%	152.63%
Easy problem	24	15	1.92%	126.32%
Difficulty in idea generation	21	16	1.68%	110.53%
Total	**18**	**1247**	**100.00**	**100.00**

Overall, based on Table 4, positive experiences with a frequency of 578 and a percentage of 46.35% of the total experiences perceived by the designers indicate that designers mostly had positive experiences in the design thinking process. This could be considered a significant factor in improving their quality and performance. In contrast, negative experiences with a frequency of 454 and a percentage of 36.40% of the total experiences were perceived considerably less than positive experiences. These results clearly highlight the stress, pressures, and psychological challenges designers face throughout the different stages of the design thinking process. Experiences such as lack of ideas, time constraints, and lack of focus can have negative impacts on the design thinking process. On the other hand, neutral experiences with a frequency of 215 and a percentage of 17.24% of the total experiences suggest that designers may not have sufficient awareness of their experiences or that in some parts of the design thinking process, they did not have strong experiences to adequately perceive them (Table 4-2).

Table 4-2: Types of Emotional-Cognitive Experiences of All Designers in the Design Thinking Process

Types of emotional-cognitive experiences in the design thinking process				
All designers				
Type of Experience	**Names of Experiences**	**Total Frequency**	**Percentage of Designers**	**Percentage of Total Experiences**
Positive	Having good thoughts, Enjoyment, enough time, Too many ideas, Feeling good, Better thoughts, Excitement	578	578,00	46,35
Negative	Confusing problem, Lack of focus, Lack of time, Frustration, Fatigue, Lack of sufficient ideas, Difficulty in idea generation, Getting stuck	454	454,00	36,40
Neutral	Lack of specific emotional perception, Easy problem, Doubt	215	215,00	17,24

4-5-2- Comparative Analysis of Emotional-Cognitive Experiences of All Designers in the Four Stages of the Design Thinking Process

This section examines the frequency of emotional and cognitive experiences of designers in the four main stages of the design thinking process (problem analysis, ideation, evaluation and selection of ideas, and implementation of the final idea and sketching) in detail. The analysis reveals that designers in each stage of the design thinking process have encountered a combination of positive and negative experiences, along with cognitive challenges (Table 4-3).

Table 4-3: Emotional and Cognitive Experiences of All Designers Across the Four Stages of the Design Thinking Process, Broken Down by Stages

Emotional and Cognitive Experiences in the Four Stages of the Design Thinking Process Breakdown							
All Designers							
Problem Analysis		**Idea Generation**		**Idea Evaluation and Selection**		**Sketching**	
Type of Experience	Frequency	Type of Experience	Frequency	Type of Experience	Frequency	Type of Experience	Frequency
Having good thoughts	57	Enjoyment	45	Having doubts	57	Having doubts	66
Confusing the problem	41	Enough time	40	Enough time	38	Enough time	48
Enjoyment	41	Many ideas	32	Enjoyment	42	Enjoyment	46
Enough time	38	Not having enough ideas	33	Difficulty in selecting the final idea	38	Difficulty in selecting the final idea	34
Lack of specific feeling	27	Difficulty in ideation	30	Many ideas	22	Many ideas	32
Lack of time	19	Excitement	30	Excitement	23	Excitement	25

Emotional and Cognitive Experiences in the Four Stages of the Design Thinking Process Breakdown							
All Designers							
Problem Analysis		Idea Generation		Idea Evaluation and Selection		Sketching	
Type of Experience	Frequency	Type of Experience	Frequency	Type of Experience	Frequency	Type of Experience	Frequency
Lack of concentration	21	Lack of time	19	Not having enough ideas	21	Not having enough ideas	18
Ease of the problem	18	Lack of specific feeling	21	Lack of specific feeling	19	Lack of specific feeling	10
Excitement	52	Getting stuck	18	Lack of concentration	11	Lack of concentration	8
Getting stuck	16	Lack of concentration	12	Lack of time	11	Lack of time	6
Frustration	7	Frustration	6	Fatigue	9	Fatigue	6
Fatigue	5	Fatigue	0	Frustration	4		
12	342	12	286	12	295	11	299

4-5-2-1- Stage 1: Problem Analysis

In this stage, designers encountered a range of experiences, from positive emotions to cognitive challenges. The most frequently reported experience was having good ideas, which, with the highest frequency, indicates a positive experience in the problem analysis process. Additionally, experiences such as enjoyment, having enough time, and feeling confused by the problem, with similar frequencies in second place, reflect a mix of positive emotions and challenging feelings.

4-5-2-2- Stage 2: Ideation

The most common experience in this stage was enjoyment, ranked first, followed by the feeling of having enough time, indicating that most designers enjoyed the ideation process and had sufficient time to generate ideas. However, the lack of sufficient ideas and the difficulty of ideation highlight the challenges some designers faced in producing innovative ideas at this stage. On the other hand, an equal number of designers reported having too many ideas, which suggests a more complex dimension of this stage—while it was challenging for some, it was enjoyable and full of ideas for others.

4-5-2-3- Stage 3: Evaluation and Idea Selection

In this stage, the experience of doubt ranked first, followed by the difficulty of selecting the final idea in third place, indicating that designers faced doubt and mental challenges when choosing the final idea. This stage requires careful evaluation and decision-making among various ideas to select the best one. The feelings of having enough time and enjoyment were also common experiences in this stage. Therefore, this stage, being one of the most challenging design phases, requires firm decision-making, accompanied by doubt and more complex emotions.

The figure below shows the emotional-cognitive experiences of all designers in the four stages of the design thinking process, categorized into positive, negative, and neutral experiences. In the stage of implementation and sketching, positive experiences peaked at 66%, with designers experiencing the highest level of positive emotions due to the satisfaction of implementing their ideas and hands-on designing. Following this, designers reported the most positive experiences in the problem analysis, idea generation, and evaluation and selection of ideas stages. The most negative experiences were associated with the idea generation stage, which had a frequency of 41%, reflecting the complexity of the idea generation process, lack of ideas, and the challenges designers faced in generating innovative and creative ideas (Figure 4-11).

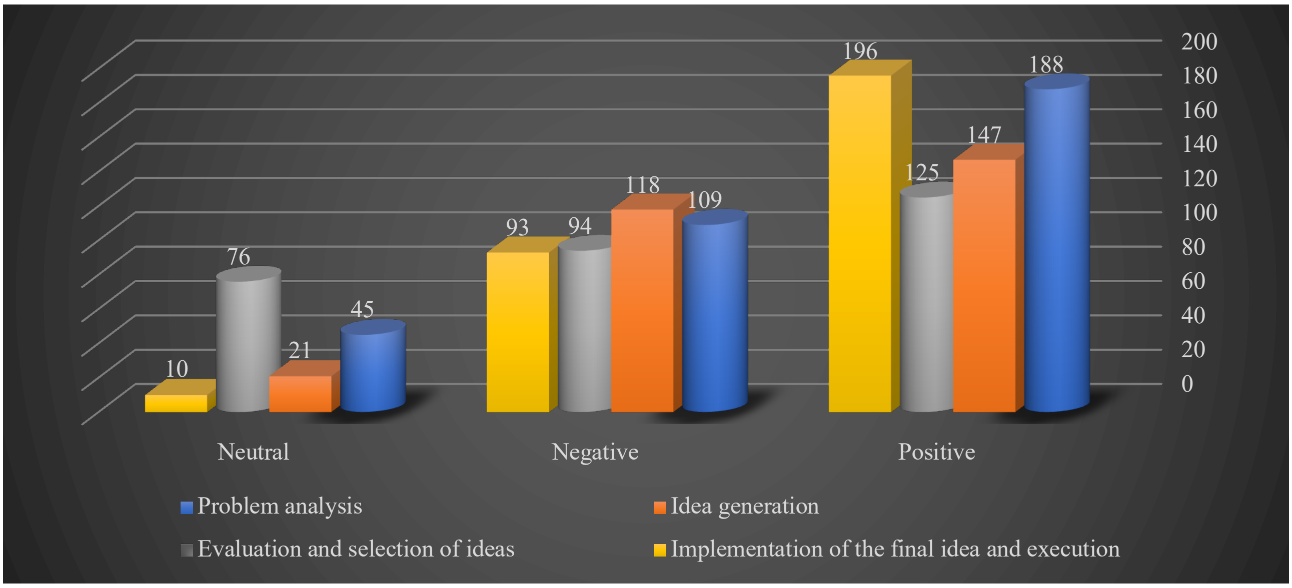

Figure 4-11: The type of emotional and cognitive experiences of all designers across all four stages of the design thinking process, broken down by stages.

The most frequent negative experiences, in order, occurred after the idea generation stage and were associated with the problem analysis stage, idea generation, evaluation and selection of ideas, and the final idea implementation and sketching stage. In the evaluation and selection of the final idea stage, the most commonly reported neutral emotion, with a frequency of 26%, was doubt, which is attributed to the difficulty of selecting the final idea. However, overall, neutral experiences were reported far less frequently compared to other emotions by the designers. In contrast, positive emotions were reported more frequently, particularly in the initial and final stages of the design thinking process, likely due to the initial excitement of solving the problem and the satisfaction of completing and implementing the idea to resolve the issue. Additionally, negative experiences were perceived fairly equally across all stages (Table 4-4).

Table 4-4: The type of emotional and cognitive experiences across the four stages of the design thinking process, broken down by stages

Types of emotional and cognitive experiences in the four stages of the design thinking process, broken down								
All designers								
	Problem analysis		Idea Generation		Idea Evaluation and Selection		Sketching	
Type of Experience	Frequency	Percentage of Total Experiences	Frequency	Percentage of Total Experiences	Frequency	Percentage of Total Experiences	Frequency	Percentage of Total Experiences
Positive	188	55%	147	51%	125	42%	196	66%
Negative	109	32%	118	41%	94	32%	93	31%
Neutral	45	13%	21	7%	76	26%	10	3%
Total	342		286		295		299	

4-5-3- Evaluation of Cognitive-Emotional Experiences of Designers Using the MetaCogno Tool Based on the Time Variable

The first analysis examines the impact of the time variable on the intensity, type, and distribution of designers' emotional and cognitive experiences during the design thinking process. In the **problem analysis** step, both groups primarily experienced positive emotions. Designers with time constraints reported more positive emotions and fewer negative emotions, while the group without time constraints experienced more time scarcity and fatigue. In the **ideation** step, enjoyment was identified as the dominant experience in both groups. However, negative experiences such as lack of ideas and difficulty in ideation also had the highest frequency, indicating that designers in both groups experienced both positive and negative cognitive-emotional experiences during the ideation process, with positive experiences slightly outweighing the negative ones. Still, the group with time constraints reported more experiences compared to the other group. In the **evaluation and selection of the final idea** step, doubt was the dominant experience in both groups, reflecting the mental challenge designers face when choosing the best idea. Positive experiences ranked second for both groups. The group with time constraints reported more positive and negative emotions than the group without time constraints. The **final idea implementation and sketching** step saw an increase in positive experiences, particularly emotions like excitement, which were dominant in both groups. Time scarcity was recognized as a significant negative experience in both groups. Notably, the group with time constraints reported more positive emotions, while the group without time constraints experienced more fatigue and frustration.

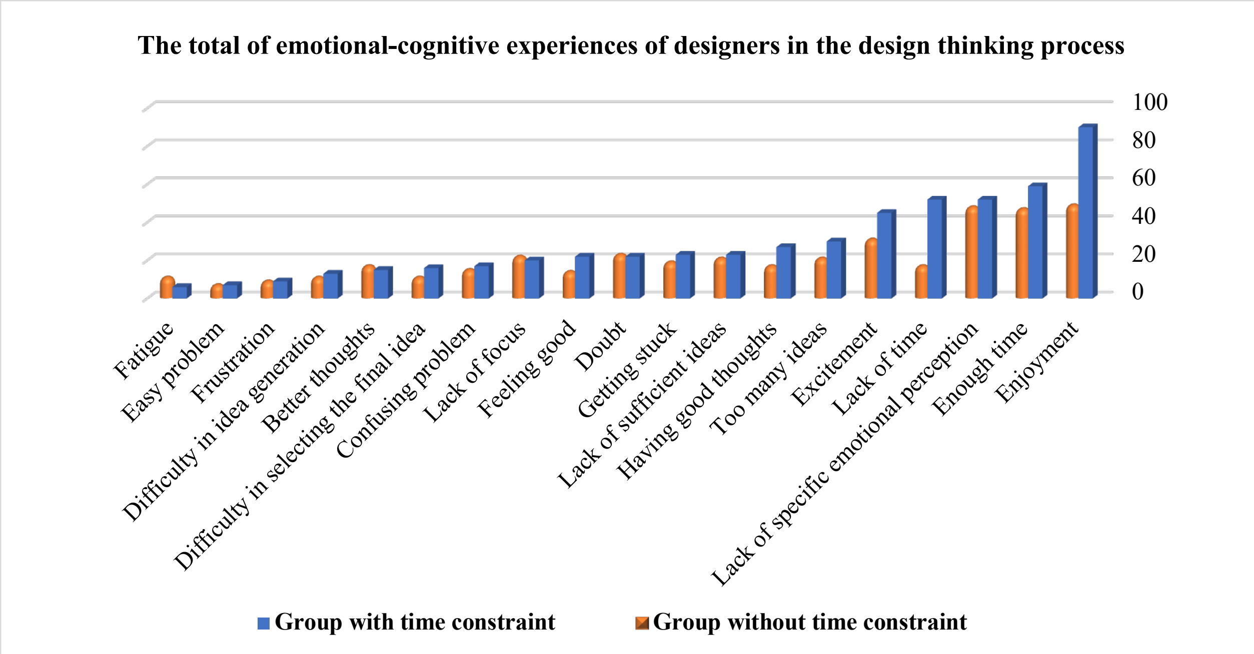

Figure 4-12: Emotional-Cognitive Experiences of Designers in the Design Thinking Process Based on the Time Variable.

The analysis of designers' cognitive-emotional experiences during the design thinking process suggests that the time variable plays a crucial role in shaping designers' experiences. Designers in time-constrained conditions perceived more cognitive-emotional experiences across all three types: positive, negative, and neutral. Moreover, time as a limiting factor created a moderate level of stress in the time-constrained designers, which improved their performance and ultimately resulted in greater satisfaction within this group. Specifically, the time-constrained group reported more experiences of **time scarcity, difficulty in final ideation,** and **getting stuck,** indicating stress due to time pressure. Additionally, the group without time constraints reported more **fatigue** than the time-constrained group, suggesting that the prolonged duration of the design thinking process reduces motivation and performance, increases fatigue, and leads to a more exhausting design thinking process (Figure 4-12).

4-5-4- Evaluation of Cognitive-Emotional Experiences of Designers Using the MetaCogno Tool Based on the Variable of Handedness

There are significant differences in the cognitive-emotional experiences of left-handed and right-handed designers throughout the design thinking process. These findings emphasize the importance of considering individual differences in the design thinking process and their potential impacts on performance and final outcomes. In various steps of the design process, left-handed designers generally reported more positive experiences compared to right-handed designers, while right-handed designers reported more negative and neutral emotions. In the **problem analysis step**, left-handed designers experienced more positive emotions such as excitement, while right-handed designers reported more neutral emotions. On the other hand, confusion about the problem was reported more frequently by left-handed designers. In the **idea generation step**, enjoyment was the dominant experience among left-handed designers, while right-handed designers reported fewer positive emotions and faced challenges such as a lack of ideas or an excess of ideas. In the **evaluation and idea selection step**, doubt was the dominant experience in both groups, reflecting the mental challenge of selecting the best idea. However, right-handed designers reported more negative emotions, while left-handed designers had more positive experiences. In the final **implementation of the final idea and sketching step**, both groups reported positive emotions such as enjoyment and having good thoughts. However, right-handed designers experienced more negative emotions such as getting stuck and a lack of time, while left-handed designers were more focused on positive experiences. Overall, left-handed designers experienced more positive emotions throughout the design process and demonstrated better ability to manage emotions and challenges during the design process. In contrast, right-handed designers reported more neutral and negative experiences. The highest number of positive emotions in both groups was reported in the **implementation of the final idea and sketching step**, while the **evaluation and idea selection step** was the most challenging for them. These results emphasize the importance of considering individual differences, such as handedness, in the design thinking process (Figure 4-13).

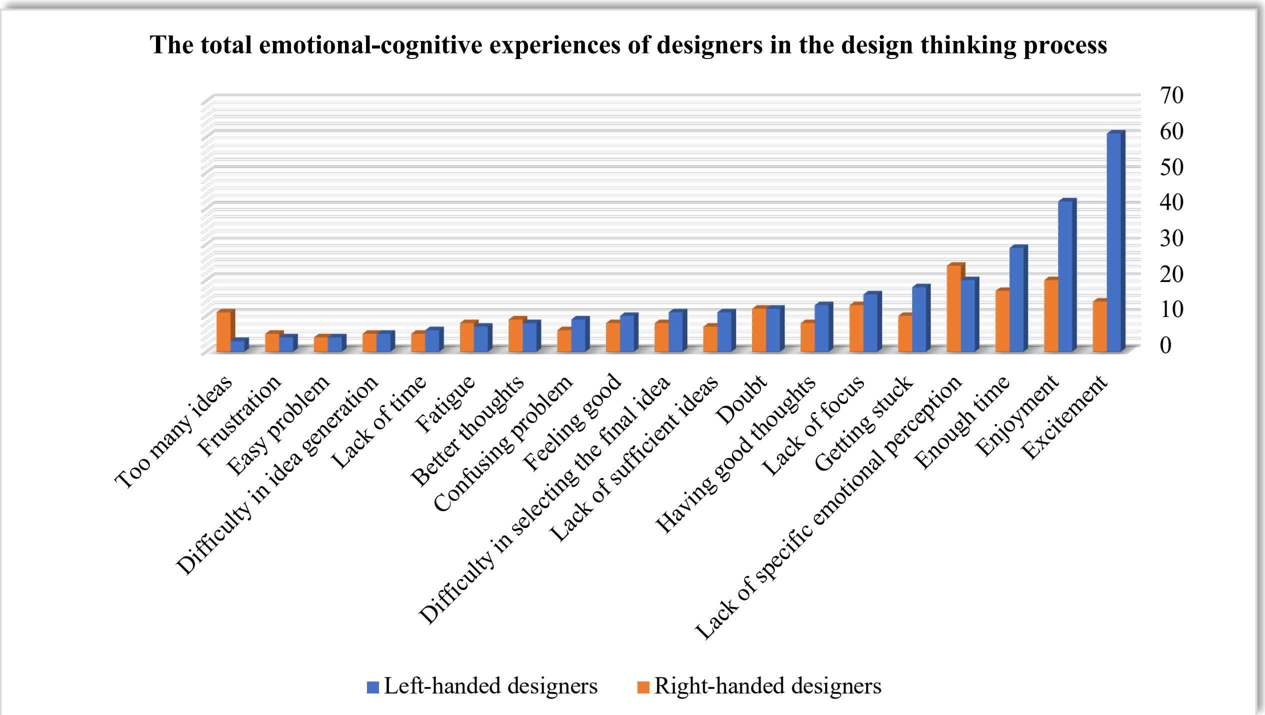

Figure 4-13: Emotional-Cognitive Experiences of Designers Based on Handedness in the Design Thinking Process

The following chart illustrates the frequency and percentage of emotional-cognitive experiences reported by designers across the four stages of the design thinking process, broken down by groups based on the variables of time constraints and handedness. Significant differences in frequency and percentage of experiences are observed, reflecting the impact of these variables on the design thinking process. The chart presents these results in terms of the percentage of emotional-cognitive experiences at each stage (Figure 4-14). In the problem analysis stage, left-handed designers reported the highest emotional-cognitive experiences, accounting for 37% of all experiences. The time-constrained group reported 25% of the total experiences, and the group without time constraints reported 26%, indicating high frequency in this stage, though the effect of time constraints is less noticeable here. In the idea generation stage, the time-constrained group and the group without time constraints reported emotional-cognitive experiences at similar frequencies, with 24% and 25% of all experiences, respectively. In contrast, left-handed designers reported the fewest experiences in this stage, accounting for only 20% of the total experiences.

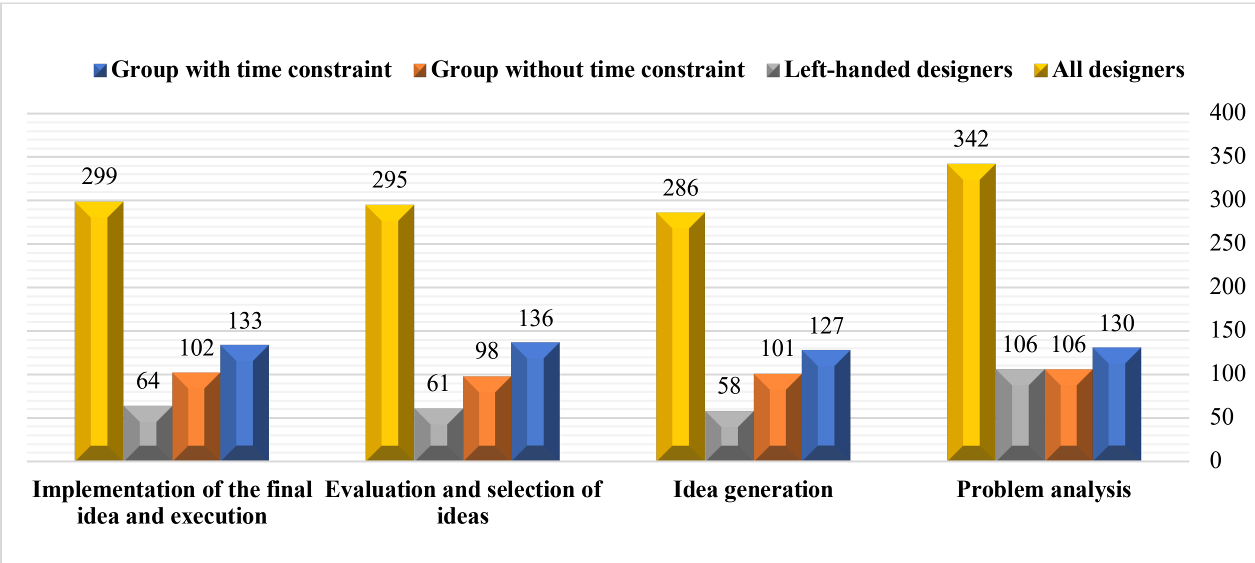

Figure 4-14: The type of emotional and cognitive experiences across the four stages of the design thinking process, broken down by stages

In the evaluation and selection of the final idea stage, left-handed designers reported a relatively moderate level of experience, accounting for 21% of the total experiences. The time-constrained group reported the highest frequency in this stage, with 26% of all experiences. The group without time constraints reported 24% of all experiences in this stage, which was similar to the time-constrained group. In the final stage, implementation of the final idea and sketching, left-handed designers reported the lowest frequency, with 22% of all experiences compared to the previous stages. Both the time-constrained group and the group without time constraints reported similar frequencies in this stage, with each accounting for 25% of all experiences. This suggests that the implementation stage, being more practical and hands-on, generated more positive experiences for all groups. These results indicate that left-handed designers generally perceived more experiences in the problem analysis stage, while their experiences in the other stages were consistent. In contrast, the time-constrained group and the group without time constraints reported similar emotional-cognitive experiences across all stages of the design thinking process, with the time-constrained group reporting only a very slight increase in experiences during the evaluation and selection of ideas stage. Finally, all designers reported the most emotional-cognitive experiences in the first stage of the design thinking process, with similar experiences in the subsequent stages.

4-6- Data Analysis of Phase Four: Stress Level Assessment Using Questionnaires

This section is dedicated to analyzing the data obtained from the questionnaires used in the present study. Each questionnaire was designed to assess a specific aspect and one of the existential dimensions of designers. The data from the four groups (designers without time constraints, designers with time constraints, and left-handed designers) were analyzed separately for each questionnaire and statistically examined to determine the significance of the relationships. These analyses were conducted to identify differences between groups and to gain a deeper understanding of the impact of various factors on designers' stress levels. The results from the **Perceived Stress Scale (PSS)** and the **Physiological Arousal Questionnaire (PAQ)** showed no statistically significant differences among the four designer groups; therefore, their results are presented collectively. However, in the **Coping Strategies Inventory (CSI)** questionnaire, significant differences were observed among the four groups, necessitating the separate presentation of results.

Table 4-5: Classification of Results from the Perceived Stress Scale (PSS) Questionnaire

Variable	Category	Count	Percentage
Perceived stress level	Low stress	20	20%
	Moderate stress	49	49%
	High stress	28	28%
	Severe stress	3	%3
Total	All designers	100	%100

4-6-1- Comparative Analysis of Perceived Stress Scale (PSS) Questionnaire Results

The classification results of the Perceived Stress Scale (PSS) questionnaire show that 20% of designers are in the "low stress" group, meaning they experienced less stress during the design thinking process. The largest percentage of participants (49%) are in the "moderate stress" group, indicating a level of stress that could be influenced by the pressures and stressors of the design thinking process. 28% of designers are in the "high stress" group, indicating relatively higher stress, and this group may have been more influenced by stressors from the design thinking process. Finally, 3% of designers fall into the "very high stress" group, indicating very high levels of stress during the design thinking process.

To examine the relationship between the results from the EEG tool and the PSS questionnaire, Pearson's correlation test was used. The Pearson correlation coefficient of r = 0.92 indicates a strong positive linear relationship between the EEG results and the PSS. The p-value for this test was 0.027, which is lower than the commonly accepted significance level. Therefore, it can be concluded that the observed correlation between the two measures is statistically significant. This result suggests that as EEG values increase, PSS values also increase linearly (Table 4-5).

Table 4-6: Classification of Results from the Physiological Arousal Questionnaire (PAQ)

Variable	Category	Count	Percentage
Level of physiological arousal	Low arousal	75	75%
	Moderate arousal	18	18%
	High arousal	6	6%
	Very high arousal	1	1%
Total	All designers	100	%100

4-6-2- Comparative Analysis of the Physiological Arousal Questionnaire (PAQ) Results

The results from the Physiological Arousal Questionnaire (PAQ) indicate that most of the designers participating in this study report low levels of arousal, with 75% of them falling into the "low arousal" category. This suggests that many designers exhibited mild physiological reactions to the stress they perceived and may have managed their emotions effectively. Additionally, 18% of the designers fall into the "moderate arousal" category, indicating they showed balanced physiological responses. In contrast, 6% of designers are in the "high arousal" category, likely experiencing more intense physiological reactions under stressful conditions, which could have affected their performance during the design thinking process. Only 1% of participants fall into the "very high arousal" category, indicating a very high level of physiological arousal during the design thinking process. To examine the relationship between the results from the EEG data analysis and the PAQ questionnaire, both Pearson and Spearman correlation tests were conducted. The results indicate that the linear relationship between EEG and PAQ is not statistically significant (Table 4-6).

4-6-3- Comparative Analysis of the Coping with Stressful Situations Questionnaire (CSI) Results

To analyze the results of the coping styles with stress questionnaire for designers working with and without time constraints, as well as left-handed designers, the scores for each group were examined and their meanings evaluated. The Kolmogorov-Smirnov test was initially applied to compare coping styles in the three groups, and since the data distribution was not significant, it indicated normal distribution. Therefore, a one-way ANOVA test was used.

The comparison of results among the three groups of designers (without time constraints, with time constraints, and left-handed) across four coping strategies reveals interesting patterns in how stress and challenges are managed during the design process. In the problem-focused coping strategy, the group of designers with time constraints had the highest average score (65.96). In the emotion-focused coping strategy, left-handed designers had the highest average (63.98), followed by designers with time constraints (62.51), and designers without time constraints (56.26). These differences suggest that designers with time constraints and left-handed designers may have a greater tendency to manage their emotions. In the problem-avoidance coping strategy, the averages for all three groups were similar, indicating that this coping style was generally less used by designers, who tend to avoid avoidance when facing problems. In the emotion-avoidance coping strategy, left-handed designers had the highest average score (61.30), while designers with time constraints (60.45) and designers without time constraints (58.15) ranked next. These differences may stem from left-handed designers' preference for avoiding direct confrontation with negative emotions, which could act as a mechanism for reducing psychological tension. Overall, the results suggest that time pressure and individual characteristics, such as handedness, can slightly influence the use of coping styles. Designers with time constraints make significantly more use of both problem-focused and emotion-focused coping strategies. Left-handed designers, especially in emotion-focused strategies (both active and avoidance), perform distinctly, likely reflecting psychological differences in stress management.

Chapter 5
Discussion and Conclusion

5-1- Introduction

The present study aims to define the novel research domain of design stress, establish a conceptual framework for the ontology of design stress, identify, analyze, and measure stress arising from the design thinking process, and explore its multifaceted impact on designers. The chapters of this research have been purposefully and systematically structured to create a coherent and precise connection between different phases of the study. Chapter 1, titled **"Research Overview,"** outlines the fundamental aspects of the study and its theoretical framework. By presenting an overarching perspective on the anticipated outcomes, this chapter lays the foundation for a novel research area with a comprehensive theoretical and content-based framework for further exploration.
Building upon this foundation, Chapter 2 provides a **systematic literature review** conducted using the PRISMA protocol. The study integrates bibliometric analysis with the **VOSviewer** tool for quantitative analysis of research keywords, **Grounded Theory** for qualitative and thematic analysis, and **qualitative content analysis** to evaluate existing theories within this domain.
Chapter 3 focuses on examining and categorizing various **methods for measuring design stress** and presents an innovative approach to stress assessment. Through four research phases, design stress was measured throughout the design thinking process to ensure a precise and comprehensive analysis In Chapter 4, the findings from the previous chapter were thoroughly analyzed and presented using analytical tools and statistical methods. Finally, Chapter 5 provides a **comprehensive discussion and conclusion** based on the research findings, offering insights into the implications of design stress and future research directions.

5-2- Overview and Methodology

Chapter Five is dedicated to the synthesis and conclusion of the research. Following the introduction and chapter outline, the primary objectives of the study will be presented in Section 3, followed by the secondary objectives in Section 4. A comparison of the research findings with previous studies will be conducted in Section 5. Section 6 will highlight the innovations of the present study in relation to existing research in the field of design stress. The practical applications of design stress studies across various domains will be illustrated in a diagram in Section 7. Additionally, Section 8 will address the limitations of this research and the challenges encountered. Finally, recommendations for future research and strategies based on the study's findings will be proposed to support designers in improving their design experience and performance (Figure 5-1).

Figure 5-1: Overview of the Research Process in Chapter Five – Conclusion

5-3- Achievement of the Research's Main Objectives

5-3-1- Definition of Design Stress

Based on the studies conducted, the findings of this research, and the theoretical and conceptual framework presented in Chapter 2, a novel research domain called "design stress" can be proposed. This term, clarified and defined through existing literature, serves as a comprehensive concept for this study. Specifically, in this research, "design stress" has been used to encompass various aspects of stress within the field of design studies. Design stress is a multifaceted concept with broad dimensions, revealing a complex and bidirectional relationship between stress and design. It emerges from various stages and elements of the design process, including thinking, problems, concepts, procedures, and methodologies within different areas of design. It encapsulates a range of mental, physical, behavioral, cognitive, and emotional pressures that designers face throughout their careers. These stressors can stem from various sources, such as the complexity of design problems, idea generation, and the constant need for creativity and innovation, which may have long-term negative effects on designers' mental and physical health, such as reduced concentration and increased anxiety. Moreover, design stress can have both positive and negative impacts on designers' professional performance and design outcomes. Therefore, design stress is a significant research area that encompasses a wide range of dimensions and factors. Each of these factors can directly or indirectly affect the designer, the design process, the product, and even the user experience. This area calls for more comprehensive studies to fully understand its diverse impacts on the professional and personal aspects of designers' lives.

5-3-2- Ontology of Design Stress

In this section, based on the article "Ontology of Human Stress," an ontology for design stress has been developed across five main classifications from the ontology of human stress (stressors, stress mediators, stress impacts, stress measurement, and coping strategies). The presentation and development of the design stress ontology is crucial for the comprehensive and structured analysis of stress in the design field, as it helps to precisely identify and categorize the various dimensions of stress involved in the design profession and its processes. This identification and classification enable a more scientific analysis of which factors exert the highest levels of stress on designers and what impacts these stressors have on designers and their performance. Based on this, effective solutions can be proposed to mitigate these factors and manage design stress. By utilizing this framework, researchers, designers, and specialists can base their studies on a scientific and credible foundation, using a common language and model to analyze design stress. This will lead to more accurate studies and comparisons within this field. This approach will advance the knowledge within the field of design stress and foster innovative and effective solutions for managing it. As a result, the design and its processes will improve, leading to higher-quality products that not only improve the design experience, mental health, and performance of designers, but also positively impact users' experiences when interacting with the product, resulting in products that are easier to use, of higher quality, and offer better user experiences (Figure 5-2).

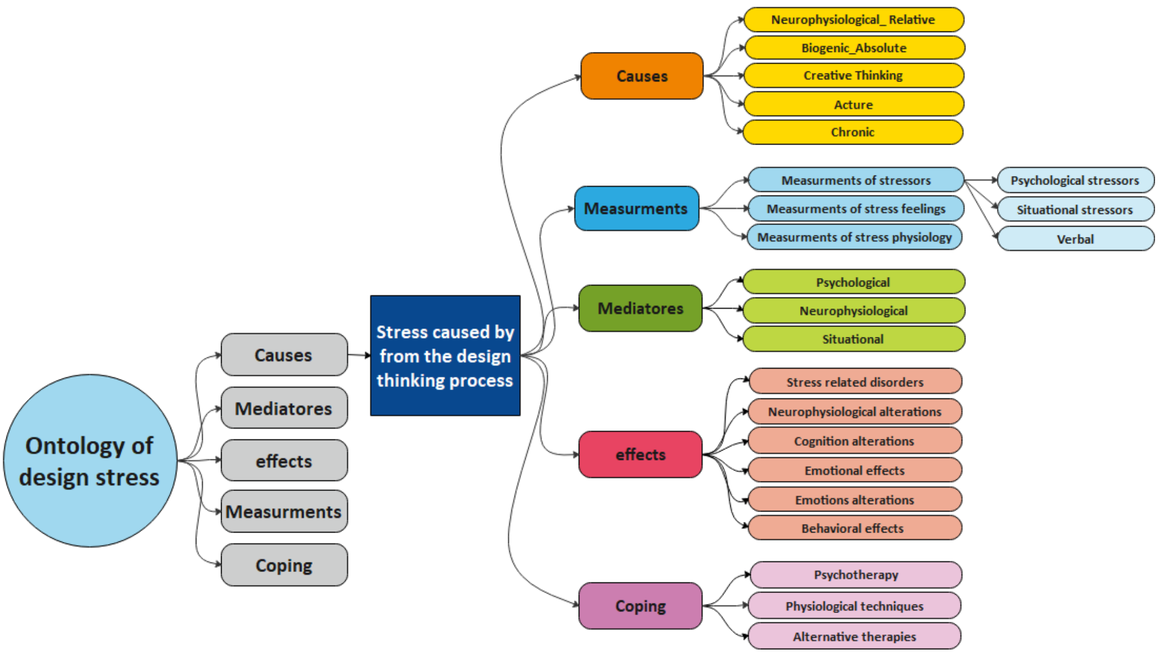

Figure 5-2: Ontology of Design Stress: Causes, Mediators, Effects, Measurement Methods, and Coping Strategies Based on Human Stress Ontology

In this study, due to the vastness of the topic and the multiple dimensions related to design stress, the focus has been placed on stress arising from the design thinking process and its effects on designers and their performance. The studies conducted in this area, as detailed in the previous chapters of this research, have been categorized into five ontological categories of design stress. However, it is hoped that future research will also explore aspects related to the product and user, in order to develop a comprehensive and precise definition of the concept of stress in design (Figure 5-2).

5-3-2-1- Stressors of the Design Thinking Process

Stress stemming from the design thinking process falls within the primary category of the ontology of design stress. This type of stress, encompassing intellectual pressures, uncertainty, decision-making, the need for creativity, innovation, and many other factors, can be classified into subcategories such as psychological-relative, subjective, internal, dependent on personal and creative thinking, acute-short-term and transient, or chronic-permanent. Furthermore, stress arising from the design thinking process is typically short-term, as it is specifically related to the various stages of the design thinking process and its associated challenges. This type of stress temporarily emerges during problem-solving in design and generally subsides after completing each stage and achieving the desired result. However, if designers are continuously exposed to intense mental and psychological pressures across multiple designs and fail to adopt effective methods for managing stress, this stress may evolve into chronic stress. In such cases, chronic stress can have more profound negative effects on the mental health and performance of designers.

5-3-2-2- Stress Mediators in the Design Thinking Process

In the second category of the ontology of design stress, stress mediators in design thinking are classified into three main categories—psychological mediators, physiological mediators, and situational mediators—to better understand designers' responses to stressors. These stress mediators are factors that illustrate the relationship between a stressor and the resulting responses. Additionally, these mediators can determine why or how an individual experiences stress in response to a specific stimulus.

Psychological mediators involve responses related to the personality, emotional, and cognitive traits of the designer. Physiological mediators address the physiological and neural changes related to the designer's reaction. Situational mediators focus on responses related to environmental factors, workload, time constraints, and situational requirements in relation to stress.

Table 5-1: Classification of Stress Impacts in the Design Thinking Process Based on the Ontology of Design Stress

Effects of Stress Due to Design Thinking	Measurement Tools	Characteristics
Emotional Effects	MetaCogno / EEG / PSS	Effects on Negative and Positive Emotions, Instantaneous Brain Reactions
Cognitive (Perceptual) Effects	EEG / MetaCogno	Effects on Focus, Creativity, and Innovation, Information Processing Ability, Decision-Making, Emergence of Doubt and Weak Analysis, Disruption in Using Previous Knowledge, Effects on Attention
Physiological Effects	EEG / PAQ	Effects on Brain Activity, Effects on the Body
Behavioral Effects	PAQ / EEG / MetaCogno	Effects on Behaviors, Performance, Quality and Accuracy in Task Execution, Problem Solving, Decision-Making
Emotional Changes	MetaCogno / PSS	Effects on Emotions

5-3-2-3- Effects of Stress from the Design Thinking Process

Stress arising from the design thinking process has wide-ranging effects on designers and various aspects of their performance. These effects can be examined in several areas including psychological, physiological, emotional, cognitive, affective, and behavioral domains. Tools such as MetaCogno have helped identify these impacts in the cognitive, behavioral, and emotional dimensions, while the results from EEG tools have contributed to identifying emotional and physiological effects. These impacts demonstrate that stress from the design thinking process is a multidimensional phenomenon, requiring comprehensive analysis and various tools for its management and reduction. All identified impacts of stress from the design thinking process in this study, along with the measurement tools used, are displayed in the table below (Table 5-1).

5-3-2-4- Methods for Measuring Stress from the Design Thinking Process

According to the ontology of design stress, the fourth category is dedicated to methods for measuring stress arising from the design thinking process. In this category of the ontology, measurement methods are considered as tools used to assess and record the level and extent of stress in designers at different stages of the design thinking process. In the present study, various methods in three domains—cognitive design, neurocognitive, and physiological—were employed to measure and analyze stress arising from the design thinking process. Given the multidimensional nature of this subject, stress measurement methods for the design thinking process were carried out in several stages using different tools to identify and analyze the various dimensions of this stress and its effects on designers, as detailed in the table below (Table 5-2).

Table 5-2: Classification of Stress Measurement Methods Based on the Ontology of Design Stress

Measurement of Stress Caused from the Design Thinking Process	Subcategories	Tools
Measurement of Stressor Factors	Mental Stressors	EEG
	Situational Stressors	EEG / PSS / PAQ / MetaCogno
Measurement of Emotional Stress	Verbal	MetaCogno
Measurement of Physiological Stress	Physiological Responses	EEG / PAQ

5-3-2-5- Coping Strategies for Stress in the Design Thinking Process

The final category in the ontology of design stress addresses coping strategies for managing stress in the design thinking process, as derived from this study. The data analysis indicates that adopting appropriate approaches for managing stress can be highly beneficial. Among the effective methods for coping with designer stress explored in this study are the following:

- **Regular Breaks Between Stages of the Design Thinking Process**

  According to the results from the EEG data analysis, periodic breaks are critical for energy recovery and maintaining focus. The findings reveal an inverse relationship between stress levels and the duration of breaks, indicating that as stress increases, break time decreases. In high-stress situations, due to the need for greater focus and energy, there is less opportunity to return to a state of relaxation, while lower stress levels allow for more frequent breaks and quicker recovery. This pattern suggests that designers who experience less stress benefit more from breaks, enabling them to continue designing with greater focus and energy, thereby improving their performance. Based on these findings, strategies such as scheduling regular breaks between stages of the design thinking process can help enhance their ability to cope with stress. These strategies are particularly impactful in the design thinking process, especially before the ideation stage, which requires high innovation and creativity, and during which designers perceive high levels of stress.

- **Rest, Meditation, and Mindfulness at the Start of the Design Thinking Process**

  To reduce designers' stress levels during the design thinking process, a series of relaxing activities and stress-reduction techniques, including mindfulness, were implemented. As the first step, after an initial assessment of stress levels and the psychological state of the designers, calming music featuring ocean waves and nature sounds, which is soothing and appropriate for meditation, was played to create a relaxing environment. This music was designed to help reduce both mental and physical stress and assist designers in reaching a state of calm. Additionally, designers were placed in a short rest period (five minutes) before the test. During this phase, they were asked to close their eyes in a quiet and peaceful environment, clear their minds of any thoughts or distractions, take deep breaths, release their bodies, and remain in complete relaxation. This stage resembled meditation exercises intended to reduce stress levels and improve focus and performance. During this rest phase, brainwaves of the designers were recorded using EEG equipment, and the results indicated that these actions had positive effects on the designers' psychological state. Following these steps, it was observed that their stress levels had decreased to the lowest possible point, and their performance had improved to its highest level. Therefore, these actions can be considered effective strategies for reducing designers' stress before beginning the design process, enabling them to start with readiness and calm.

- **Rest, Meditation, and Mindfulness Continuously**

  Immediately after the test, designers were placed in a short rest period (five minutes) post-test. Similar to the pre-test rest phase, they were asked to apply stress-reduction techniques and mindfulness. The results obtained were similar to the pre-test rest phase. Therefore, these actions can also be considered effective strategies for reducing designers' stress after completing the design process. The difference is that the rest, meditation, and mindfulness strategies at the beginning of the design thinking process reduce stress and prepare designers for the task, preventing short-term stress throughout the design thinking process. However, the same strategies at the end of the design thinking process help reduce designers' stress and return them to a normal state, preventing long-term stress. It is even recommended that designers incorporate this strategy into their daily or weekly routines to better manage their stress, maintain peak performance, and enhance their design abilities, productivity, and creativity for a better design experience.

- **Emotion-Focused Coping Strategy**

  On the other hand, the results of the Coping with Stressful Situations (CSI) questionnaire indicate that designers generally prefer a problem-focused coping strategy when facing stress and challenges in the design process, which reflects their tendency for active coping and problem-solving. This result aligns with the nature of design, which requires analytical and creative thinking. However, it is noteworthy that among left-handed designers, the emotion-focused strategy had the highest average, indicating that these designers pay more attention to regulating their emotions and improving performance under stress. In contrast, problem-focused avoidance strategies and emotion-focused avoidance strategies were less favored by designers, suggesting a lower tendency to avoid problems. These strategies may be used as short-term mechanisms to reduce stress. Therefore, teaching emotion-focused coping strategies could be a suitable approach for helping designers cope with stress effectively.

5-4- Achieving Sub-Research Objectives

5-4-1- Recognizing and Presenting Methods for Measuring and Evaluating Stress Caused by the Design Thinking Process

This research focuses on recognizing appropriate methods for measuring design stress within the fields of design, cognitive science, cognitive psychology, stress, and categorizing them into three types: Cognitive Design Stress (DSC), Neurocognitive Design Stress (DSNC), and Physiological Design Stress (DSPH). These methods enable researchers to more accurately recognize and examine the various dimensions and effects of stress caused by design, thinking, and its process on designers, their performance, and the design outcomes. Accordingly, this study selected methods from all three categories. The simultaneous examination of brain activity and stress effects using EEG neuroscience methods, cognitive-emotional experiences with the innovative cognitive design tool MetaCogno, along with interviews and questionnaires for assessing the psychological status of designers and measuring stress levels and coping strategies, provide a comprehensive framework for measuring and evaluating stress arising from the design thinking process, its impact on designers, and strategies to cope with it. This study examines stress across four main design steps (problem analysis, ideation, evaluation and selection of the final idea, and implementation and execution of the final idea) using the MetaCogno tool. MetaCogno, as one of the outcomes of this research, allows for the real-time recording of designers' cognitive-emotional experiences during the design thinking process, the categorization of these experiences by steps, integration with EEG recording systems, and continuous data support and storage for future analyses. It enables a simultaneous and multilayered analysis of designers' emotional and cognitive responses to stress-inducing factors. Unlike methods such as retrospective sessions and questionnaires, MetaCogno provides higher accuracy and validity, and by recording data in real time, it minimizes cognitive biases caused by recall delays. This tool also provides a comprehensive view of the cognitive and emotional transformations of designers immediately after each step of the design thinking process, helping to recognize stress patterns at each design step.

In this research, machine learning methods and classification models, Random Forest and SVM, were used for the first time in analyzing and recognizing stress patterns in the design thinking process and comparing them with each other. The Random Forest model, by creating multiple decision trees based on random sampling of the data and combining the results of these trees, demonstrates high accuracy and robustness when facing complex and unstable data. This feature is particularly effective in analyzing EEG data, which tends to be more unstable under high stress conditions due to frequency and amplitude variations. The 98% accuracy of this model proves its high capability in detecting complex stress patterns and adapting to real-world conditions. The correlation analysis between stress levels in the design thinking process and classification accuracy shows that an increase in designer stress leads to a decrease in model accuracy. This is because, at high stress levels, EEG data becomes more difficult to analyze due to increased fluctuations and complexities caused by stronger reactions from the nervous system. The Random Forest model, with its ability to reduce noise and irregular fluctuations, shows higher accuracy in detecting moderate stress. At this level, the relative stability of EEG signals and the balanced cognitive activity of designers leads to better model performance, and its ability to reduce the impact of noise and adapt to complex EEG data makes it a powerful tool for assessing stress in the design thinking process.

5-4-2- Recognition and Analysis of Stress Resulting from the Design Thinking Process

5-4-2-1- Recognition of Stress Levels and Intensity in the Design Thinking Process

In this research, the distribution of stress levels and intensity in the design thinking process, identified through EEG data analysis and machine learning methods, indicates that the majority of designers experience moderate stress levels, which reflect a balanced and controllable stress experience in this process, with an overall average stress level of 35%. This average was used as a reference criterion to classify stress into five levels, showing that 15% of designers experienced very low stress, 20% experienced low stress, 35% experienced moderate stress, 18% experienced high stress, and 12% experienced very high stress. In line with this analysis, the findings from the Perceived Stress Scale (PSS) questionnaire, which correlate with these results, further support this analysis. 20% of designers perceived a low level of stress during the design thinking process. The highest percentage, 49%, experienced a moderate level of stress, while 30% of designers perceived a high level of stress. The overall distribution of stress levels reveals that although the majority of designers experience moderate stress during the design thinking process, the relative distribution between very high and very low stress provides insight into the wide range of stress responses among designers during the design thinking process. This diversity may be due to factors such as design skills, experience level, stress management abilities, and other factors. Additionally, time constraints, the complexity of the design problem, ambiguity and poor definition, the difficulty of various stages in the design process, cognitive activities, and creativity can all have different impacts on the stress levels of these designers.

5-4-2-2- Recognition of Temporal Stress Patterns in the Design Thinking Process

This research examines the distribution of stress duration in the design thinking process, revealing that each step of this process is associated with varying degrees and patterns of stress. A detailed analysis of the data shows that the majority of stress periods (40%) occurred in time intervals shorter than 0.1 time units, while longer stress periods (over 0.9 time units) accounted for only 8% of the instances. This distribution suggests that stress in the design process is primarily short-term and transient, with designers generally returning to a balanced state quickly after experiencing stress from the process. However, longer stress periods may indicate deeper challenges that require stress management strategies to prevent negative effects on the mental health and performance of designers. Furthermore, designers in the design thinking process experienced three main temporal states: rest, normal, and stress. The rest state represents periods of calm and low activity, during which designers experienced lower levels of stress. The normal state reflects a stable condition without intense psychological pressure, allowing designers to maintain their performance. In contrast, the stress state typically occurred during more complex stages of the design process, such as idea generation. Balanced stress in these conditions helped to increase focus and motivation, while excessive stress led to reduced creativity and performance decline.

Additionally, the data show that, on average, designers shifted between different stress states 40 to 60 times. This pattern indicates the flexibility and adaptability of designers in responding to the challenges and complexities of the design process. Such shifts may represent a potential ability to recover and cope with design pressures but could also lead to mental fatigue. Overall, this temporal stress pattern underscores the importance of balancing these three states within the design thinking process. The results highlight the need for effective stress management and the provision of rest periods so that designers can face the challenges of the design process with optimal performance while maintaining their mental health.

5-4-2-3- Analysis of the Distribution of Designers' Mental States in the Design Thinking Process

The results from analyzing the research findings indicate that in stressful conditions, designers experience significant changes in their mental states, continuously engaging in emotional and cognitive experiences. These changes become particularly more intense in high-stress conditions, reflecting constant fluctuations between stress and rest states. Additionally, in more complex design activities, the stress level significantly increases, with this increase occurring more rapidly and intensely. In contrast, in simpler activities, the stress level remains more stable and lower. The increase in mental state fluctuations at high-stress levels may lead to severe emotional and psychological reactions in designers. As observed in the data, designers reported complex emotional-cognitive experiences throughout the design thinking process. These experiences were especially pronounced during the ideation stage, where designers simultaneously perceived a wide range of both positive and negative experiences.

It seems that these frequent mental state changes limit designers' ability to achieve a stable and consistent state, leading to reduced focus and performance. This situation may be due to the increasing challenges designers face in the design process, causing greater cognitive and emotional fluctuations and resulting in more immediate and intense reactions. Overall, these stress fluctuations suggest that designers, in response to different design activities and the challenges associated with them, dynamically and momentarily alter their stress levels, mental states, and emotional experiences. These changes contribute to the identification of stress variations in short time intervals and a deeper understanding of the mental and emotional processes designers undergo throughout different stages of the design process.

5-4-2-4- Recognizing the Most Stressful Step in the Design Thinking Process

The findings indicate that the level of stress and the performance of designers exhibit significant changes across different steps of the design thinking process. In the first step, **problem analysis**, an increase in stress is observed along with a relative decrease in performance. This increase in stress can be attributed to the ambiguous and complex nature of design problems. Designers often encounter poorly-structured and multidimensional problems that require deep thinking and high concentration to understand their various aspects. This situation leads to an additional cognitive load, as designers must process and analyze large amounts of information. In cases where the cognitive load becomes excessively high, performance tends to decline. On the other hand, the observed relative decrease in performance can be seen as the result of the mental pressure stemming from the effort to precisely define the problem and find appropriate frameworks to initiate the design thinking process in the initial step, which causes a feeling of confusion among the designers. In this step, designers also experience a variety of emotional experiences, with positive experiences being predominant. This could indicate a sense of progress and satisfaction with their ability to analyze and understand the problem.

In the second step, **ideation,** the highest level of stress in the design thinking process was experienced. In this step, designers are under mental pressure to generate innovative and creative ideas. This mental pressure leads to elevated stress levels and a decrease in performance and productivity among designers. However, despite the high level of stress, the experience of enjoyment in this step had the highest frequency. This indicates that most designers, alongside the high stress they experienced, also enjoyed the ideation step. Moreover, both positive and negative experiences, as well as experiences of having insufficient ideas, finding ideation challenging, and simultaneously having too many ideas, were reported by designers at equal rates. This highlights a more complex dimension of this step. These contradictions demonstrate that while the ideation step is engaging and creative, it can simultaneously become a highly stressful and difficult phase. This reflects a complex challenge where emotional contradictions between enjoyment and difficulty are clearly evident. Overall, it can be concluded that ideation is a step that serves as both a significant source of stress and a source of creative enjoyment.

In the **evaluation and final idea selection** step, a reduction in stress levels and an improvement in designers' performance is observed. However, doubt emerges as one of the most common experiences in this step, indicating that designers may face mental challenges and uncertainties in selecting the final idea. This feeling of doubt can be particularly prominent when designers are confronted with multiple exceptional ideas. Additionally, the difficulty of choosing the final idea is another common experience reported by designers, as this step requires them to evaluate and make a definitive decision among various ideas, each with its unique features and innovations. Alongside these experiences, designers also reported feelings such as having enough time and enjoying the process. This indicates that some designers found enjoyment in their evaluation and decision-making process. Overall, this step is recognized as one of the most complex and challenging phases of the design process, accompanied by doubt and a blend of positive, negative, and neutral emotions.

In the final step of **implementation and execution of the idea**, designers' stress levels decrease, and their performance significantly improves. This step, which involves practical activities such as sketching and hand-drawing and serves as the concluding phase of the design thinking process, results in reduced stress levels and enhanced performance among designers. Moreover, a higher frequency of positive experiences is reported during this step. Feelings of satisfaction and enjoyment derived from implementing ideas and completing the design process indicate that designers were able to successfully bring their ideas to fruition and found pleasure in the act of hand-drawing. These positive experiences, coupled with a sense of excitement, highlight the critical role of the implementation step in reducing stress levels and enhancing the overall design process experience.

5-4-3- Recognizing the Effects of the Time Variable on Designers and Their Performance

The results from analyzing designers' EEG data indicate that the time variable can act as a positive stimulant for mental stability and calmness. Contrary to the initial assumption that time constraints in the design thinking process might be stress-inducing, the findings of this research reveal that moderate time constraints have beneficial effects. A comparison of the time spent between the groups with and without time constraints shows only a slight difference in the total time spent on the design thinking process. This can likely be attributed to the moderate level of time constraints applied in this study. Excessive time constraints, however, may increase stress levels and exert significantly negative effects on designers and their performance. The moderate time constraint implemented in this research has reduced excessive stress, enhanced focus on design activities, improved mental rest and cognitive recovery periods, stabilized mental states, decreased fluctuations in psychological conditions, and improved designers' performance throughout the design thinking process.

The effects of the time variable on designers’ mental experiences can be summarized as follows:

- **Inducing a Moderate Level of Stress**: The findings indicate that the time constraint in this study, by inducing a moderate level of stress, positively affected designers' performance. This balanced stress, often referred to in scientific literature as eustress, enhanced motivation and efficiency in performing complex design tasks. This effect is particularly evident in the comparative results between the groups with and without time constraints.

- **Connection with Mental Stability and Fatigue Reduction**: Moderate time constraints, by reducing mental dispersion and facilitating cognitive recovery, have contributed to greater mental stability among designers. This has reduced mental fatigue and prevented performance decline. Conversely, the group without time constraints reported higher levels of fatigue and psychological pressure due to the prolonged design process and the absence of moderate stress levels. These findings indicate that a prolonged design process negatively affects performance and leads to adverse outcomes.
- **High Positive and Negative Experiences**: In line with these findings, the results from the MetaCogno tool analysis also reveal that the time variable plays a pivotal role in shaping the emotional-cognitive experiences of designers. Under time constraints, designers reported a higher number of experiences (including positive, negative, and neutral) compared to the group without time constraints. These findings suggest that time, as a limiting factor in the design thinking process, presents both challenges and opportunities for designers, particularly during the ideation stage, which is the most stressful phase. On the other hand, designers under time constraints experienced more positive emotions than the group without time constraints, which improved their performance and ultimately resulted in a better design experience. This demonstrates the beneficial effects of this level of stress.
- **Problem-Focused and Emotion-Focused Coping Strategies**: The results from the Coping Strategies Inventory (CSI) questionnaire showed that the group of designers under time constraints recorded the highest averages in problem-focused and emotion-focused coping strategies. This reflects their greater inclination to solve problems and regulate their emotions. The use of these strategies helped designers in this group effectively manage their stress during the design thinking process and improve their performance.

This research highlights that moderate time constraints, by creating a balance in stress levels, act as a positive factor in enhancing emotional-cognitive experiences, reducing stress levels, and improving designers' performance. Conversely, the absence of time constraints or excessive time constraints may lead to negative effects such as fatigue or severe stress, ultimately reducing productivity and potentially causing negative emotions and decreased motivation.

5-4-4- Recognition of the Effects of Handedness on Designers and Their Performance

The findings from the EEG data analysis of designers indicate that handedness can also influence how stress is managed, resting patterns, mental stability, and mental calmness in designers. Specifically, the differences between left-handed and right-handed designers in their reactions to design challenges and cognitive load management during the design thinking process have been clearly revealed. The results show that left-handed designers have effectively managed their mental and emotional pressures during the design thinking process, as follows:

- **Mental Stability and Consistency, More Positive Experiences, and Better Performance of Left-handed Designers:** Left-handed designers exhibited higher mental stability at various steps of the design thinking process, which reduced cognitive and emotional fluctuations, enabling them to maintain continuous focus on design tasks. Additionally, the emotional-cognitive experiences reported by this group of designers indicate that they generally experienced more positive experiences throughout all steps of design. Their ability to manage emotions and cope better with design challenges has played a key role in improving their overall performance. Particularly in challenging conditions, such as the ideation step that requires more creativity and focus, they performed better and were less stressed or mentally scattered.
- **The Need for Frequent Breaks to Maintain Efficiency, More Negative and Neutral Emotional-Cognitive Experiences in Right-handed Designers:** Right-handed designers required more mental breaks to maintain their stability and focus during the design thinking process. This indicates their greater sensitivity to cognitive load and design challenges. On the other hand, the emotional-cognitive experience data shows that this group of designers reported a higher level of neutral and negative emotions, such as fatigue. This reflects their increased susceptibility to the complexities of the design thinking process and their lesser ability to manage stress and negative emotions.
- **Emotion-focused Coping Strategies and Emotion-focused Avoidance Strategies:** The results from the Coping with Stressful Situations (CSI) questionnaire showed that left-handed designers had the highest average in these emotion-focused coping strategies and emotion-focused avoidance strategies, which may indicate their greater tendency to manage and avoid confronting negative emotions. In contrast, right-handed designers reported more problem-focused coping strategies. Emotion-focused coping strategies include techniques that help individuals reduce their negative emotions and effectively cope with the stress related to the design process. Additionally, emotion-focused avoidance strategies allow left-handed designers to avoid direct confrontation with emotional and stress-inducing stimuli, thus helping them maintain focus and perform better. These characteristics enable them to maintain a higher level of control and efficiency under stressful conditions and work pressures.

5-5- Correlating Research Findings with Previous Studies

5-5-1- Analysis of Design Thinking Process Stages Based on the Yerkes-Dodson Law

The findings of this study exhibit a significant alignment with previous research, particularly with the Yerkes-Dodson Law (1908). According to this law, the relationship between stress and performance follows an inverted U-shaped curve, indicating that individuals perform optimally at moderate stress levels. In other words, both extremely low and excessively high stress levels lead to decreased performance. In this study, the analysis of designers' stress levels and performance during the resting phase and various stages of the design thinking process has been compared to the Yerkes-Dodson Law, as detailed below:

- **Resting Phase:** As previously mentioned, during the resting phase, designers were instructed to listen to soft music in a calm environment, relax their minds and bodies, and practice deep breathing exercises before beginning the design process. These techniques aimed to facilitate mental relaxation, reduce stress, and enhance cognitive clarity. The findings indicate that stress levels were at their lowest during this phase. Contrary to the Yerkes-Dodson Law, which suggests that extremely low stress levels hinder performance, designers exhibited their highest performance in this stage. This discrepancy may be attributed to the positive effects of mindfulness techniques and meditation.
- **Problem Analysis and Definition:** As the initial stage of the design process commenced, stress levels increased while performance declined compared to the resting phase. At this stage, designers were required to process complex information and develop a deeper understanding of the problem, leading to heightened stress and a relative decrease in performance. This trend aligns, to some extent, with the Yerkes-Dodson model.
- **Evaluation and Selection of the Final Idea:** In this stage, stress levels decrease compared to the previous stage, and performance improves. This phase aligns with the stress-performance equilibrium section of the Yerkes-Dodson Law.
- **Implementation and Execution of the Final Idea:** This stage allows designers to practically implement their final idea. Stress reaches its lowest point during this phase, and performance significantly improves. Contrary to the Yerkes-Dodson Law, which suggests that low stress may lead to decreased performance, here, the reduction in stress is associated with enhanced performance. In this phase, designers shift focusses from complex cognitive processing to practical and creative aspects of execution.

Overall, the ideation phase and the high stress levels associated with it clearly align with the predictions of the Yerkes-Dodson Law. In this phase, high stress leads to reduced performance, demonstrating the negative impact of excessive stress on performance. During the evaluation and selection of the final idea, stress levels are moderate, which facilitates improved performance. This is consistent with the Yerkes-Dodson model, which suggests that moderate stress enhances performance. In the implementation and execution of the final idea (sketching), the low stress levels result in increased performance. Contrary to the law, this phase, due to its practical and hands-on nature, significantly reduces stress levels and improves designers' performance. Additionally, during the resting phase, despite the Yerkes-Dodson model associating low stress with decreased performance, the highest level of performance was observed.

5-5-2- Analysis of the Time Variable Based on the Yerkes-Dodson Law

Designers' performance in both the time-constrained and non-time-constrained groups was influenced by stress levels. The results indicate that the time-constrained group experienced lower stress levels and performed better compared to the non-time-constrained group. This finding suggests that the stress levels in the time-constrained group were closer to the optimal range defined by the Yerkes-Dodson Law. According to the law, optimal performance occurs when stress levels are moderate, as moderate stress can enhance motivation and focus. In contrast, the non-time-constrained group, due to the absence of clear time pressure, experienced higher stress levels. This increase in stress led to a decline in their performance, aligning with the second part of the Yerkes-Dodson Law. These findings indicate that the lack of time constraints may not reduce stress, but instead have a negative impact on designers, compromising their performance. Overall, the comparative analysis between the two groups, and with the Yerkes-Dodson Law, emphasizes that managing stress within an appropriate range is a key factor in improving designers' performance. This highlights the importance of adjusting factors such as time constraints as a tool to achieve an optimal balance in stress levels and enhance designers' productivity.

5-5-3- Analysis of Stress Concepts in the Design Thinking Process

According to theoretical foundations and classifications presented in the scientific literature, stress is generally divided into three categories: eustress (positive stress), neutral stress, and distress (negative and harmful stress), each of which has distinct characteristics and impacts on human performance and psychology (Brian, 2002) (Grahn & Stigsdotter, 2010) (Cran, 1993). The results of comparing the time-constrained and non-time-constrained groups and analyzing their performance in the design thinking process show significant alignment with these theories.

Stress in the design thinking process plays a dual role and can be categorized into two types: eustress and distress. Eustress refers to situations where stress acts as a motivational factor, driving individuals toward better performance, personal growth, and success (Brian, 2002). In the current study, optimal performance was observed in the time-constrained group, which experienced moderate stress levels.

This level of stress contributed to improved performance in the various stages of the design thinking process. Consistent with the concept of eustress, in this group, time acted as a positive motivator by creating moderate levels of stress.

On the other hand, distress occurs when an individual lacks the ability to cope with challenges and pressures (Cran, 1993). This type of stress can lead to psychological disorders and a decline in performance (Grahn & Stigsdotter, 2010). In this study, distress was observed in the non-time-constrained group, as the absence of a clear time framework led to increased stress and a reduction in productivity compared to the time-constrained group. Additionally, in the ideation stage, stress levels reached their peak, disrupting performance. In both cases, stress reached a detrimental level, aligning with the concept of distress.

5-5-4- Cognitive Theories of Stress

In the theoretical foundations of the research, stress is defined as a dynamic phenomenon influenced by three main components: the individual, time, and environment. This definition emphasizes that stress changes over time and is affected by personal characteristics and environmental conditions. Researchers such as Lazarus and Folkman (1984) view stress as a result of the interaction between the individual and the situation. They argue that the individual's cognitive appraisal of a situation and their way of coping with it play a crucial role in the experience of stress. This approach suggests that personal traits, along with cognitive appraisals and coping styles, can influence the perceived level of stress (Sarafino, 1974).

In this study, these concepts were examined with a focus on the dimensions of time, the individual, and the environment within the context of the design thinking process. The alignment of the findings with previous studies highlights the following key points:

- **The Impact of Personal Characteristics on Designers' Stress Levels**: This study explored the effect of handedness (a personal trait) on the stress levels of designers during the design process. The results showed that this characteristic influences the perceived level of stress and the way designers interact with the design situation.
- **The Influence of Time on Designers' Stress Levels**: The results of this study suggest that the time variable has a significant impact on the stress levels of designers in design situations. Time constraints led to a moderate level of stress in the designers, improving their performance.

5-5-5- Physiological Effects of Stress in the Design Thinking Process

The results from the Physiological Arousal Questionnaire (PAQ) suggest that the majority of designers experience mild or moderate physiological responses to the stress associated with the design process. This could be because the stress in the design thinking process is primarily experienced mentally, cognitively, emotionally, and behaviorally, rather than through observable physical physiological reactions. These findings are somewhat aligned with previous studies which argued that designers do not exhibit physiological responses (Nolte, Huff & McComb, 2022). However, the present study indicates that designers perceive this type of stress in a mild form.

Nevertheless, the absence of observable physiological reactions or the inability of designers to recognize and identify such responses to stress is refuted, as the emotional-cognitive experiences and responses provided in the questionnaires align perfectly with the EEG data. This suggests that designers are fully aware of their emotions, experiences, and the level of perceived stress. To further validate this, more precise studies and the use of advanced cognitive science tools are necessary to comprehensively examine the physiological effects of stress during the design thinking process and measure these effects more accurately.

5-5-6- Comparative Analysis of Stress in Design Thinking, Critical Thinking, and Creative Thinking

Design thinking is a creative and problem-solving process that requires designers to analyze problems, brainstorm, make decisions, evaluate, select final ideas, test solutions, and deal with ambiguity and complexity. In this process, designers must not only generate innovative ideas but also turn these ideas into practical and executable solutions. This characteristic, along with time, resource, and real-world constraints, generates a unique form of stress that arises from the effort to balance the various aspects of the design thinking process.

In contrast to design thinking, critical thinking primarily focuses on analysis, evaluation, and logical judgment, examining the accuracy and quality of information. Stress in this process often stems from the need for high precision, strong logic, and sound reasoning. Unlike design thinking, critical thinking is less dependent on generating innovative ideas or executing them, and its structured and linear nature typically generates less stress related to creativity and uncertainty.

On the other hand, creative thinking is an open and unbounded process that emphasizes generating new and innovative ideas. Stress in this process mainly arises from the demand for innovation, the challenges of producing unconventional ideas, and pushing the boundaries of conventional thinking. Unlike design thinking, in creative thinking, practical issues, logical evaluation, and attention to detail are less emphasized, which reduces the stress associated with practical aspects.

Thus, while all three processes generate stress, the nature and sources of stress in design thinking are more multifaceted, involving creativity, execution, and problem-solving within constraints, whereas critical thinking tends to involve more structured stress around logical accuracy, and creative thinking involves stress from the pressure of innovation and breaking boundaries.

Design thinking is an integration of creative and critical thinking, requiring the simultaneous generation of innovative ideas, evaluation and selection of the best idea, and ultimately the practical execution of these ideas. These combined features make the stress experienced in design thinking encompass elements of both creative and critical stress, but it is not limited to them. During the ideation phase, designers face stress from the requirement to generate creative and innovative ideas, while in the evaluation and selection phase, they experience the pressure of logical analysis and decision-making. Additionally, during the implementation phase, stress arises from the need to transform ideas into actionable and tangible solutions.

Moreover, the quality of the final output in design thinking is of greater importance, and stress is not only related to the different phases but also connected to the final result. Therefore, compared to other types of thinking, design thinking is a more complex and multidimensional process in terms of stress. The stress in this process not only stems from creative and logical elements but also includes pressures related to practical execution and achieving tangible outcomes. This combination of factors makes design thinking a challenging process that requires more in-depth investigation and the development of strategies to effectively manage stress within this domain.

5-6- Innovations of the Current Study in Comparison to Existing Research in the Field of Design Stress Studies

The results obtained in the present study align with existing theories in the field of design studies regarding stress. However, this research has advanced in certain aspects, serving as a further step and complement to previous studies. In addition to confirming existing theories in this domain, this study enhances and builds upon previous research. It also provides a more comprehensive and detailed analysis of various dimensions of stress in design, distinguishing it from other studies. Unlike previous research, which often focused on a single dimension of stress, this study investigates stress arising from the design thinking process from multiple perspectives. The key innovations of this research, which contribute to the validation and reinforcement of existing theories in the field of design stress, include:

1- **Clarification of the Concept of Design Stress**: One of the key aspects of this study is the clarification and precise definition of the concept of design stress. Unlike many previous studies that have addressed this topic in a general and fragmented manner, this research aimed to articulate this concept specifically within the context of design, presenting it through a clear and comprehensive theoretical framework. This not only contributes to a better understanding of design stress but also analyzes it at various levels.

2- **Presentation of the Ontology of Design Stress**: In this study, the effort was made to provide a comprehensive ontology for design stress. Given that design stress is a complex and multifaceted phenomenon, this ontology serves as a framework for the structured and comprehensive analysis of design stress. It enables the identification of its various dimensions, stress-inducing factors, impacts, measurement methods, and coping strategies. This provides a scientific and credible framework for researchers to become familiar with the diverse aspects of design stress.

3- **Structured Clinical Interviews and Use of Pre-Test Questionnaires**: Another innovation in this study is the use of structured clinical interviews and standardized questionnaires to assess and understand the psychological state of designers prior to the experiment. This approach ensures that the designers participating in the study are in a similar mental state before the testing, thus enhancing the reliability and validity of the findings.

4- **Utilization of Novel Cognitive Design Methods**: One of the notable innovations of this research is the design and development of the MetaCogno tool, which instantaneously evaluates the emotional-cognitive experiences of designers at each stage of the design thinking process. This tool provides a real-time assessment of how designers experience and process emotions and cognition during the design stages, offering valuable insights into their cognitive and emotional states.

5- **Use of Cognitive Science Methods**: This study employs EEG tools to measure and analyze the physiological and neurocognitive impacts associated with design stress. By utilizing EEG, the research provides insights into the neural activity related to stress during the design process, offering a deeper understanding of the cognitive processes involved.

6- **Post-Test Questionnaires**: In addition to utilizing neurocognitive techniques and advanced cognitive design tools, this research incorporates standard post-test questionnaires immediately after the experiment to assess designers' perceived stress levels and their coping strategies. These questionnaires help capture self-reported emotional and psychological responses, complementing the objective measurements provided by EEG and MetaCogno.

7- **Use of Machine Learning Models**: The present study employs advanced machine learning techniques, specifically the Random Forest model, to classify and predict the stress levels of designers. This model provides high accuracy in predicting the levels and patterns of stress, identifying temporal patterns, mental states, and stress-related behaviors across various stages of the design process.

8- **Examining the Effects of Time and Handedness Variables**: This study investigates the impact of the time and handedness variables on the stress levels and performance of designers. The research explores how time constraints and handedness influence the cognitive and emotional experiences of designers during the design process.

9- **Larger Sample Size**: The research aimed to exceed the minimum sample size typically considered for cognitive science studies in each group. Measuring stress levels in designers through multiple methods within a sample of 100 participants was a challenging and complex process. However, this approach was undertaken to enhance the scientific precision and validity of the study.

10- **New Research Domain**: For the first time, this research extends beyond the engineering field and delves into the area of industrial design. This study introduces a novel approach to stress analysis within the context of industrial design, offering new insights into the cognitive and emotional aspects of design thinking.

5-7- Limitations and Challenges

In this study, every effort was made to ensure that all stages were conducted with high precision and in conditions as close as possible to real-world design scenarios. The primary goal was to ensure that the data and results obtained closely aligned with actual conditions and had high scientific validity and reliability. However, despite all efforts to minimize errors and create a standardized environment, every study is subject to limitations based on available resources and circumstances, which can impact the generalizability and applicability of the results. This study is no exception and has several limitations, including the following:

- One of the limitations of this study pertains to the equipment used. The EEG device employed was technologically outdated, and more modern alternatives were not available. Due to this limitation, it was not possible to utilize all the advanced features of modern devices.
- Additionally, the EEG device used was limited in terms of the number of channels it could record. It only had the capacity to record data from 32 channels, whereas using devices with 64, 128, or 256 channels would have provided greater accuracy in signal recording and data analysis.
- Due to limited access to a large sample of professional and experienced designers, the study sample was primarily drawn from students, with only a few experienced designers included. Although students have experience in the design thinking process, generalizing the results to professional designers may present challenges. Access to a larger and more diverse sample of both novice and expert designers and comparing them could have provided more accurate and comprehensive results.
- The population of left-handed designers was also very small and limited due to statistical constraints (the low number of left-handed designers). The small number of available left-handed participants may have affected the generalizability of the results for this group.
- This study focused on analyzing stress and performance in designers over short-term periods. As a result, the long-term effects of this stress on the psychological, cognitive, and performance status of designers were not examined.
- The research was centered on individual design, and the impact of stress in team-based design environments, which may have different stress-inducing factors, was not explored. This limits the

generalizability of the findings to collaborative or group design environments.

5-8- Recommendations

5-8-1- Recommendations for Future Studies

To address the limitations and challenges in design stress research, it is recommended that more studies be conducted in the field of design stress. These studies should comprehensively and precisely examine the various dimensions of design stress and develop effective solutions for managing it. The following suggestions can provide valuable guidance for future research on managing design stress and contribute to improving designers' performance in professional environments.

1. **Expanding the Research Scope to Different Design Domains**: It is recommended that future research explore design stress in areas beyond engineering design, interior design, and architecture. These areas could include product design, industrial design, service design, and graphic design. Expanding the research scope can help identify stress-inducing factors and performance patterns across a wide range of design activities.
2. **Enhancing Research Equipment and Tools**: It is recommended that future studies use more advanced EEG devices with a higher number of channels (such as 128, 256, or 64 channels). This enhancement can contribute to the collection of more accurate data and provide deeper analysis of brain activity during the design process.
3. **Expanding the Sample Population**: Future studies should aim to access a broader and more diverse sample population of professional and experienced designers. This can help generalize the results better and provide a more comprehensive understanding of stress and its impacts on designers.
4. **Utilizing Real-World Design Environments**: It is recommended that future studies be conducted in real-world design environments to obtain better results that simulate actual conditions.
5. **Combining Multiple Methods for Multidimensional Analysis of Design Stress**: The use of combined methods, such as EEG, ECG, fNIRS, and biometric sensors, alongside cognitive design methods, could provide more accurate and comprehensive data in future research.
6. **Creating a Balanced Level of Stress**: Effective stress management strategies should be employed to help designers maintain their stress at a balanced and constructive level. The goal should be to reduce high stress levels and increase low levels of stress to moderate levels, as moderate stress is considered optimal and beneficial for enhancing productivity and design quality. This approach should be tested in future studies to examine its effects on reducing or increasing designers' stress levels and its impact on design outcomes.

7. **Examining the Impact of Stress on Final Design Outcomes**: Future studies should investigate the impact of stress on the final design outcomes and their quality. In particular, it is recommended that each designer's output be compared with their perceived stress levels throughout the design process. This examination can clarify how stress at various stages of the design thinking process influences the quality and accuracy of the final design results and contribute to a better understanding of the complex relationship between stress, the design thinking process, and its outcomes.
8. **Development of Design Models with Stress Management Approach**: The design and development of innovative design models for managing designers' stress is essential. These models can assist designers in achieving optimal performance under stressful conditions.
9. **Focusing on Ill-Structured and Complex Issues in Design**: Since many design problems are ambiguous, complex, and poorly defined, it is recommended that future research specifically focus on identifying the stressors caused by these types of issues. This research could improve the understanding of how designers deal with ambiguous and ill-structured problems.
10. **Reducing Cognitive Load in the Face of Complex Problems**: Future research should focus on actions that help reduce cognitive load and enhance the mental efficiency of designers during the design process.
11. **Teaching Problem-Solving Skills and Stress Management**: To improve designers' performance, training in creative problem-solving skills and stress management techniques should be included in design education programs. These training sessions can help designers manage the stresses of the design process more effectively.
12. **Development of Stress Management Tools**: Future studies could focus on designing and evaluating new tools that help designers manage their stress during various stages of the design thinking process.
13. **In-depth Analysis of the Impact of Time Variables**: It is recommended that future research conduct a more detailed analysis of the impact of time variables in the design thinking process, particularly examining how different time constraints (e.g., shorter or longer time limits) affect stress levels and designers' performance. This approach could help optimize the timing in the design process.
14. **Investigating the Impact of Experience and Expertise**: Future studies could explore the influence of experience, expertise, and design skills on perceived stress levels and performance. This could yield valuable and practical insights.
15. **Studying Different Types of Stress**: It is suggested that future research examine external stress factors, such as environmental, occupational, and lifestyle factors, and their impact on stress in designers.

16. **Examining Variables Affecting Designers' Stress Levels**: Future research should explore the impact of important variables such as age, gender, education, and individual personality traits on stress levels in designers.
17. **Interdisciplinary and Comparative Studies**: Future research can adopt an interdisciplinary approach to studying design stress, integrating behavioral, cognitive, and psychological sciences. Additionally, comparative studies between different design fields could offer new perspectives on how different areas face stress.
18. **International Comparison**: It is recommended that multi-national studies be conducted to better explore design stress patterns and cross-cultural differences. These factors may influence perceived stress levels and the performance of designers across various cultures.

5-8-2- Proposed Strategies for Stress Management in the Design Thinking Process

Stress, as one of the influential factors on designers' performance, can act both as a driving force and as a barrier to productivity and creativity at various levels. The findings of this study also indicate that managing stress levels in design is of paramount importance. Therefore, proposing strategies in this regard can be an effective step toward improving design quality and enhancing designers' productivity. These strategies not only focus on stress reduction but also help create a dynamic and constructive environment for designers, enabling them to engage in their activities with greater mental clarity. Attention to these factors can serve as a practical guideline for designers in future studies and in real-world settings:

1- **Effective Planning and Scheduling**: To optimize the design thinking process, it is essential to develop a precise planning and scheduling for the design process (preferably separately for each stage of the design process). This scheduling should be arranged in such a way that it creates the necessary challenges while preventing excessive pressure on designers. A realistic schedule can help achieve a better balance between challenge and relaxation.

2- **Utilizing Time Management Techniques**: Techniques such as working in short time intervals with brief breaks (such as the Pomodoro technique) can aid in better managing tasks and time throughout the design process.

3- **Stress Management Training and Stress Reduction Techniques**: Offering courses and workshops to teach stress management skills and coping techniques, such as relaxation methods like deep breathing exercises, meditation, and mindfulness, can help reduce psychological pressure and improve mental clarity for designers, thereby increasing their productivity. These techniques could be incorporated into design training programs.

4- **Music Therapy**: Playing calming music, such as the sound of ocean waves or nature, can have a positive impact on reducing mental and physical stress. This method can serve as a simple and effective tool for creating a more relaxed environment during design activities and their various stages.

5- **Regular Break Scheduling**: Allocating regular breaks throughout different stages of the design process for energy restoration and stress reduction is essential. These breaks can improve mental productivity and prevent burnout.

6- **Emotion-Focused Coping Strategies**: It is recommended that these strategies be comprehensively and purposefully taught to designers through workshops and training programs. The training should include practical examples of how to apply each strategy in stressful situations. Using these skills will help designers effectively manage stress in challenging situations.

7- **Use of Note-Taking and Hand Drawing to Reduce Stress and Enhance Designer Performance**: During the implementation and execution phase of the final idea (sketching), hand drawing helped reduce stress levels, thereby improving designers' performance. Therefore, it is recommended that designers use note-taking and hand drawing in all stages of the design thinking process

8- **Utilizing Creativity Techniques for Stress Management and Improving the Design Process**: Employing creativity techniques can assist designers in solving design problems innovatively and with minimal stress.

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