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RESEARCH ARTICLE / ARAŞTIRMA YAZISI

The Relationship Between Social Media Addiction and Psychological Distress: A Meta-Analytic Study

Sosyal Medya Bağımlılığı ve Psikolojik Sıkıntı Arasındaki İlişki: Meta-Analitik Bir Çalışma

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Abstract:

In recent years, the widespread integration of social media use into nearly every aspect of daily life has made it necessary to evaluate the connections between addictive behaviors and mental health indicators within a comprehensive, quantitative, and evidence-based framework. This necessity highlights the meta-analytic approach, which combines findings obtained from different samples to provide a more reliable estimate of effect size. This study aims to examine the relationship between social media addiction and psychological distress using a meta-analytical approach. To this end, a literature review was conducted across the Web of Science, Scopus, and Google Scholar databases, covering the period from January 2020 to 2025. Based on the inclusion criteria, 28 studies with a total sample size of 26,671 were included in the meta-analysis process. Data analysis was performed using Jamovi 2.6.23, an open-source and free software. An examination of the descriptive characteristics of the included studies revealed that 35.7% of the publications were published in 2024, 21.4% were conducted in China, and 60.7% were indexed in SSCI. According to the random-effects model, a moderate effect (r = 0.382) was found between social media addiction and psychological distress within a 95% confidence interval. In other words, higher levels of social media addiction were associated with increased levels of psychological distress, including symptoms of depression, anxiety, and stress. Therefore, the findings of this study highlight the importance of preventive interventions and awareness programs at both individual and societal levels to protect the mental health of social media users.

Keywords: Social Networking Sites, Addictive Behavior, Depression, Stress, Anxiety.

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Öz:

Son yıllarda sosyal medya kullanımının gündelik yaşamın hemen her alanına yayılması, bağımlılık davranışları ile ruh sağlığı göstergeleri arasındaki bağlantıların nicel ve kanıta dayalı bir çerçevede bütüncül olarak değerlendirilmesini gerekli kılmaktadır. Bu gereksinim, farklı örneklemlerden elde edilen bulguların bir araya getirilmesiyle daha güvenilir bir etki büyüklüğü sunan meta-analiz yaklaşımını öne çıkarmaktadır. Bu çalışmada sosyal medya bağımlılığı ve psikolojik sıkıntı arasındaki ilişkinin meta-analitik bir yaklaşımla incelenmesi amaçlanmıştır. Bu amaç doğrultusunda Web of Science, Scopus ve Google Scholar veri tabanlarında Ocak 2020-2025 tarihlerini kapsayan bir literatür taraması gerçekleştirilmiştir. Buradan hareketle, dâhil edilme kriterlerine uyan ve toplam örneklem büyüklüğünün 26.671 olan 28 çalışma meta-analiz sürecinde değerlendirilmeye uygun bulunmuştur. Verilerin analizinde açık kaynak kodlu ve ücretsiz bir yazılım olan Jamovi 2.6.23 programı kullanılmıştır. Çalışmanın tanımlayıcı özellikleri incelendiğinde, yayınların %35,7'sinin 2024 yılına ait olduğu, %21,4'ünün Çin'de gerçekleştirildiği, %60,7'sinin SSCI indeksli olduğu belirlenmiştir. Rastsal etkiler modeline göre %95 güven aralığında, sosyal medya bağımlılığı ile psikolojik sıkıntı arasında orta düzeyde (r: 0,382) bir etkinin mevcut olduğu saptanmıştır. Bir diğer ifadeyle, sosyal medya kullanıcılarının bağımlılık düzeyleri arttıkça depresyon, anksiyete ve stres temelli psikolojik sıkıntı düzeylerinin de arttığı anlaşılmıştır. Dolayısıyla bu çalışmanın bulguları, sosyal medya kullanıcılarının ruh sağlığını korumaya yönelik bireysel ve toplumsal düzeyde önleyici müdahalelerin ve bilinçlendirme çalışmalarının önemini vurgulamaktadır.

Anahtar Kelimeler: Sosyal ağ siteleri, Bağımlılık davranışı, Depresyon, Stres, Anksiyete.

Introduction

The increasing use of social media daily has become an integral part of individuals' daily lives (Yang et al., 2025; Taşkıran, 2025). By April 2024, there are over five billion social media users worldwide (Statista, 2024). Similar to global trends, Turkey also shows a similar increase in the use of social media platforms. According to the Ministry of Transport and Infrastructure of the Republic of Turkey (2024), approximately 66% of the Turkish population uses social media, resulting in 303 million active social media accounts across various platforms. This report indicates that the average Turkish citizen spends 2 hours and 37 minutes on social media and 6 hours and 51 minutes on the internet daily. Globally, Facebook leads with 3.07 billion users, while TikTok is reported as the most time-consuming platform, with 34 hours and 15 minutes (Ministry of Transport and Infrastructure of the Republic of Turkey, 03.02.2025). These rapidly growing numbers signal a concerning possibility that social media may lead to addiction over time. The increasing prevalence of social media addiction gains deeper significance when interpreted through psychological addiction theories. According to the Behavioral Addiction Theory, addiction is not merely a physical need but is also associated with cognitive and emotional processes (Griffiths, 1996). Similarly, within the framework of Self-Regulation Theory, the weakening of individuals' ability to regulate and control their social media use may increase the risk of addiction (Hagger et al., 2010). Problem Behavior Theory provides an important framework for understanding the negative consequences of social media use. Moreover, this theory is particularly valuable in explaining the relationship between addiction and psychological distress among adolescents (Jessor, 1991).

Addiction, which refers to the loss of control, has become a more widely discussed issue with the excessive use of social media platforms (Karakuş et al., 2024). Social media addiction, regarded as a subcategory of internet addiction, refers to the uncontrolled and compulsive use of social platforms (Kuss & Griffiths, 2011). It is defined as an excessive preoccupation with networks such as Instagram, Facebook, TikTok, Snapchat, and X, often involving repeated checking for likes, comments, and friend requests (Al-Samarraie et al., 2022). In summary, this concept is characterized by the excessive use of social media to a degree that negatively affects individuals' psychological well-being.

With the widespread adoption of the internet and smartphones, various issues related to the use of social media platforms have emerged. Social media addiction, defined as a psychological condition, is marked by an unhealthy dependence on social media platforms and may evolve into symptoms characteristic of behavioral addiction (Feng et al., 2025). For example, a study (Yang et al., 2025) conducted in China examining the relationship between excessive social media use and psychological distress found that the most central symptoms in the comorbidity network were panic, anxiety, agitation, stress, downheartedness, and depression.

A meta-analysis conducted by Marino et al. (2018) found a moderate (r = 0.340) and positive relationship between problematic Facebook use and psychological distress, while a low (r = -0.220) and negative relationship was observed with psychological well-being. The findings of Sepas et al. (2024) reported a moderate and positive relationship between problematic Instagram use and depression (r = 0.350) as well as anxiety (r = 0.310), whereas a low and negative relationship was found with psychological well-being (r = -0.170). The results of Shannon et al. (2022) indicated moderate and positive relationships between problematic social media use and depression, anxiety, and stress.

A meta-analysis conducted by Gao and Du (2025), covering the years 2012–2024, reported an effect size of 0.340 for the relationship between digital addiction and rumination (the tendency to dwell on negative thoughts continuously). In other words, the study findings revealed a moderate, positive, and significant relationship between these variables. Similarly, the results of Zewude et al. (2025) indicated that internet and social media addiction have a direct negative impact on young people's mental health.

In a study conducted with 369 participants to identify the key predictors of social media addiction (Liao et al., 2025), it was found that dark personality traits such as Machiavellianism, narcissism, and FoMO (Fear of Missing Out) are associated with social media addiction. Similarly, a study conducted in Turkey (Kaya, 2024) reported that as individuals' levels of social media addiction increased, so did their levels of narcissism, Machiavellianism, and psychopathy. Based on a review of the existing literature, the psychological variables most frequently associated with social media addiction include psychological distress (depression, anxiety, stress), psychological well-being, insomnia, rumination, life satisfaction, self-esteem, nomophobia, FoMO, narcissism, Machiavellianism, and psychopathy. This study aims to examine the relationship between social media addiction and psychological distress using a meta-analytic approach.

Although previous meta-analyses have investigated the relationship between social media addiction and psychological distress, many of these studies are limited by conceptual ambiguities and methodological heterogeneity. The present study aims to address these gaps on two levels. First, social media addiction is conceptualized not merely as a digital habit but as a psychological issue within the framework of behavioral addiction theories; accordingly, only studies employing psychometrically validated measurement tools were included. This approach enhances conceptual consistency and strengthens the theoretical framework. Second, the analysis was restricted to peer-reviewed journal articles indexed in international databases that met specific statistical and measurement criteria, while grey literature such as theses, conference proceedings, and reports was excluded. This methodological choice improves sample quality and strengthens the reliability of the findings. In sum, the study provides a comprehensive contribution to the literature by offering both theoretical depth and methodological rigor in examining the relationship between social media addiction and psychological distress.

Materials and Methods

Study Design
This study, using a meta-analytic approach, examined the direction and significance of the relationship between social media addiction and psychological distress. "Meta-analysis" refers to a set of statistical techniques that integrate findings from numerous publications to offer a comprehensive overview of a research topic (Paul and Barari, 2022). By calculating a weighted average of results from different studies, meta-analysis helps achieve statistically robust conclusions and clarifies inconsistencies across research findings (Gök and Yılmaz Koğar, 2021).

Literature Review

A literature search was conducted using the Web of Science, Scopus, and Google Scholar databases to identify studies investigating the relationships between social media addiction and psychological distress. The search covered publications from January 2020 to January 2025. During the search process, keywords related to social media addiction (excessive social media use, problematic social media use, addictive social media use, fear of missing out*, nomophobia*) and psychological distress (stress, anxiety, depression, mental health, negative emotion, emotional disturbance, psychological well-being, psychological burden) were combined using the AND operator. In this study, the terms "social media addiction" and "psychological distress" were intentionally selected as primary keywords, because they are among the most widely used concepts in the literature and they conceptually align with the measurement tools employed (BSMAS and DASS-21). The use of wildcard characters in terms such as "fear of missing out*" and "nomophobia*" was intended to capture various lexical forms of these concepts. For example, the term "fear of missing out*" enabled the inclusion of variations such as "fear of missing out," "fear of missing out-based anxiety," and "fear of missing out-related behaviors" in the search process. Similarly, the keyword "nomophobia*" allowed the retrieval of related expressions like "nomophobia-related distress," "nomophobia symptoms," and "nomophobia scale." This technical approach was employed to encompass the lexical diversity of relevant terms in the literature and to minimize the risk of omitting eligible studies during the search process. To maximize the comprehensiveness of the search, the reference lists of the identified publications were also manually reviewed. The study applied nine inclusion criteria, with their opposites serving as exclusion criteria. The inclusion criteria of the study are as follows:

i) Sufficient statistical data reported to calculate the correlation between social media addiction and psychological distress variables (the r value, representing the Pearson correlation coefficient, must be specified).

ii) The sample size must be reported to calculate the weighted average effect size of the variables.

iii) The "Bergen Social Media Addiction" scale must be used to measure social media addiction.

iv) The "Depression, Anxiety and Stress Scale (DASS-21)" must be used to measure psychological distress.

v) The DASS-21 scale must report the overall average, not the subscales (depression, anxiety, stress).

vi) The publication must be in the form of a research article.

vii) The publication must be from January 2020 to 2025.

viii) The publication must be in English.

ix) The publication must be published in a journal indexed by SCI, SSCI, SCI-E, ESCI, or Scopus.

After conducting the search, 255 studies related to the topic were identified, but 227 of them were excluded from the study. It was determined that 82 of the excluded studies were duplicates, 54 did not contain the statistical data required for meta-analysis, 33 used tests other than correlation analysis, 26 evaluated only the subscales of the DASS-21 without assessing its overall dimension, seven were written in languages other than English, and 25 were not research articles. Based on this, 28 studies meeting the inclusion criteria were found suitable for inclusion in the meta-analysis process (Figure 1). This study adhered to the PRISMA guidelines.

In social sciences, skewness and kurtosis values are used to assess the normality of data distribution. Therefore, in this study, the skewness and kurtosis values have been examined. To indicate the normality of the distribution, certain cutoff points for the skewness and kurtosis coefficients are provided in the literature. If the distribution is normal, the skewness and kurtosis coefficients should fall within the range of -2 to +2 (George & Mallery, 2010). Therefore, based on the skewness and kurtosis values, it is assumed that the data of the study follow a normal distribution, and parametric tests have been used in the analyses.
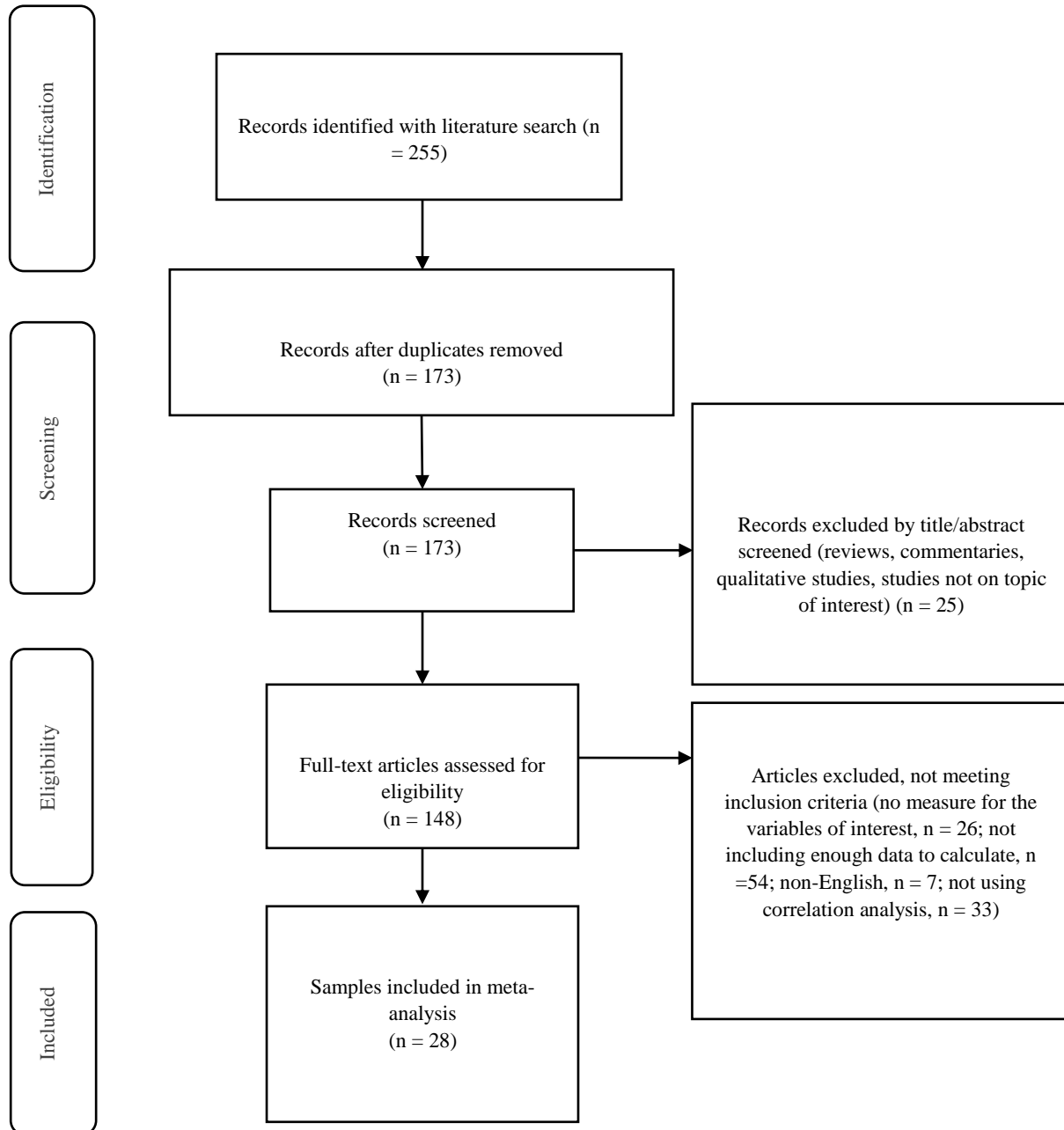

Figure 1. *Flow Diagram of Study Inclusion*

The titles, abstracts, and full texts of the relevant publications were independently reviewed by the authors. The inter-rater reliability, assessed using Cohen's Kappa coefficient, was calculated as 0.87. In line with the classification proposed by Landis and Koch (1977), this value indicates a high level of agreement, commonly interpreted as almost perfect concordance.

Data Analysis
The data analysis was performed using Jamovi 2.6.23, an open-source and free software (https://www.jamovi.org, 15.01.2025). For each study included in the meta-analysis, the author, year, correlation coefficient, and sample size were entered into the program or introduced, allowing the automatic calculation of the correlation's lower and upper bounds, as well as the z and p values for each study. In this analysis, correlation coefficients are used instead of effect size, and the Fisher z transformation is applied to convert these values back into correlations (Huang, 2022). This is because the Fisher z method is known to provide accurate estimations and present the level of statistical significance through the p-value. The implementation process of Fisher's z transformation, along with a comparison of values before and after the transformation, is presented below. This transformation was applied to ensure that the

correlation coefficients approximate a normal distribution and can be appropriately combined using weighted averages in the context of meta-analysis.

$$z = \frac{1}{2} \ln \left(\frac{1+r}{1-r} \right)$$

According to the classification proposed by literature, correlation coefficients can be interpreted in terms of effect size based on specific intervals. Accordingly, correlations between 0.10 and 0.29 are considered small, those between 0.30 and 0.49 are considered medium, and those of 0.50 and above are considered large effect sizes.

In addition to the 95% confidence interval, a prediction interval was calculated to estimate the potential range of effect sizes in future studies. Based on the random-effects model, the 95% prediction interval was found to be [0.226, 0.538], indicating that the relationship between social media addiction and psychological distress may vary within this range in different samples. The fact that the prediction interval is wider than the confidence interval reflects the high level of heterogeneity among the included studies ($I^2 = 82.42\%$). This suggests that the findings of the current study may vary across different contexts.

Results

Before proceeding with the meta-analysis process, the descriptive characteristics of the publications were first examined. The total sample size of the 28 publications included in the meta-analysis was calculated to be 26,671. It was found that 35.7% of the publications were published in 2024, 21.4% were conducted in China, and 60.7% were indexed in SSCI (Table 1).

Table 1. *Descriptive Features of the Publications.*

Year	f	%	Country	f	%	Index	f	%
2020	1	3.6	China	6	21.4	SSCI	17	60.7
2021	2	7.1	İtaly	4	14.3	SCI-E	4	14.3
2022	5	17.9	Germany	4	14.3	Scopus	7	25.0
2023	9	32.1	Türkiye	3	**10.7**	**Total Publication**	**28**	**100.0**
2024	10	35.7	Iran	2	**7.1**	**Total Sample Number**		**26.671**
2025	1	3.6	Others	9	**32.1**			

In the meta-analysis process, the initial step involves assessing heterogeneity among studies. The "fixed-effects model" requires effect sizes to be consistent across studies, whereas the "random-effects model" applies when effect sizes vary significantly. A commonly used criterion for detecting heterogeneity is that if the Q statistic has a significance level of $p < 0.05$ and the I^2 value exceeds 70%, substantial heterogeneity is indicated. Based on the Q(p) and I^2 values reported in Table 2, the results suggest an elevated degree of heterogeneity among the variables. Consequently, this study employed the "random-effects model" using the "DerSimonian-Laird approach".

Table 2. *Heterogeneity Statistics.*

Tau	Tau²	I²	H²	df	Q	p
0.074	0.0055 (SE= 0.0027)	82.42%	5.689	27.000	153.603	<.001

Upon reviewing the random-effects model presented in Table 3, a moderate effect (r = 0.382) between social media addiction and psychological distress variables is observed (Fisher's *z* transformation = 0.402). The 95% confidence interval for the random-effects model was found to range from 0.350 to 0.413.

Table 3. *Random-Effects Model (k = 28).*

	Estimate	se	Z	p	CI Lower Bound	CI Upper Bound
Intercept	0.382	0.0162	23.6	<.001	0.350	0.413

Tau² Estimator: DerSimonian-Laird

The Forest Plot for each study included in the meta-analysis is presented in Figure 2.
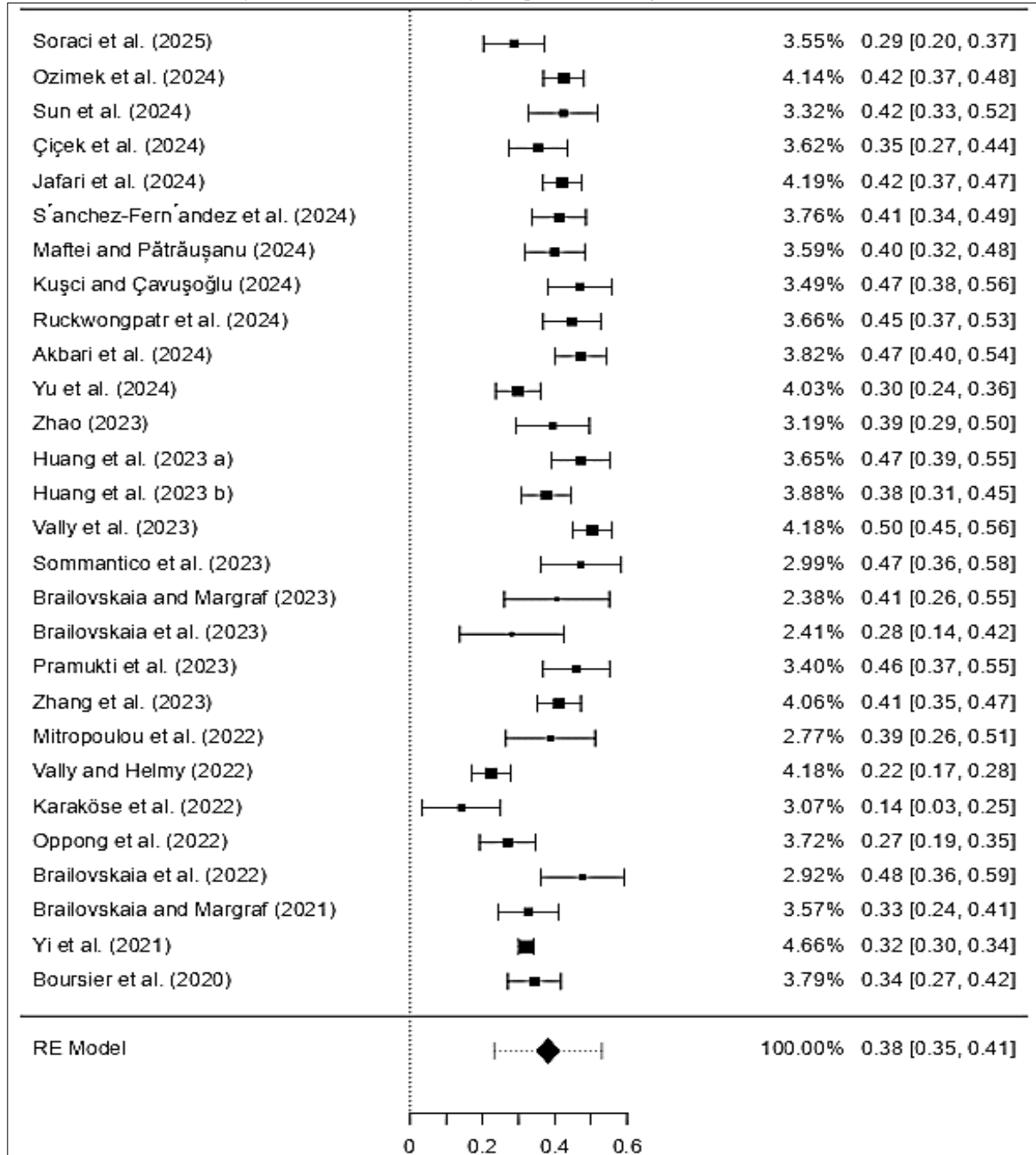

Figure 2. *Forest Plot of the Studies Included in the Meta-Analysis (k = 28)*

After determining the heterogeneity and the effect size between the variables, the next aspect to be examined is the presence of publication bias. One of the most commonly used methods for examining publication bias in meta-analysis studies is the Funnel Plot. However, upon reviewing the existing literature, it is noted that while asymmetry in the Funnel Plot may suggest the presence of publication bias, it is emphasized that this is only one of the potential causes (Lau et al., 2006). As shown in the Funnel Plot in Figure 3, most studies are clustered in the upper region and closely align with the pooled effect size, indicating a symmetrical distribution. This suggests that there is no publication bias in the studies included in the meta-analysis. However, additional scientific evidence is required to detect publication bias definitively
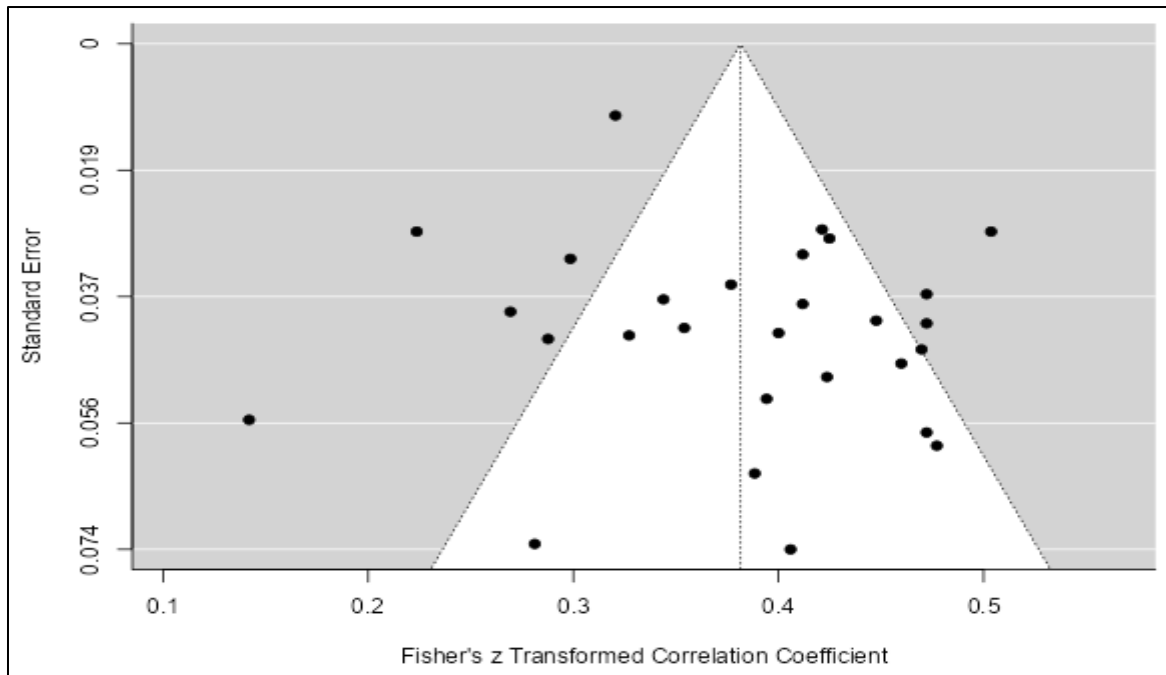
Figure 3. *The Funnel Plot for Publication Bias*

In addition to the Funnel Plot, four different bias detection methods were employed in this study. Rosenthal (1979) introduced a method to evaluate the reliability of meta-analysis results and identify any potential publication bias. According to this method, if a certain ratio involving the number of studies included in the meta-analysis and other parameters exceeds a specified threshold, the results are considered robust, and the likelihood of publication bias is minimal. In addition to this approach, another commonly used method for detecting publication bias is the rank correlation test by Begg and Mazumdar (1994), which involves calculating the two-tailed p-value using Kendall's test. If the p-value is greater than 0.05, it indicates that publication bias is unlikely. Another parameter for determining the presence or absence of publication bias is the results of Egger's Regression Test. If the p-value is greater than 0.05 in this test, it confirms the lack of publication bias. An alternative method for evaluating publication bias is the trim and fill procedure developed by Duval and Tweedie. This test suggests that, in the absence of publication bias, there should be no significant difference between the observed and expected values. This means that there is no missing data on either side of the center line of the funnel plot; in other words, there is no publication bias. An analysis of Table 4 reveals that the outcomes from all five methods consistently show the absence of publication bias in the studies.

Table 4. *Publication Bias Assessment.*

Test Name	Value	p	Final Situation
Fail-Safe N	30.236.000	<.001	No bias
Begg and Mazumdar Rank Correlation	-0.066	0.621	No bias
Egger's Regression	0.177	0.860	No bias
Trim and Fill Number of Studies		.	
↳ Observed Number of Significant Findings (28)			
↳ Expected Number of Significant Findings (28)	4.000		No bias
↳ Observed Number / Expected Number (1)			

Not. Fail-Safe N Calculation Using the Rosenthal Approach

Discussion

This study, which examines the international relationship between social media addiction and psychological distress, included and evaluated 28 publications with a cumulative sample size of 26,671 individuals. The results indicated that over one-third of the publications were published in 2024, more than one-fifth were conducted in China, and over half were published in SSCI-indexed journals. The results of the meta-analysis, also known as an analysis of analyses, revealed a moderate positive and significant relationship between social media addiction and psychological distress (r = 0.382). Additionally, the absence of publication bias between the variables was confirmed by four different methods, in addition to the Funnel Plot.

A review of the literature revealed publications consistent with our study findings. For example, meta-analyses conducted by Marino et al. (2018) and Huang (2022) reported moderate relationships between problematic social media use and psychological distress. The results of Sepas et al. (2024) also confirmed a moderate relationship between problematic Instagram use and depression (r = 0.350) and anxiety (r = 0.310). Similarly, the findings of Shannon et al. (2022) revealed moderate, significant relationships between problematic social media use and depression (r = 0.273), anxiety (r = 0.348), and stress (r = 0.313).

The relationship between social media addiction and psychological distress can be interpreted within the framework of various psychological processes and theoretical approaches. Self-regulation theory emphasizes individuals' ability to control their behavior in pursuit of goals. Social media platforms, through constant notifications and infinite scrolling features, may disrupt individuals' attention and challenge their self-regulation capacity, which can lead to increased psychological distress (Baumeister & Vohs, 2007). Social comparison theory posits that individuals evaluate themselves by comparing themselves with others. On social media, users are often exposed to idealized portrayals of others' lives, which may lead to feelings of inadequacy. Such upward comparisons can evoke negative emotions such as envy and low self-esteem, thereby exacerbating psychological distress (Festinger, 1954; Vogel et al., 2014). Cognitive load theory suggests that individuals have a limited capacity for processing information, and excessive information input can lead to cognitive overload. The constant flow of content and multitasking on social media may deplete cognitive resources and increase mental fatigue and stress levels (Sweller, 1988). These theoretical frameworks provide meaningful insights into the mechanisms underlying the link between social media addiction and psychological distress. Future studies could develop intervention strategies based on these theories to help individuals manage their social media use more healthily.

In summary, our study's findings demonstrate a high degree of parallelism with the results of international studies employing the same methodology. On the other hand, a key aspect highlighting the originality and strength of our research, unlike other studies, is its specific focus on investigations utilizing solely the 'Bergen Social Media Addiction Scale' and the 'DASS-21'. This is due to the widespread use of these scales in relevant research, as well as their established validity and reliability. Consequently, it can be asserted that the findings of our study hold the potential for citation in both national and international scholarly literature.

The finding that social media addiction is moderately associated with psychological distress aligns with previous meta-analyses and individual studies in similar domains. One possible reason for this consistency is the widespread use of similar self-report measures across studies, such as the Social Media Addiction Scale and the Depression, Anxiety, Stress Scales (DASS). Moreover, most of the included studies focused on adolescent and young adult samples, which represent age groups that are particularly sensitive to the psychological impacts of social media. Therefore, due to the concentration on specific age groups and countries, the demographic limitations of the sample should be taken into consideration. The inclusion of only English-language publications may also restrict the generalizability of the findings in terms of cultural diversity. Additionally, some of the variations in effect sizes may stem from methodological differences, such as the use of cross-sectional versus longitudinal designs, or from cultural contexts where norms regarding social media use and mental health stigma vary. These contextual factors may be among the primary sources of heterogeneity in the reported results, suggesting that context-specific variables could moderate the observed relationship. However, given that this study primarily relies on correlational findings, it is methodologically inappropriate to infer causality. Therefore, future research is recommended to employ experimental and longitudinal designs.

Notwithstanding these strengths, our study also presents certain limitations. Specifically, the DASS-21 scale was evaluated based on the overall scale average, rather than the subscales of depression, anxiety, and stress. Within the scope of this study, subgroup analyses were not conducted due to the distribution of the available sample and the general model under investigation. Furthermore, the exclusion of publications indexed in international databases other than SCI, SSCI, or Scopus, as well as the exclusion of grey literature, can be considered another limitation.

Recommendations
Based on the findings of the study, it is recommended that awareness programs be increased for the conscious management of social media use, psycho-social support services strengthened, and digital literacy education promoted. Academically, more comprehensive meta-analyses could be conducted by including various addiction scales and psychological distress scales. Longitudinal studies examining the long-term effects of these findings and evaluating the effectiveness of intervention programs would be important. Moreover, including moderator variables such as country, age group, and social media platform in the analysis could allow for a better understanding of the relationship between social media addiction and psychological distress within the framework of contextual factors.

In summary, it is recommended that awareness programs be developed specifically for different age groups to promote the conscious and balanced use of social media. For instance, educational content focusing on coping with online risks and digital social pressure can be provided for adolescents. At the same time, programs targeting adult users may emphasize attention management, digital minimalism, and strategies for dealing with information overload. Differentiating digital literacy training based on age, education level, and the platforms used would enhance the effectiveness of such interventions. In addition to individual counseling-based psychosocial support services, expanding group-based intervention programs is also advised. From an academic perspective, there is a need for meta-analytical studies that incorporate various addiction and psychological distress scales to better understand this relationship in a comprehensive manner. Lastly, including contextual variables such as age group, gender, social media platform, and country as moderators in the analysis could help identify under which conditions the relationship between social media addiction and psychological distress becomes stronger or weaker, thereby contributing to the development of context-specific preventive strategies.

Declarations

Ethics Committee Approval
This study was conducted in accordance with general ethical guidelines in psychology. No data were collected from human participants; no original data were produced or analyzed as part of the study. Therefore, ethical committee approval was not required for this study.

Consent for Publication
Not applicable

Availability of Data and Materials
Not applicable

Competing Interests
The author declares that no competing interests in this manuscript.

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Not applicable.

Authors' Contributions
HKH and HG proposed the main idea of the research, while HKH and HG were involved in reviewing and discussing the literature. HKH and HG contributed to drafting the article and revising its content. All authors have reviewed and approved the final version of the article.

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