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# Science-Based Mobile Apps for Reducing Anxiety: A Systematic Review and Meta-Analysis

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## ABSTRACT

This systematic review and meta-analysis examines the effectiveness of science-based mobile apps for reducing anxiety. A systematic review was employed to identify experimental studies on science-based mobile applications developed anxiety disorders. International databases such as PubMed, Web of Science, SCOPUS and ProQuest were searched to locate relevant articles. After the systematic review, 16 ( $k=20$ ) experimental studies on the effectiveness of science-based mobile apps for reducing anxiety that met the inclusion criteria were included in the meta-analysis study. The analysis findings concluded that science-based mobile apps have a noteworthy impact on reducing anxiety symptoms. Additionally, the moderator analysis indicated that various factors, including participant characteristics (such as gender and age), methodological factors (such as the measurement tool for anxiety and type of control group) and the intervention duration, play a crucial role in this impact. These findings suggest that science-based mobile apps can provide a helpful tool for individuals seeking to manage their anxiety symptoms and that a range of therapeutic techniques, such as mindfulness, cognitive restructuring and psychoeducation, can be effectively employed in these apps.

## 1 | Introduction

Anxiety is a complex physiological, cognitive, behavioural and emotional response system that is activated when events or conditions are perceived as potentially threatening, unpredictable or uncontrollable (Barlow 2002; Clark and Beck 2010). Prolonged and intense feelings of fear and distress characterize it, often accompanied by physiological symptoms such as increased heart rate, shortness of breath, nausea, sweating and tense muscles (Baxter et al. 2014; Clark and Beck 2010). In anxiety disorders, individuals frequently experience hyperarousal, excessive worry,

dysfunctional cognitions, impaired functioning and hypersensitivity to stimuli (Baxter et al. 2014; Clark and Beck 2010; Remes et al. 2016). The spectrum ranges from generalized anxiety disorders and panic disorders to various phobic disorders (Andlin-Sobocki and Wittchen 2005; Szuhany and Simon 2022). The current conceptualization of its aetiology involves the interaction of a genetic vulnerability with psychosocial factors such as childhood stressful events (Thibaut 2017). Anxiety disorders, which are chronic and highly prevalent mental health problems typically begin in childhood and youth, are characterized by an intermittent course of illness (Baxter et al. 2014; Tiller 2013).

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## Summary

- Science-based mobile apps have a significant impact on reducing anxiety symptoms.
- Participants' characteristics influence the effectiveness of these apps.
- Methodological factors play a crucial role in determining how effective science-based mobile apps are.
- The duration of the intervention also plays an important role in reducing anxiety symptoms.

Millions of people worldwide struggle with anxiety and its symptoms, which develop in the context of the changing pressures, demands, and stresses of daily life (Clark and Beck 2010). Anxiety disorders are one of the mental disorders with the highest lifetime prevalence (Bandelow, Michaelis, and Wedekind 2017). According to a study by Szuhany and Simon (2022), it was discovered that anxiety disorders have a lifetime prevalence of around 34%. Among these disorders, generalized anxiety disorder has a lifetime prevalence of 6.2%, social anxiety disorder has a prevalence of 13%, and panic disorder has a prevalence of 5.2%. Additionally, anxiety disorders, which are associated with high disease burden and health care costs (Bandelow, Michaelis, and Wedekind 2017), have individual and social costs such as increased health expenditures, impaired functionality and reduced lifetime (Kessler et al. 2009). In individuals with anxiety disorders, the rates of chronic unemployment and related financial dependence, emotional problems and substance use are quite high (Leon, Portera, and Weissman 1995; Michael, Zetsche, and Margraf 2007); it has been determined that increased anxiety prevents the ability to adapt to daily tasks such as work or social relationships (Hartley and Phelps 2012).

Pharmacotherapy and psychotherapy, especially cognitive behavioural therapy (CBT), are interventions with proven effectiveness in the treatment of anxiety disorders (Andlin-Sobocki and Wittchen 2005; Bandelow and Michaelis 2015; Bandelow, Michaelis, and Wedekind 2017; Tiller 2013). Bandelow and Michaelis's (2015) meta-analysis study indicates that combining psychotherapy with pharmacotherapy has a relatively high effect size. Tiller (2013) emphasizes the importance of psychological interventions for sustainable positive outcomes. However, there is also proof that anxiety disorders are significantly under-treated (Bandelow, Michaelis, and Wedekind 2017; Tiller 2013; WHO World Mental Health Survey Consortium 2004). Specifically, only 20.6% of individuals with anxiety disorders seek professional help (Bandelow, Michaelis, and Wedekind 2017), and just 8% of them are actually receiving the adequate treatment (Goodwin et al. 2005). Therefore, although effective treatments for anxiety disorders are available, many people do not apply to health services for treatment or do not benefit from these services sufficiently (Bandelow and Michaelis 2015). Uncertainty about where to turn for help and financial restrictions (Olsson et al. 2000), lack of recognition of symptoms in primary care (Tiller 2013) and feelings of shame or embarrassment due to mental disorders (Patel et al. 2002) are effective in delaying treatment. Therefore, there is a treatment gap due to inadequate treatment of individuals with anxiety disorders (Tiller 2013). Considering the chronic nature, high persistence and high

prevalence of innovative treatment approaches are needed to reduce this treatment gap in mental health services (Dworschak, Heim, and Maercker 2022; Kazdin and Blase 2011).

E-mental health services refer to 'mental health services delivered or developed through the internet and related technologies' (Christensen, Griffiths, and Evans 2002, 3). These services, also called 'Internet-based interventions', include various types of interventions (Dworschak, Heim, and Maercker 2022). These interventions provide users with access to treatment without time or location constraints, reduce the time and financial burden on them and mitigate the impact of social stigma (Bekker, Griffiths, and Barrett 2017; Wang, Zhang, and An 2023). These interventions, particularly mobile applications ('apps') developed for use of easily portable wireless devices such as smartphones and tablets, therefore have the potential to minimize the limitations of traditional treatments and significantly increase access to mental health services (Dworschak, Heim, and Maercker 2022; Kertz et al. 2017; Sucala et al. 2017). These self-help apps refer to various psychological treatment protocols in which users interact autonomously or independently with therapeutic programs delivered via a mobile device (Cuijpers and Schuurmans 2007; Wang, Zhang, and An 2023). These interventions can be unguided (or self-directed), therapist-guided (as a partial substitute for face-to-face therapy) or self-help interventions as an independent intervention (Balaskas et al. 2021; Cuijpers and Schuurmans 2007). Previous studies suggest these interventions are cost-effective and generally have similar outcomes to face-to-face interventions (Andersson and Titov 2014). These treatments, which include therapeutic tasks handed over to a computer, smartphone or tablet, can be delivered in a self-guided, therapist-guided or a combination of these formats (Andersson and Titov 2014; Lal and Adair 2014). Mobile applications have significant potential to address the gap between the community's identified need for mental health services and the limited capacity and resources to provide traditional treatment services (Lal and Adair 2014). These interventions have advantages, such as facilitating access to treatment, especially for rural and remote populations, and minimizing financial or temporal barriers (Andersson and Titov 2014; Chan et al. 2019; Dworschak, Heim, and Maercker 2022; Lal and Adair 2014). It is also promising for those who avoid treatment due to stigmatization (Dworschak, Heim, and Maercker 2022; Lal and Adair 2014). Previous studies have shown that Internet-based mental health applications can effectively reduce anxiety symptoms (Taylor et al. 2023; Yang and Chung 2022). Kiriopoulos et al. (2008) compared face-to-face and online treatment and found equivalent results. For instance, Kosasih et al. (2023) found that participating in a CBT-based mHealth program can effectively reduce worry and anxiety.

The effectiveness of mobile app interventions on anxiety has been examined in previous meta-analyses (Firth et al. 2017; Linardon et al. 2019; Lu et al. 2022). Linardon et al. (2019) explored the impact of these interventions on mental health issues, such as depression, anxiety and overall psychiatric distress; Lu et al. (2022) focused on their effects on anxiety and depression symptoms; and Firth et al. (2017) specifically investigated their effects on anxiety symptoms. These meta-analyses consistently favour smartphone interventions. However, these studies were limited to randomized controlled trials, a restriction we did not

impose. Additionally, Linardon et al. (2019) and Lu et al. (2022) evaluated trials that addressed not only anxiety but also other mental health problems. Furthermore, meta-analyses conducted by Firth et al. (2017) and Linardon et al. (2019) did not capture global events in the past few years (e.g., the COVID-19 pandemic). Alongside the rapid development of information and communication technologies, the pandemic has also led to significant increases in the development, accessibility and ease of use of mobile applications. These events, such as the pandemic, wars and natural disasters in the past few years, especially, may have contributed to an increase in anxiety rates. For individuals suffering from anxiety, these mobile apps have become increasingly important due to their ability to minimize the barriers to accessing treatment faced by this group. Therefore, it can be argued that there is a need for an updated meta-analysis specifically examining the impact of evidence-based mobile self-help applications on anxiety. Additionally, investigating various factors such as gender, age, measurement tools used for anxiety, type of control group and duration of intervention will be crucial in understanding how these evidence-based mobile apps affect the reduction of anxiety symptoms.

## 1.1 | The Present Study

This systematic review and meta-analysis study aims to examine the technical and therapeutic properties of science-based mobile applications developed for anxiety, to evaluate their effectiveness and to investigate their future effects. The study also aims to examine how participants' characteristics, methodological factors and intervention duration may moderate the effects of science-based mobile apps on reducing anxiety symptoms. We will conduct a moderator analysis to examine how these factors potentially affect the effectiveness of science-based mobile apps in reducing anxiety symptoms. Nowadays, as a result of factors such as the rapid development of technology and ease of access and use (Becker et al. 2014), a large number of anxiety apps have been developed. Although these apps play an essential role in increasing access to mental health services, there is a significant deficiency in examining the technical and therapeutic properties of these applications and evaluating their effectiveness (Chan et al. 2019; Lal and Adair 2014; Sucala et al. 2017). The lack of knowledge about these constitutes a significant obstacle to utilizing the mobile apps' benefits. Therefore, we present an up-to-date review of intervention approaches, techniques and therapeutic properties of empirically supported science-based mobile apps for anxiety.

## 2 | Method

### 2.1 | Research Strategy

This study was conducted and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Page et al. 2021). The literature search was conducted in August 2023 by examining four electronic databases: PubMed, Web of Science (WoS), SCOPUS and ProQuest. These databases were searched by the sixth author and an independent doctoral student using variations of the following search terms: 'anxi\* AND 'mobile OR smartphone OR software AND app\*';

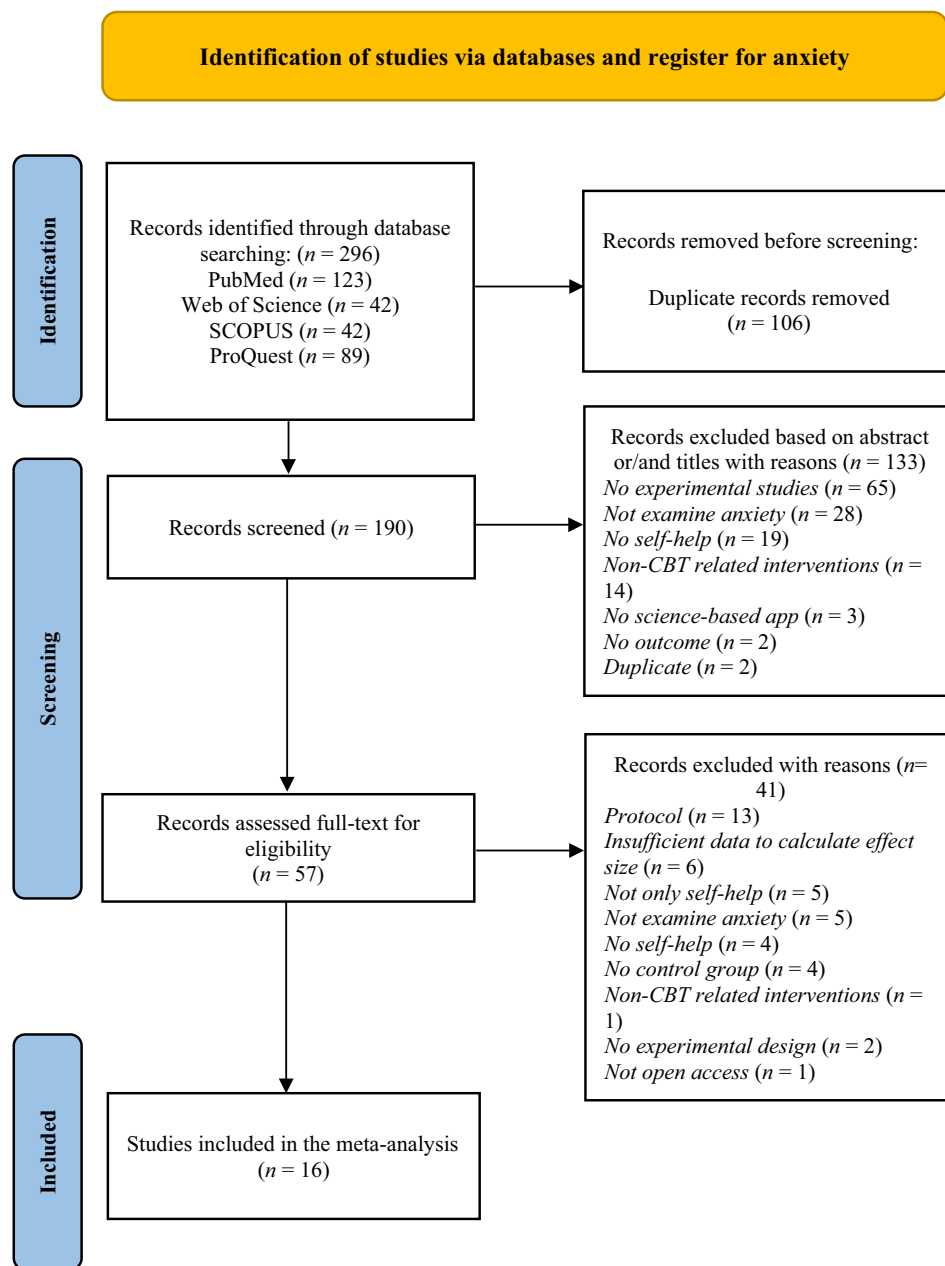
'cognitive behavioral therapy OR cognitive behavioural therapy OR CBT'. When searching the abstracts of WoS, SCOPUS and ProQuest, PubMed was searched in all fields.

### 2.2 | Eligibility Criteria

The following eligibility criteria were used to include studies in the systematic review and meta-analysis: (i) addressed anxiety; (ii) provided a CBT-based intervention; (iii) provided a scientifically based self-help mobile app intervention; (iv) had at least one control (or alternative) group; (v) had sufficient data to calculate effect size (reporting means and standard deviations for groups or differences in means between groups); and (vi) reported anxiety according to a valid measure. Exclusion criteria were used as follows: (i) no experimental study; (ii) interventions were not CBT-based; (iii) not on anxiety; (iv) not a scientifically based mobile application study (i.e., a study without a mobile application or mobile applications with content that is not scientifically based); (v) not a self-help method; (vi) no control (or alternative) group in the studies; and (vii) insufficient data to calculate effect size (not reporting means and standard deviations for groups or differences in means between groups).

### 2.3 | Study Selection

After a systematic search of the databases, 296 records were identified through database searching. All database records were exported to the Rayyan website. Rayyan is a website/app that is user-friendly and simplifies detecting duplicate studies. Then, 106 duplicates were removed from the identified references. The remaining 190 studies were reviewed by the sixth author and an independent doctoral student, under the supervision of the third and fourth authors primarily on the basis of title and abstract. At this stage, 133 of 190 studies were removed based on title and abstract for the following reasons: no experimental studies ( $n=65$ ); not examining anxiety ( $n=28$ ); not self-help intervention ( $n=19$ ); not based on CBT ( $n=14$ ); no science-based application (i.e., a study without a mobile application or mobile applications with content that is not scientifically based) ( $n=3$ ); no outcome ( $n=2$ ); and duplicate ( $n=2$ ). Full-text copies of the remaining included studies were independently screened by the fifth author and two independent doctoral students under the supervision of the third and fourth authors according to our eligibility criteria. At this stage, 41 of 57 studies were removed for the following reasons: protocol not suitable ( $n=13$ ); insufficient data to calculate the effect size ( $n=6$ ); not only self-help ( $n=5$ ); not examining anxiety ( $n=5$ ); no self-help intervention ( $n=4$ ); no control group ( $n=4$ ); no experimental design ( $n=2$ ); non-CBT-related interventions ( $n=1$ ); and not open access ( $n=1$ ). When reviewing full-text studies, researchers used a tool that included items for our eligibility criteria (e.g., was the mean, standard deviation or difference between group means reported to calculate effect size, was there a control group or did it address anxiety as an outcome). This form was used to screen studies more rigorously and to minimize differences in assessment between researchers, and studies were marked as 'included', 'maybe' or 'excluded'. Where there was disagreement, we discussed and reached a consensus before proceeding to analysis, thus ensuring full agreement.



**FIGURE 1** | PRISMA flow diagram.

Accordingly, 16 independent samples for anxiety ( $k = 20$ ) were identified as a result of the literature review conducted according to the eligibility criteria. The results of the literature review are presented in Figure 1.

## 2.4 | Data Collection Process

We developed coding keys to identify and facilitate the analysis of the studies included in this study. Author surnames, year of publication, type of anxiety intervened, software tool used, participants' demographic characteristics (e.g., gender and age), study design (e.g., randomized and quasi-experimental), intervention characteristics, type of comparison (e.g., passive control group and active control group) and measurement tools used for anxiety were reported. Anxiety scores and standard deviations

for both the experimental and control groups were reported before the intervention, as well as in the initial post-intervention measurements. When means and standard deviations were not provided in the studies, if the difference in means between the experimental and control groups were reported, they were converted to  $g$  values and included in the analyses. Two independent doctoral students and the fifth author coded the keys. When there was disagreement, the first four authors discussed it and agreed upon before proceeding to analysis so that full agreement was achieved.

## 2.5 | Data Analysis

This study used Comprehensive Meta-Analysis (CMA; Borenstein 2005) software under a random-effect

meta-analysis model to estimate the overall effect size of science-based mobile apps on anxiety. Anxiety severity is measured with continuous scales. The studies included in this meta-analysis used a variety of self-report measures. Hedges'  $g$  coefficient was calculated for each included study to estimate the effect of CBT-based mobile app interventions. A 95% confidence interval ( $CI$ ) was used for effect size in all calculations. Effect sizes are interpreted as follows: Hedges'  $g$ ;  $<0.5$  were accepted as small effect size;  $>0.8$  were considered large effect size; those falling between 0.5 and 0.8 were classified as medium effect size; (Cohen 2013; Fritz, Morris, and Richler 2012; Hedges 1981).

In this study, Rosenthal's fail-safe  $N$  and funnel plot were used to assess the likelihood of publication bias. A calculated fail-safe  $N$  value  $<5k+10$  ( $k$ =number of observed effect sizes) indicates the presence of publication bias (Rosenthal 1979). Furthermore, in the funnel plot, the effect size of the studies is symmetrically distributed around the overall effect size, which is considered evidence of the absence of publication bias (Borenstein et al. 2011). To assess the heterogeneity between the included studies, the  $Q$ -test and  $I^2$  values were examined. The  $I^2$  value is interpreted as 25% low heterogeneity, 50% moderate heterogeneity and 75% high heterogeneity (Cooper et al. 2019).

Moderator analyses were performed to identify potential moderator roles of characteristics of participants, methodological factors and intervention duration. To conduct a moderator analysis, it is recommended to have two or more studies in each subgroup (Borenstein et al. 2011). As potential moderators, participant characteristics included gender and age. The age of adult participants was determined based on the American Psychological Association's (APA 2023) dictionary definition. The dictionary definition provided by APA (2023) categorizes adulthood into young adulthood (roughly 20–35 years of age), middle adulthood (about 36–64 years) and later adulthood (age 65 and beyond). As potential moderators, methodological factors included the scale used for measuring anxiety symptoms and the type of control group. Moreover, intervention duration was categorized as interventions lasting longer and shorter than 6-week interventions. This categorization was determined by calculating the average intervention duration of all the studies included in the analysis.

### 3 | Results

#### 3.1 | Study Characteristics

The meta-analysis analysed 20 different effect sizes from 16 studies that met the inclusion criteria and were published between 2017 and 2023. A total of 2377 participants were included in the analyses, 1131 ( $M=70.69$ ) in the experimental group and 1246 ( $M=77.88$ ) in the control group. Most of the studies had over 50% female participants ( $n=13$ ), and the mean age was 33.60. Half of the studies (50%) focused on young adulthood, whereas the seven (43.75%) focused on middle adulthood. The majority of the studies were conducted in Korea ( $n=4$ ), followed by the United Kingdom ( $n=3$ ), the United States

( $n=3$ ), China ( $n=1$ ), Italy ( $n=1$ ), Canada ( $n=1$ ), Singapore ( $n=1$ ), Germany ( $n=1$ ) and Japan ( $n=1$ ). Various scales were used to measure anxiety levels, including General Anxiety Disorder (GAD-7) ( $n=5$ ), State-Trait Anxiety Inventory-Trait ( $n=2$ ), Depression Anxiety Stress Scale (DASS) ( $n=2$ ), Hospital Anxiety and Depression Scale-Anxiety Subscale (HADS-A) ( $n=2$ ), State-Trait Anxiety Inventory-State ( $n=1$ ), Beck Anxiety Inventory ( $n=1$ ) and Agoraphobia Scale ( $n=1$ ), and one-item anxiety scale ( $n=1$ ) was used to measure the anxiety levels of the participants. In one study, both the state and trait versions of the State-Trait Anxiety Inventory were used. Randomized control trials (RCT) were employed in the majority of the studies ( $n=15$ ), with one study (Hamamura et al. 2018) utilizing a quasi-experimental design. Among them, 10 (63%) studies had a passive control group, whereas six (37%) had an active control group. In the study conducted by Hur et al. (2018) with an active control group, the control group received a daily mood chart app program. In the approximately 15-min program, participants completed a daily mood diary, recording their mood state and sleep quality/quantity. In Kosasih et al.'s (2023) study, participants in the active control group received a 'Procrastination' program similar to the 'Anxiety and Worry' program received by the experimental group. In this 2-week program, participants in the active control group completed content on understanding and defining worries, working with anxiety and learning to manage anxiety. In the study by Ham et al. (2019), participants in the active control group received a simple card-format HARUCard program consisting of (1) information on anxiety, (2) exercise tips, hobbies, and travel, (3) movies and books, (4) famous quotes and (5) artworks. In the study by Litvin et al. (2020), the active control group received a CBT Thought Diary program based on CBT and positive psychology once a week for 10 min. The program's content included five smiley icons for tracking mood, labelling emotions, identifying negative and distorted thinking patterns, doing a typical CBT exercise and maintaining a mood diary and gratitude journal. In the study by Greer et al. (2019), the active control group received detailed information on cancer treatment, exercise, nutrition, memory and cognition, sexual health and quality of life (QOL) through slide decks with voiceover accompaniment. They did not receive tailored programming logic, videos or homework assignments similar to those received by the experimental group. Lastly, in the study by Christoforou, Sáez Fonseca, and Tsakanikos (2017), the active control group received a Stress Free app focused on teaching relaxation techniques and generic CBT skills through a virtual therapist. Finally, the intervention duration ranged from 2 to 12 weeks, with an average of 7.06 weeks (see Table 1).

#### 3.2 | Meta-Analysis Findings and Moderator Analyses

The effect of science-based mobile apps in reducing anxiety, compared to control groups, was statistically significant and moderate ( $g=-0.31$ ,  $SE=0.09$ , 95%  $CI$   $-0.48$  to  $-0.14$ ,  $p<0.001$ ). Moderator analyses were conducted to examine the impact of participant characteristics, methodological factors and intervention duration. The findings of these moderator analyses are summarized below and in Table 2.

**TABLE 1** | Key characteristics of the included studies in the systematic review.

Study	N		Mean age	Domicile	Used software tools	Population	Scale for anxiety	Design	Control	Intervention duration
	Tx	Cont								
Hur et al. (2018)	17	17	23.71	Korea	Todac Todac	Participants had significant symptoms of depression	STAI-X2-Trait	RCT	Active control (a daily mood diary, recording their mood state, and sleep quality/quantity)	3 weeks
Al-Refae et al. (2021)	78	87	25.24	Canada	Serene	Almost 25% of participants had a diagnosis a with a mental health disorder	DASS-21	RCT	WL	4 weeks
Danieli et al. (2022)	8	10	55.58	Italy	Therapy Empowerment Opportunity	Participants with stress symptoms and mild to moderate anxiety	GAD-7	RCT	WL	8 weeks
Hwang et al. (2022)	63	63	37.95	Korea	BetterLife	Participants had work-related stress	BAI	RCT	WL	10 weeks
Kosasih et al. (2023)	150	149	22.05	Singapore	Anxiety and Worry Programme	18 years and above, has not participated in similar mHealth studies	GAD-7	RCT	Active control (Procrastination Programme)	2 weeks
Qin et al. (2022)	52	53	31.91	China	CareMom	Participants who mothers were not diagnosed with ant mental disorders any time	GAD-7	RCT	WL	4 weeks
McCloud et al. (2020)	41	57	24.17	UK	Feel Stress Free	University students self-identified as experiencing symptoms of anxiety or depression	HADS-A	RCT	WL	6 weeks
Ham et al. (2019)	21	21-21	44.5	Korea	HARUToday	Cancer patients	STAI-State STAI-Trait	RCT	WL and active control (HARUCard)	10 weeks

(Continues)

TABLE 1 | (Continued)

Study	N		Mean age	Domicile	Used software tools	Population	Scale for anxiety	Design	Control	Intervention duration
	Tx	Total								
Nicol et al. (2022)	10	17	14.7	USA	W-GenZ	Adolescents with depression and anxiety	GAD-7	RCT	WL	12 weeks
Litvin et al. (2020)	135	130–95	NS	Germany	eQuoo	Bosch UK employees	one-item anxiety scale	RCT	WL and active control (CBT Thought Diary)	5 weeks
Hunt et al. (2021)	62	59	32	USA	Zemedy	Patients with irritable bowel syndrome (IBS)	DASS	RCT	WL	8 weeks
Yang and Chung (2022)	15	30	20.97	Korea	HARU ASD	Individuals with autism spectrum disorder (ASD)	STAI-State	RCT	WL	10 weeks
Greer et al. (2019)	65	128	56.45	USA	CBT Mobile App Intervention	Patients with incurable cancer	HADS-A	RCT	Active control (Health education)	12 weeks
Taylor et al. (2023)	97	102	36.8	UK	Unmind	Working adults	GAD-7	RCT	WL	3 weeks
Hamamura et al. (2018)	248	224	38.82	Japan	Self Record	Japanese workers	STAI-Trait	Quasi-experimental	WL	4 weeks
Christoforou, Sáez Fonseca, and Tsakamikos (2017)	73	69	39.21	UK	Agoraphobia Free	Participants who self-identified as having agoraphobia	Agoraphobia Scale	RCT	Active control (Stress Free)	12 weeks

Abbreviations: BAI, Beck Anxiety Inventory; DASS-21, Depression, Anxiety, and Stress Scale-Anxiety Subscale; GAD-7, General Anxiety Disorders-7; HADS-A, Hospital Anxiety and Depression Scale-Anxiety Subscale; RCT, randomized controlled trial; STAI-X2-Trait, State-Trait Anxiety Inventory-Trait Subscale; WL, waitlist.

**TABLE 2** | Results of categorical moderator analyses.

Moderators	Categories	<i>k</i>	<i>ES</i>	<i>SE</i>	95% <i>CI</i>
Characteristics of participants					
Gender	Over 50% female	16	−0.34**	0.10	[−0.54 to −0.15]
	Over 50% male	4	−0.21	0.19	[−0.57 to 0.16]
Age	Young adulthood	7	−0.30	0.15	[−0.59 to 0.00]
	Middle adulthood	12	−0.31**	0.12	[−0.54 to −0.08]
Methodological factors					
Scale	STAI-Trait	4	−0.34	0.21	[−0.74 to 0.06]
	GAD-7	5	−0.15	0.18	[−0.51 to 0.21]
	STAI-State	3	−0.88**	0.27	[−1.40 to −0.16]
Type of control group	Non-active	13	−0.36**	0.11	[−0.58 to −0.15]
	Active	7	−0.22	0.15	[−0.51 to 0.07]
Intervention duration	Over 6 weeks	11	−0.46***	0.12	[−0.70 to −0.22]
	Six weeks or fewer	9	−0.18	0.11	[−0.40 to 0.04]

Abbreviations: CI, confidence interval; ES, Hedges' *g*; *k*, number of effect sizes; SE, standard error.

\* $p < 0.05$ .

\*\* $p < 0.01$ .

\*\*\* $p < 0.001$ .

### 3.2.1 | Characteristics of Participants

In the moderator analysis examining the effect of the gender percentage on the effectiveness of science-based mobile apps in reducing anxiety, 16 outcomes from studies with over 50% female participants and four outcomes from studies with over 50% male participants were included. The results showed that the gender percentage of the participants had a significant effect on the effectiveness of science-based mobile apps in reducing anxiety ( $p < 0.001$ ). Specifically, in studies with over 50% female participants,  $g$  was  $-0.34$  ( $SE = 0.10$ , 95%  $CI$   $-0.54$  to  $-0.15$ ,  $p = 0.001$ ). On the other hand, in studies with over 50% male participants,  $g$  was  $-0.21$  ( $SE = 0.19$ , 95%  $CI$   $-0.57$  to  $0.16$ ,  $p = 0.267$ ).

Moreover, the analysis included seven outcomes from studies involving young adulthood participants and 12 outcomes from studies involving middle adulthood participants to examine the effect of age on the effectiveness of science-based mobile apps in reducing anxiety. The age of the participants significantly affected the effectiveness of science-based mobile apps in reducing anxiety ( $p = 0.001$ ). The efficacy of science-based mobile apps in reducing anxiety was found to be slightly more effective in studies with middle adulthood participants ( $g = -0.31$ ,  $SE = 0.12$ , 95%  $CI$   $-0.54$  to  $-0.08$ ,  $p = 0.008$ ) compared to those involving young adulthood participants ( $g = -0.30$ ,  $SE = 0.15$ , 95%  $CI$   $-0.59$  to  $0.00$ ,  $p = 0.051$ ).

### 3.2.2 | Methodological Factors

In the moderator analysis conducted to examine the impact of different scales used to measure anxiety on the efficacy

of science-based mobile apps; we included five outcomes for GAD-7, four for STAI-Trait and three for STAI-State. The results showed that the effectiveness of science-based mobile apps varied depending on the scale used ( $p = 0.016$ ). Specifically, the analysis revealed that science-based mobile apps had stronger effects in the studies that used the STAI-State scale ( $g = -0.88$ ,  $SE = 0.27$ , 95%  $CI$   $-1.40$  to  $-0.35$ ,  $p = 0.001$ ). In studies using the GAD-7 scale, the  $g$  value of  $-0.15$  was found ( $SE = 0.18$ , 95%  $CI$   $-0.51$  to  $0.21$ ,  $p = 0.409$ ), whereas in studies using the STAI-Trait scale, the  $g$  value was  $-0.34$  ( $SE = 0.21$ , 95%  $CI$   $-0.74$  to  $0.06$ ,  $p = 0.098$ ).

Furthermore, we examined the type of control group as a moderator variable in the effectiveness of science-based mobile apps in reducing anxiety. In this context, we included 13 outcomes from studies with a non-active control group and seven outcomes from studies with an active control group. The results indicated that the type of control group had a significant impact on the effectiveness of science-based mobile apps in reducing anxiety ( $p < 0.001$ ). Specifically, the  $g$  was  $-0.36$  ( $SE = 0.11$ , 95%  $CI$   $-0.58$  to  $-0.15$ ,  $p = 0.001$ ) for studies with a non-active control group and  $-0.22$  ( $SE = 0.15$ , 95%  $CI$   $-0.51$  to  $0.07$ ,  $p = 0.141$ ) for studies with an active control group.

### 3.2.3 | Intervention Duration

Lastly, we conducted a moderator analysis to examine the effect of intervention duration on the effectiveness of science-based mobile apps in reducing anxiety. We included 11 outcomes for interventions lasting over 6 weeks and nine outcomes for interventions lasting 6 weeks or fewer. The effectiveness of science-based mobile apps differed based on the intervention duration

( $p = 0.024$ ). Effectiveness of science-based mobile apps in reducing anxiety was found to be more effective in studies, comprised over 6 weeks of length intervention ( $g = -0.46$ ,  $SE = 0.12$ , 95%  $CI$   $-0.70$  to  $-0.22$ ,  $p < 0.001$ ) than 6 weeks and less lengthy intervention ( $g = -0.18$ ,  $SE = 0.11$ , 95%  $CI$   $-0.40$  to  $0.04$ ,  $p = 0.114$ ).

### 3.3 | Publication Bias and Heterogeneity

We assessed the possibility of publication bias using funnel plot and classical fail-safe  $N$  methods. First, when analysing the funnel plot, we can observe that the studies are asymmetrically distributed, potentially indicating publication bias (see Figure 2). However, we found that the fail-safe  $N$  number is 176, indicating no publication bias.  $Q$ -statistic and  $I^2$  values were examined for potential homogeneity. The  $Q$ -statistic was found to be significant ( $Q = 77.52$ ,  $p < 0.001$ ) and failed to reject the hypothesis of homogeneity. In addition, heterogeneity between the studies was high ( $I^2 = 75.49$ ). In this context, there is no publication bias and heterogeneity in the studies included in the analysis.

## 4 | Discussion

In this respect, this meta-analysis study, which included 16 experimental studies with no evidence of publication bias and heterogeneity, examined the statistical effectiveness of science-based mobile apps compared to control groups for anxiety. It was found that science-based mobile applications for anxiety had a statistically significant and moderate effect compared to control groups. The effectiveness results align with those observed in earlier meta-analyses (Firth et al. 2017; Linardon et al. 2019; Wu et al. 2021). This underscores the potential of these interventions as viable alternatives or complements to traditional anxiety treatments. Clinicians can consider integrating mobile app-based interventions into their therapeutic repertoire, particularly for patients who may prefer or benefit from digital health solutions. Although the results are promising for clients to access effective and science-based psychological help, it needs to be repeated by independent research groups by the American

Psychological Association Presidential Task Force on Evidence-Based Practice (2006).

The study aimed to investigate the effectiveness of science-based mobile applications for anxiety. In this context, the studies were examined based on CBT applications. Effective studies (Ivanova et al. 2016; Levin, Haeger, and Cruz 2018; Orosa-Duarte et al. 2021) are carried out with different methods within the scope of science-based mobile applications. Different methods within the scientific framework (Litvin et al. 2020) are considered important for the generalizability of mobile applications. In addition, it is thought that examining the effectiveness of CBT in science-based mobile applications (Danieli et al. 2022; Hur et al. 2018; Litvin et al. 2020) in detail within the scope of the study allows a specific method to be explained in depth.

As a result of this meta-analysis, it was found that science-based mobile apps for anxiety were more effective in studies with over 50% female participants than in studies with over 50% male participants. The potential reason for this finding can be women tend to use mental health apps more frequently compared to men (Anguera et al. 2016; Balaskas et al. 2022). They are also more open to using these apps (Kern et al. 2018) and are more likely to engage in the interventions offered by these apps (Borghouts et al. 2021). Moreover, considering that women have a higher prevalence of anxiety disorders compared to men (Asher, Asnaani, and Aderka 2017; Wittchen 2002), it can be expected that science-based mobile apps would have a greater impact on anxiety in studies with more female participants. Notwithstanding, it may be advantageous for clinicians to consider utilizing mobile applications more frequently for female clients experiencing anxiety issues. However, conducting more gender-specific studies on the effectiveness of these apps for anxiety could contribute to the development of more tailored mobile apps for anxiety.

Another finding of this meta-analysis is that the effectiveness of science-based interventions in alleviating anxiety is higher in studies involving middle adulthood participants than in young adulthood. Some studies in the literature are

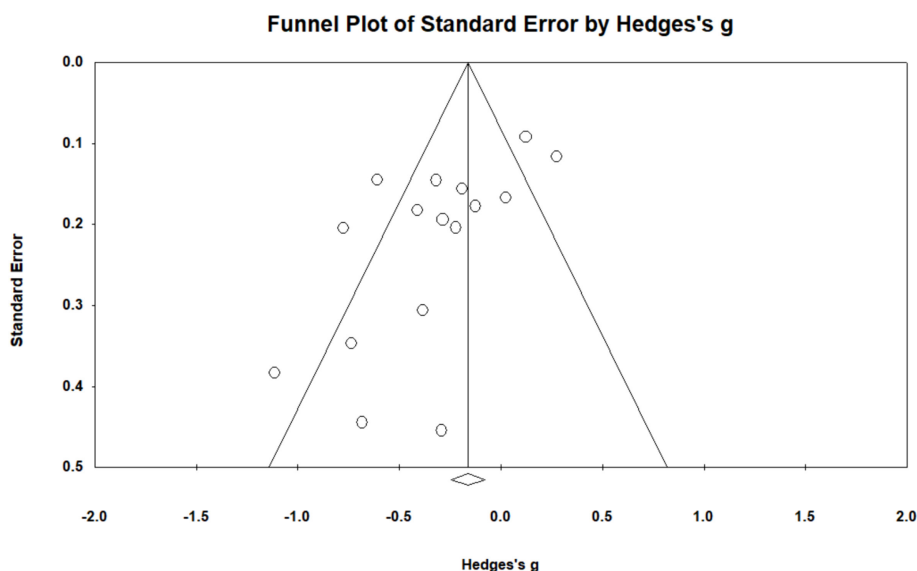


FIGURE 2 | Funnel plot.

inconsistent with this finding. According to the study by Lipschitz et al. (2020), middle-aged and younger individuals show more interest in mobile apps, whereas older individuals show less interest. In studies conducted with middle-aged and older adults, age was not associated with a decrease in depressive and anxiety symptoms (Gould et al. 2021), and there was no relationship between age and mobile device proficiency and application engagement (Alfaro et al. 2024). However, CBT interventions help adults identify and change negative thought patterns and increase coping skills and resilience (Amer et al. 2023). In this context, CBT offered online or through mobile apps serves as an accessible platform for adults to receive therapy (Addepally and Purkayastha 2017). Although recent research suggests that middle-aged individuals can overcome barriers to accessing mobile apps and derive comparable benefits to other age cohorts, the difference observed in this meta-analysis underscores the imperative for further research. Also, this finding suggests that age-specific adaptations may be necessary to maximize the impact of mobile interventions across different age groups. Integrating elements that resonate with their unique stressors and lifestyles may enhance engagement and effectiveness for young adults.

The study's findings suggest that research using the STAI-State scale was the study in which science-based interventions were most effective. Afterwards, there are STAI-Trait and GAD-7. It can be said that the situational effects on participants in studies using the STAI-State (Ham et al. 2019; Yang and Chung 2022) contributed to these findings. Participants in the study by Ham et al. (2019) were cancer patients, whereas those in the study by Yang and Chung (2022) were individuals with autism spectrum disorder. Additionally, Yang and Xu (2022) found that the state anxiety levels of papillary thyroid cancer patients were higher than their trait anxiety levels. Similarly, Kim et al. (2021) indicated that the mean state anxiety of adolescents with ASD was higher than their mean trait anxiety. These higher state anxiety levels may be associated with the greater effectiveness of science-based mobile apps utilizing the STAI-State scale in these studies. In the earlier studies, the correlation between GAD-7 scores and STAI-Trait scores was moderate (Cotiga et al. 2023; White and Karr 2023), and in another study, the correlation between GAD-7 scores and STAI-Trait scores was higher than STAI-State scores (Konkan et al. 2013). Whereas STAI-State measures the intensity of current anxiety symptoms, STAI-Trait measures the frequency and pervasiveness of anxiety symptoms (Spielberger 1983). Whereas STAI-State focuses on how the individual feels at a certain moment and under certain conditions, STAI-Trait focuses on how the individual generally feels, regardless of his/her situation and conditions. Therefore, STAI-Trait is less sensitive than STAI-State to changes over a short period. GAD-7 is a measurement tool developed to determine the frequency of symptoms of generalized anxiety disorder (Spitzer et al. 2006). Furthermore, the STAI includes items related to positive emotions that are reverse-coded. Therefore, the STAI lacks specificity, in contrast to the GAD. As a result, it can be thought that this result of the study is due to the measurement tools measuring different structures. In addition, the anxiety symptoms examined in the studies included in the meta-analysis vary. Future studies investigating specific anxiety disorder symptoms and evaluating the effectiveness of

mHealth applications according to the measurement tool will enable steps to be taken to standardize assessment procedures in mHealth applications. Also, this finding suggests that clinicians should be mindful of the scales they use to assess anxiety, as some instruments may be more sensitive to changes caused by mobile interventions.

In this meta-analysis study, science-based mobile apps with a non-active control group were more effective in reducing anxiety than apps with an active control group. In the meta-analysis led by Firth et al. (2017) regarding the influence of mental health mobile applications on anxiety, it was observed that effect sizes were found to be significantly greater when contrasted with waitlist or inactive controls, as opposed to active control conditions. In another meta-analysis by Linardon et al. (2024), when generalized anxiety was the primary target, studies using a non-active control produced significantly larger effect sizes on generalized anxiety symptoms than placebo or care as usual. The findings of this meta-analysis consistently replicated one of the findings observed in psychological treatment procedures, which is consistent with the literature. When designing treatment protocols that include mobile applications, practitioners should be aware that the perceived efficacy may be influenced by the type of control group used in the initial studies.

The last finding of the research is that studies with an intervention duration of more than 6 weeks are more effective in reducing anxiety than studies with an intervention duration of fewer than 6 weeks. A meta-analysis by Lu et al. (2022) found that apps with an intervention duration of 7 weeks or longer have a larger effect size for reducing anxiety symptoms. When the intervention periods were examined in the reviewed studies, it was determined that the maximum intervention period was 12 weeks (Greer et al. 2019; Nicol et al. 2022), although it had different lengths. However, obtaining effective results on anxiety even in applications lasting 2 weeks (Kosasih et al. 2023) reveals the short-term effect of CBT-based interventions on anxiety. Considering the high effectiveness of CBT-based interventions with an average of eight sessions (Türkçapar 2018), it can be interpreted that the length of the intervention period has a positive effect on reducing anxiety levels. However, ensuring and maintaining user engagement is one of the biggest obstacles to mental health applications' functionality (Owen et al. 2015). It is suggested that approximately 4% of users who download a mental health app continue to use the app after 15 days and 3% continue to use it after 30 days (Baumel et al. 2019). In addition, the intervention contents of mHealth mobile apps, the techniques they contain and, therefore, the intervention intensity vary (Drissi et al. 2020). It may be helpful to consider the intervention content when considering the effectiveness of intervention duration in future studies. Additionally, this finding suggests prioritizing the design of interventions that encourage prolonged use and adherence to maximize therapeutic benefits.

#### 4.1 | Limitations

This meta-analysis, which aims to research the effectiveness of science-based mobile apps for anxiety, has several limitations. First, the sample included clinical, subclinical and non-clinical participants. It is difficult to infer the effectiveness of these

apps specifically within the context of a universal, selective or indicated preventive program (Bakker et al. 2016). Second, the meta-analysis only considered outcome measurement, so it lacks follow-up measurement values. Therefore, the long-term effects of these apps are uncertain. However, follow-up data can indicate a difference in effect size in follow-ups according to weeks (Linardon et al. 2019). Third, self-report measurement tools were used in all studies included in the meta-analysis. In anxiety measurements, self-report measurement tools can only provide information in a one-sided and narrow scope (Schat et al. 2017). Finally, the diversity of control groups included in the research did not allow for analysis of the digital placebo effect (Torous and Firth 2016).

## 5 | Conclusions

Although mobile apps in the field of healthcare are developed with commercial and economic motivations rather than scientific motivations (Martínez-Pérez, de la Torre-Díez, and López-Coronado 2013), CBT is one of the most commonly used approaches in mental health mobile apps in general (Leong et al. 2022) and anxiety-related apps (Drissi et al. 2020; Marshall, Dunstan, and Bartik 2020). The findings of this research make a substantive contribution to the measures required for standardizing the mental health services delivered via science-based mobile applications, tailoring to the target population. In this regard, considering that women and middle-adult clients may benefit more from mobile applications for anxiety, depending on the characteristics of the participants, it indicates that gender-specific and age group-specific adaptations may need to be made in these applications. Establishing that methodological approaches like measurement tools and experiment design play a role in the outcomes of studies on the effectiveness of mobile applications is instrumental in guiding the development and adoption of future treatment protocols. Additionally, the result that mobile applications with intervention durations over 6 weeks are more effective in reducing anxiety levels underscores the importance of prolonged engagement. It emphasizes the need to prioritize the design of longer duration interventions in mobile applications to maximize therapeutic benefits. In conclusion, the results of this meta-analysis provide robust evidence supporting the effectiveness of science-based mobile applications for anxiety reduction. The identified moderators offer valuable insights into optimizing these interventions for different populations and contexts. Increasing and disseminating science-based mobile applications holds promise for advancing the democratization of psychological help.

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The authors have nothing to report.

### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

The corresponding author can provide the dataset analysed for this study upon request.

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