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# Improving Usability of Smartphone Applications through User Interface Design Theory and Eye Tracking

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## Abstract

Smartphones have become ubiquitous devices used by individuals of all ages and backgrounds in modern society. In this context, User Interface (UI) design has emerged as a critical element. UI design focuses on designing the usability of applications and similar platforms, prioritizing enhancing usability over aesthetics and visual appeal. Unlike software development, which has well-established methodologies, UI design methods are not yet fully established due to the subjective nature of design, heavily influenced by individual sensibilities and preferences. Creating a completely original service often necessitates designing from scratch, making it essential to find relevant design theories for reference. A compilation of essential design theories that must be adhered to can simplify the design process and make it more approachable. However, as UI design methodologies are still evolving, designers need to explore design approaches based on information from the internet and books. The "Four Principles of Design" are prevalent among the various design theories presented by designers. Yet, the effectiveness of these principles has not been extensively studied quantitatively. This paper aims to contribute to facilitating the initiation of UI design endeavors by elucidating the effects of the Four Principles of Design through the lenses of eye-tracking, cognitive psychology, flow theory, and mental models.

*Keywords:* UI design, eye tracking, design theory.

## 1 Introduction

Smartphones have become devices utilized by individuals of all ages and genders in modern society. In this context, User Interface (UI) design has emerged as an exceptionally crucial element. UI design is commonly recognized as an abbreviation for User Interface Design. A perception exists that UI design primarily focuses on aesthetics and visual appeal. However, UI design is a concept aimed at designing the usability [2] of products such as applications. Therefore, UI design necessitates intuitive designs rather than solely focusing on visual appeal. Designing an app prioritizing aesthetics often results in designs influenced by the author's taste and preferences. While such designs may be user-friendly for individuals sharing the author's sensibility, they could be less user-friendly for others.

The methods of UI design have yet to be firmly established, requiring designers to explore design approaches based on information from the internet and books to study UI design theories. However, explanations of such design theories typically reflect each designer's subjectivity and sensibilities, as they are provided by designers themselves. In reality, there is scant data validating the effectiveness of designs through experiments involving multiple participants. Moreover, user interfaces, such as smartphone apps, serve as intermediaries between

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systems or services and users.

Among various designers introducing design theories, the "Four Principles of Design" [1] [3] are almost universally mentioned. These principles comprise the "Law of Proximity," the "Law of Alignment," the "Law of Contrast," and the "Law of Repetition." The roots of three of these design theories - "Law of Proximity," "Law of Alignment," and "Law of Repetition" - are believed to trace back to Gestalt principles [4]. Gestalt principles were researched by the psychologist Max Wertheimer in the early 20th century and are fundamental concepts in Gestalt psychology. These principles emphasize perceiving elements as a unified whole rather than as individual elements grouped together.

The "Law of Contrast" lacks identifiable roots, but the phenomenon of "Figure and Ground" elucidated by the psychologist Edgar Rubin shares similar effects. This phenomenon illustrates how humans perceive one element as a figure and another as the background when observing objects with two contrasting colors.

Theories based on Gestalt psychology are frequently utilized in product design. Donald Norman's "The Design of Everyday Things" [5], cited extensively in design-related literature, explains design concepts based on Gestalt psychology. Current UI design, web design, and slide design often borrow from design theories used in product design. The "Four Principles of Design" summarize fundamental and essential design theories derived from these principles, acknowledged as common knowledge within the design industry, particularly among UI and web designers.

However, there is a scarcity of data that logically analyzes the effects of the Four Principles of Design through experiments. Additionally, while user interfaces are visual and used with the eyes, research evaluating user interfaces using eye-tracking data is limited. Therefore, the aim of this study is to determine whether eye-tracking data can be used for analyzing UI design theories using mockups of smartphone apps created with Figma, a browser-based collaboration interface design tool. The endeavor will also be to elucidate the effects of the Four Principles of Design from the perspectives of cognitive load theory, flow theory, and mental models [6].

# 2 Concept

## 2.1 Cognitive Load Theory

Cognitive Load Theory (CLT) [7] concerns the way cognitive load affects learning in order to facilitate more effective acquisition of new knowledge and skills. Cognitive load refers to the amount of cognitive processing capacity allocated by learners when processing a task, and Cognitive Load Theory considers how learning-induced cognitive load can be managed more effectively to facilitate learning [8]. This theory is based on the concept that human working memory can only process 2-3 elements simultaneously.

Moreover, cognitive load consists of three components: intrinsic load, extraneous load, and germane load. Intrinsic load refers to the load inherent in the learning task itself, which is also influenced by the learner's proficiency. Extraneous load is the additional load caused by inappropriate teaching materials or teaching methods and can also arise due to insufficient prior knowledge. Germane load pertains to the load on the problem-solving process itself and contributes beneficially to learning.

There is a study that evaluates the impact of UI design in smartphone learning applications on learners' cognitive load [9]. This study reveals that small screen sizes and overcrowded

information layouts increase cognitive load, thereby reducing learning effectiveness. This suggests that effective UI design can enhance learning outcomes, emphasizing the need for design guidelines tailored to learners' needs. However, this prior research does not utilize eye-tracking data in the evaluation of UI design. Therefore, this study aims to evaluate UI design not only in terms of cognitive load but also by incorporating users' eye-tracking data.

The concept of cognitive load theory can be applied to the analysis of user interface design theories. By examining the cognitive load imposed on users when interacting with different user interface designs, insights can be gained into the effectiveness of design principles in minimizing extraneous load and facilitating intuitive usage. This approach allows for a quantitative evaluation of design theories from a cognitive psychology perspective.

## 2.2 Flow Theory

Flow Theory [10] [11] describes the state of flow as being fully engaged in an activity, losing track of time, feeling enjoyment, and being completely immersed in the task itself. The experience during this state is referred to as a "flow experience" or "optimal experience." Flow Theory systematically summarizes the concept of flow states and flow experiences from a psychological perspective.

Research on flow has been conducted in the field of positive psychology, which aims to enhance individuals' lives and promote societal prosperity by studying strengths and virtues. Various qualitative and quantitative studies have been conducted to explore flow, suggesting that experiencing a flow state, or a flow experience, may play a crucial role in improving motivation and sustaining learning, particularly in education.

Moreover, analyzing flow theory from the perspective of design theory is conceivable by examining the willingness to operate an application and the continuity of using the application, akin to the aspects of motivation and continuity in learning. This suggests the potential for investigating design theories from the standpoint of flow theory.

Applying flow theory to user interface design can provide valuable insights into the user experience. By analyzing factors such as user engagement, enjoyment, and immersion while interacting with an application, designers can assess the effectiveness of their design choices in facilitating flow experiences. This approach enables a deeper understanding of how design principles influence user motivation and continued usage of an application.

## 2.3 The Four Principles of Design

The Four Principles of Design are fundamental theories aimed at organizing design elements and conveying information clearly. These principles consist of four basic theories: the Law of Proximity, the Law of Alignment, the Law of Contrast, and the Law of Repetition.

The Law of Proximity involves grouping related information or elements closer together to facilitate the immediate judgment of their relationship or connection. This design principle aims to enable users to discern the relationship or connection between pieces of information at a glance.

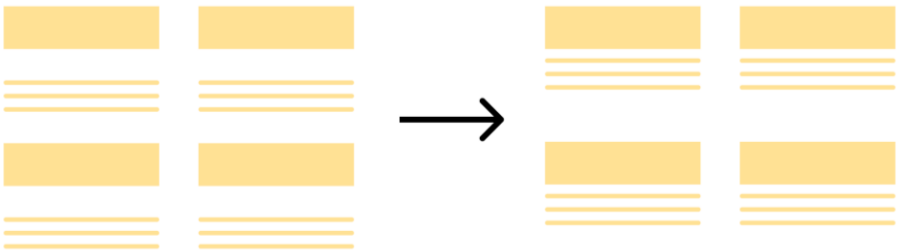

Figure 1: Example of Law of Proximity

The Law of Alignment is a design principle aimed at enhancing visibility by arranging related information or elements according to certain rules. Similar to the Law of Proximity, this design principle also serves the intuitive communication of the relationship or connection between pieces of information or elements.

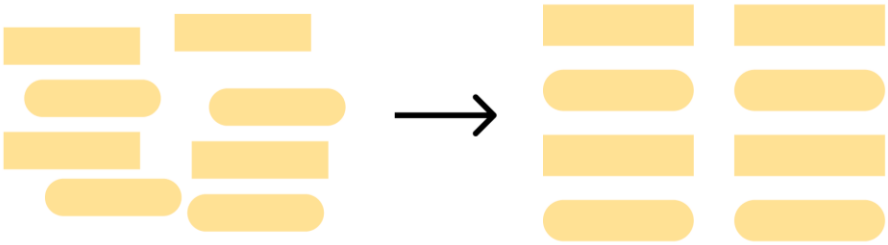

Figure 2: Example of Law of Alignment

The Law of Repetition is a design principle aimed at maintaining consistency throughout the design by repeating the same elements according to certain rules. In the context of user interface design and website design, this principle allows for the unification of the overall image of the service by using consistent theme colors, fonts, icons, and other design elements. Conversely, it is also possible to emphasize specific information or elements by designing them differently from the overall design rules, thereby adding accentuation.

Figure 3: Example of Law of Repetition

The Law of Contrast is a design principle aimed at conveying the priority of information or elements visually by adding contrast in their presentation. Designs that reflect the Law of Proximity, the Law of Alignment, and the Law of Repetition often result in designs with weak contrast, lacking emphasis or hierarchy among the information or elements. Consequently, users may struggle to prioritize which information on the screen to focus on. Therefore, it is necessary to utilize the Law of Contrast to create designs with a sense of emphasis

and hierarchy, while still maintaining the overall flatness achieved through the Law of Proximity, the Law of Alignment, and the Law of Repetition.

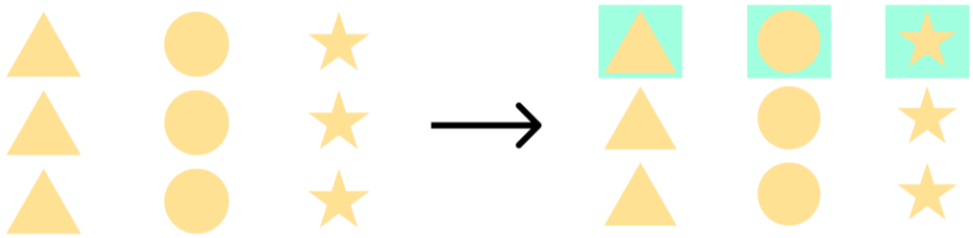

Figure 4: Example of Law of Contrast

The four principles of design, comprising the Law of Proximity, the Law of Alignment, the Law of Contrast, and the Law of Repetition, are widely recognized as the fundamental elements of design in the fields of web design and user interface design. These principles are often introduced as the foundational concepts to learn in various design resources such as websites and books. In the design industry, feedback exists indicating that designs created using these principles result in designs that are easier to comprehend. Consequently, the effectiveness of these principles in user interface design is well acknowledged. The four principles of design have become common knowledge in the contemporary design industry. However, there is limited quantitative analysis and research that explicitly demonstrate the effects of these principles. Therefore, this study aims to quantitatively elucidate the effects of the four principles of design, which are considered common knowledge in the design industry.

By applying the Four Principles of Design, designers can create user interfaces that effectively organize information, enhance visibility, maintain consistency, and establish visual hierarchy. These principles serve as guidelines for making design choices that prioritize usability and intuitive navigation for users. While the effectiveness of these principles is widely acknowledged in the design industry, quantitative research validating their impact on user experience is scarce. This study aims to address this gap by empirically investigating the effects of the Four Principles of Design on user interface usability and user behavior.

## 3 Methods

To investigate the effectiveness of the Four Principles of Design on smartphone app user interface design and to ascertain the utility of eye-tracking data in the analysis of design theories, an experiment will be conducted using mock-ups of smartphone apps. The participants in the experiment will consist of third-year undergraduates, fourth-year undergraduates, and graduate students majoring in information science, totaling 20 individuals. Mock-ups of smartphone apps created using Figma, a browser-based collaboration interface design tool, will be utilized in the experiment, where participants will be tasked with completing a task.

The mock-up used in this experiment will be for an online photography class app. The task assigned to participants will involve purchasing three tickets priced at ¥1,000 each to join the photography class. The 20 participants will be divided into two groups of 10 individuals each for the experiment. One group will be designated as the experimental group and will use mock-ups created in accordance with the Four Principles of Design, while the other group

will serve as the control group and will use mock-ups created not in accordance with the Four Principles of Design but rather from the perspective of mental models, slips, and mistakes. Eye-tracking data will be recorded using eye trackers during the experiment, and the total eye movement for each participant will be calculated post-experiment. Additionally, the operation time and number of clicks on the mock-ups will also be recorded.


Figure 5: Example of mock-up


Figure 6: Example of ticket purchase page (left: experimental group, right: control group)

If the Four Principles of Design have an impact on user interface design, it is expected that the experimental group will exhibit decreased total eye movement, operation time, and number of clicks compared to the control group. Furthermore, based on the operation time and number of clicks, it will be determined whether eye-tracking data can be used to validate design theories. If the operation time and number of clicks are lower in the experimental group compared to the control group, and similarly, if the eye-tracking data in the experimental group is lower, it can be inferred that eye-tracking data functions as an analytical tool for design theory.

After the experiment, a questionnaire consisting of 30 questions will be administered to the participants. The questionnaire will be answered on an 11-point scale (0: not at all applicable - 10: completely applicable) for subjective evaluation. Questions 1 to 5 will pertain to the participants' smartphone usage rates and usage time, while questions 6 to 11 will be based on cognitive load theory, questions 12 to 19 will be based on flow theory, and questions 20 to 30 will be based on mental models.

Table 1: Survey questions

| Number | Question |
|---|---|
| **1** | Do you use a smartphone on a daily basis? |
| **2** | Do you use social media on a daily basis? |
| **3** | Do you use online shopping websites? |
| **4** | How many hours per day do you typically use your smartphone? |
| **5** | Did you feel interested in using this app? |
| **6** | Was the content of this experiment complex? |
| **7** | Did the presented experiment include concepts or knowledge that you found difficult? |
| **8** | Were the instructions provided for the tasks (explanation of the problem statement, etc.) very unclear to you? |
| **9** | Did you find this app inappropriate (difficult to read/see)? |
| **10** | Did you find this app difficult to use? |
| **11** | Did you feel stressed by the design of this app? |
| **12** | Did you find it enjoyable to use? |
| **13** | Were you able to concentrate on using this app? |
| **14** | Was the purpose of "purchasing tickets" clear to you? |
| **15** | Did you find the screen layout and color scheme of the app appropriate? |
| **16** | Did you feel a sense of agency while operating the app? |
| **17** | Was the difficulty level suitable for your skills? |
| **18** | Were you able to operate the app without feeling discomfort? |
| **19** | Did time seem to pass quickly during the experiment? |
| **20** | Were you able to understand the terms displayed in the app? |

| | |
|---|---|
| **21** | Could you understand the content displayed in the app? |
| **22** | Did you understand the state of the app while operating it? |
| **23** | Did you understand what you needed to do to achieve your goals? |
| **24** | Could you anticipate the operating procedures of the app while using it? |
| **25** | Were you able to apply your existing knowledge to operate the app? |
| **26** | Could you understand the functions from the display and UI parts of the app? |
| **27** | Could you anticipate the roles of each part, button, and display while operating the app? |
| **28** | Could you predict the state of the app after operating it? |
| **29** | Could you anticipate the actions the app would take? |
| **30** | Could you operate the app by anticipating its functions? |

The experimental design allows for a comparative analysis of user behavior and subjective experiences between the experimental group, exposed to user interfaces designed according to the Four Principles of Design, and the control group, exposed to user interfaces not adhering to these principles. By measuring eye movement, operation time, and number of clicks, quantitative data will be collected to assess the impact of the design principles on user performance. The post-experiment questionnaire will provide insights into participants' cognitive load, flow experience, and mental model construction, enabling a comprehensive evaluation of the effectiveness of the Four Principles of Design from multiple perspectives.
This methodological approach aims to bridge the gap between industry practices and empirical research by quantitatively validating the effects of widely acknowledged design principles. The combination of eye-tracking data, user performance metrics, and subjective evaluations will contribute to a deeper understanding of how the Four Principles of Design influence user behavior and experience in the context of smartphone app user interfaces. The findings of this study have the potential to provide evidence-based guidelines for designers and researchers in the field of user interface design.

# 4 Results

The experimental results, presented in Figure 7, reveal significant differences between the experimental group and the control group in terms of operation time, total eye movement distance, and number of clicks, as determined by Welch's t-test (two-tailed) at a significance level of $p < .05$. These findings suggest that the effects of the four principles of design on user interface design are substantial. Moreover, the significant differences observed in both operation time and number of clicks indicate that eye movement data can also be used as an analytical tool in design theory.

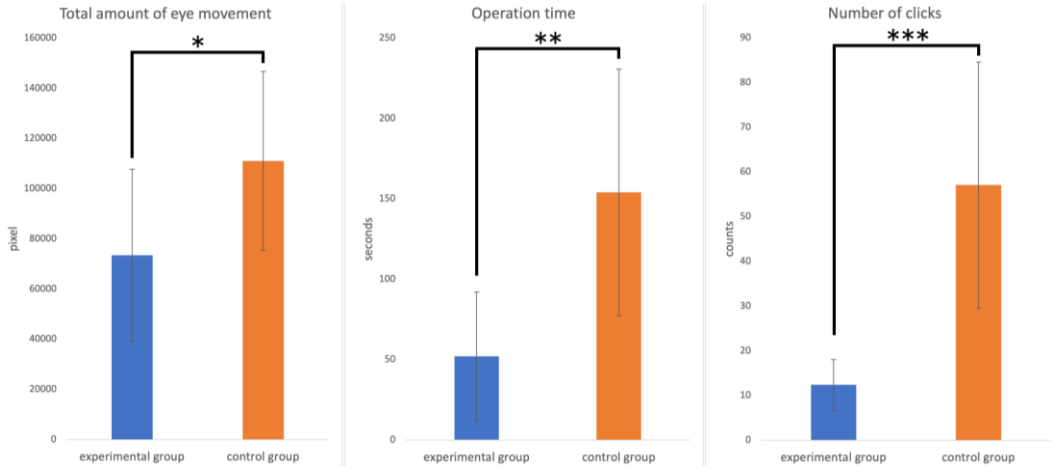


Figure 7: Experimental result

The questionnaire analysis results, shown in Figure 8, are graphically segmented into four categories: task intrinsic load and extraneous load, flow theory, and mental model construction level [13]. Task intrinsic and extraneous loads measure the burden on participants during mockup operation, while flow theory gauges the level of concentration on tasks and enjoyment during mockup manipulation. Additionally, the mental model construction level evaluates the intuitive understanding of the user interface by users while operating the mockup.

The our hypothesis assumed that task intrinsic load should not differ between the experimental and control groups, as it refers to the burden related to the experimental content and task difficulty. In contrast, extraneous load, representing the burden on users' perception and operability of the mockup's user interface, is expected to be lower in the experimental group with designs adhering to the four principles of design compared to the control group. Higher scores for the experimental group in flow theory and mental model construction level would indicate preferable results, signifying higher levels of concentration on tasks, enjoyment during mockup manipulation, and intuitive understanding of the user interface.

The questionnaire analysis, conducted using Welch's t-test (two-tailed) at a significance level of $p < .05$, revealed no significant difference in task intrinsic load between the experimental and control groups. This finding indicates that the task burden was similar for both groups, allowing for a favorable comparison regarding the evaluation of user interface design. However, a significant difference was observed in extraneous load, suggesting that the control group experienced higher perceptual and operational burdens due to factors such as poor visibility and usability of the user interface.

From the perspective of cognitive load theory, the results demonstrate that when both groups performed tasks with the same load level, designs adhering to the four principles of design imposed lower perceptual and operational burdens on users. Furthermore, significant differences were found between the experimental and control groups in terms of flow theory and mental model construction level, indicating that user interface designs based on the four principles of design facilitate user concentration and intuitive operation, aligning with human-centered design principles. The higher mental model construction levels in the experimental group suggest that applying the four principles of design enables the creation of interfaces that allow for intuitive operation, fulfilling the purpose of user interface design.

The experimental results provide empirical evidence supporting the effectiveness of the

Four Principles of Design in enhancing user interface usability and user experience. The significant differences in operation time, eye movement distance, and number of clicks between the experimental and control groups highlight the impact of these design principles on user performance. Moreover, the questionnaire analysis reveals that designs adhering to the Four Principles of Design impose lower cognitive load on users, facilitate flow experiences, and promote the construction of accurate mental models.

These findings contribute to bridging the gap between industry practices and empirical research in the field of user interface design. By quantitatively validating the effects of widely acknowledged design principles, this study provides evidence-based guidelines for designers and researchers. The combination of eye-tracking data, user performance metrics, and subjective evaluations offers a comprehensive understanding of how the Four Principles of Design influence user behavior and experience in the context of smartphone app user interfaces.

The results of this study have practical implications for user interface designers, emphasizing the importance of incorporating the Four Principles of Design - the Law of Proximity, the Law of Alignment, the Law of Contrast, and the Law of Repetition - into their design process. By adhering to these principles, designers can create interfaces that effectively organize information, enhance visibility, maintain consistency, and establish visual hierarchy, ultimately leading to improved usability and user satisfaction.

Furthermore, the findings highlight the potential of eye-tracking data as an analytical tool in design theory. The significant differences observed in eye movement data between the experimental and control groups suggest that eye-tracking can provide valuable insights into user attention and cognitive processes while interacting with user interfaces. This opens up new avenues for research and evaluation in the field of user interface design, enabling designers and researchers to gain a deeper understanding of user behavior and optimize their designs accordingly.

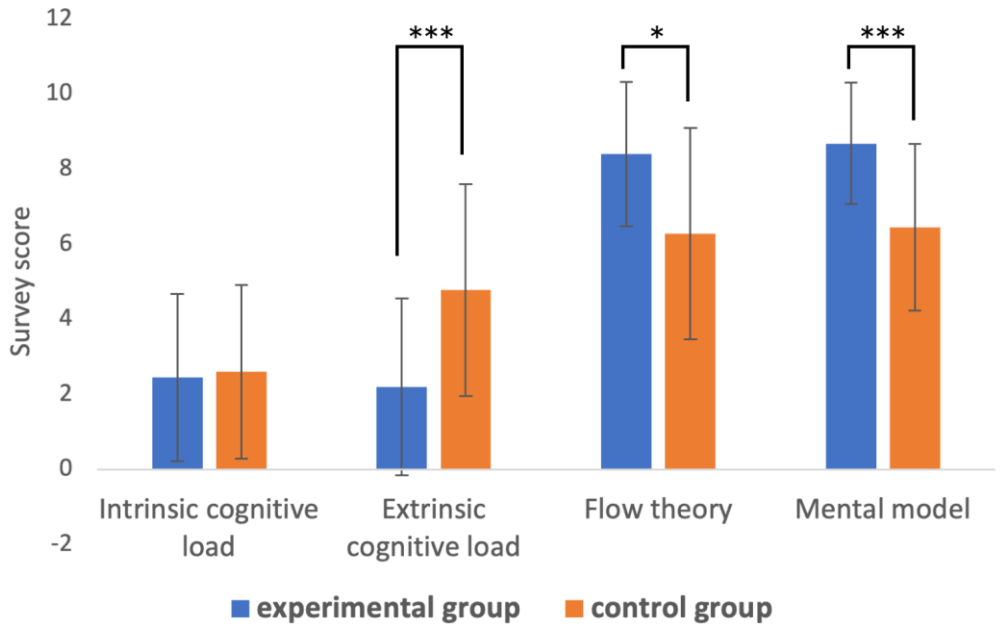


Figure 8: Survey result

# 5 Conclusion

This study demonstrated the utility of using eye-tracking data for validating user interface design theories and scientifically elucidates the effectiveness of the Four Principles of Design. Through an experimental design involving mockups of an online photography class app, the study compared user performance and subjective experiences between an experimental group exposed to user interfaces designed according to the Four Principles of Design and a control group exposed to user interfaces not adhering to these principles.

The experimental results revealed significant differences in operation time, total eye movement distance, and number of clicks between the two groups, providing evidence for the impact of the Four Principles of Design on user interface usability. Furthermore, the questionnaire analysis, based on cognitive load theory, flow theory, and mental model construction level, offers insights into the subjective experiences of participants. The findings indicate that designs adhering to the Four Principles of Design impose lower cognitive load on users, facilitate flow experiences, and promote the construction of accurate mental models.

This study will contribute to bridging the gap between industry practices and empirical research in the field of user interface design by quantitatively validating the effects of widely acknowledged design principles. The combination of eye-tracking data, user performance metrics, and subjective evaluations provides a comprehensive understanding of how the Four Principles of Design influence user behavior and experience in the context of smartphone app user interfaces.

The findings have practical implications for user interface designers, emphasizing the importance of incorporating the Four Principles of Design into their design process to create interfaces that effectively organize information, enhance visibility, maintain consistency, and establish visual hierarchy. Moreover, the study highlights the potential of eye-tracking data as an analytical tool in design theory, opening up new avenues for research and evaluation in the field of user interface design.

Future research could explore the generalizability of these findings across different types of user interfaces and user populations. Additionally, further investigations could delve into the specific mechanisms through which each of the Four Principles of Design influences user behavior and cognitive processes, providing a more granular understanding of their effects.

# Acknowledgement

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