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The Effectiveness of mHealth Intervention in Improving Sleep Health for Adolescents and Young Adults: A Scoping Review

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Abstract. Insufficient sleep is one of the most significant health concerns around the world since it could increase the risk of several chronic diseases, including diabetes, behavioral problems, and obesity. In recent years, mobile health (mHealth) technologies have been widely adopted for health monitoring and improvement. This scoping review investigates the effectiveness of mHealth intervention in improving sleep health for adolescents and young adults. This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) standard. Studies were searched in PubMed, IEEE Xplore, ACM Digital Library and Cochrane databases. The scoping review included studies employing at least one type of mHealth intervention for sleep, reporting at least one evaluation parameter for sleep health, conducting experiments with participants aged 10-25 years old. A total of 499 studies were identified and 18 studies met the inclusion criteria. Based on the findings, the majority of studies utilized subjective self-report questionnaires or diaries (N=14 of 18), whereas only four studies detected the sleep health via objective wearable sensors. More than half of the included studies (N=10 of 18) in this scoping review reported their mHealth interventions have significant impacts on at least one sleep health parameter. The CBT-I app- based mHealth interventions and digital reminder approaches have the most consistent improvement, reporting significant effects on sleep health outcomes such as sleep quality, efficiency, and insomnia symptoms. This scoping review provides a overview of the current state and limitations of mHealth intervention in improving the sleep for adolscents and young adults. One of the limitations in the article demonstrates the need for a standardized sleep outcome measurement in order to increase the comparability among different mHealth interventions and studies.

Keywords: mHealth, sleep, adolescents, young adults

1. Introduction

Sleep plays a critical role in maintaining mental and physical health for adolescents and young adults. Sufficient sleep could promote better health outcomes, including better attention, behavior, memory, emotional regulation, and quality of life [1]. The recommendation from American Academy of Sleep Medicine states that adolescents and young adults should sleep 8 to 10 hours to promote optimal health condi- tion [1]. However, the National Youth Risk Behavior Survey (YRBS) reported that 72.7% of the high school students sleep less than 8 hours per night which are

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considered as insufficient sleep [2]. More than 60% of the college students were reported to have disturbed poor-quality sleep [3]. Insufficient sleep is one of the most significant health concerns around the world since it could increase the risk of chronic diseases such as diabetes, obesity, and behavioral problems [1]. These consequences underscore the urgent need for effective technol- ogy and strategies to intervene and improve sleep health for adolescents and young adults.

During the past two decades, researchers have investigated a variety of approaches, such as school-based sleep Hygiene Education and later school start time policy, aimed at promoting sleep health [4,5]. However, one of the main reasons why sleep difficulties among adolescents and young adults remain widespread is their late-night activities on social media platforms and online games. Studies concluded that excessive screen time and smartphone usage were directly associated with poor sleep quality and insufficient sleep duration [6]. As most adolescents and young adults have their own smartphones or other mobile devices, emerging mHealth technologies, including smartphone applications, online programs, and wearable devices, present more advanced opportunities and approaches to promoting individuals' sleep health. Although a considerable number of studies and reviews have examined the effectiveness of wearable devices and other mHealth technology for sleep intervention, most existing studies only focused on broader population or specific clinical groups [7-9]. As adequate sleep is essential for adolescents and young adults emotionally and physically, it highlights the need for a scoping review to investigate the effectiveness of mHealth intervention targeting the sleep health of adolescents and young adults. Therefore, a scoping review was conducted in order to:

1). identify the key parameters commonly used to evaluate adolescent sleep outcomes

2). map and categorize the range of mHealth technologies, including smartphone applications, wearable devices, and other wireless technologies

3). and evaluate the effectiveness of these health interventions in relation to sleep outcomes have been studied.

2. Methods

This scoping review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines [10].

2.1. Information source

The literature search was conducted in PubMed, IEEE Xplore, ACM Digital Library and Cochrane databases for all clinical trials and randomized controlled trials published after January 2015. The available resources and articles were saved with the systematic online PDF management tool, Zotero [11].

2.2. Search strategies

The literature search strategy included a combination of keywords to help identify the targeted articles. The keywords included "sleep", "sleeping quality", "sleeping pattern"; AND "mobile device", "wearable device*", "sensor", "technology", "Smart watch"; AND "teenager", "adolescent", "youth", "ado- lescence".

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2.3. Eligibility criteria

In the review, clinical trials and randomized controlled data were considered if they were published after January 2015 and were written in English. Furthermore, eligible papers needed to have reported/described on all of the following requirements:

• The study must include at least one type of mHealth intervention that focuses on sleep health. The World Health Organization (WHO) defines mHealth as mobile wireless technologies, including mobile phones, patient monitoring devices, and other wireless devices [12].

• Participants should be adolescents and young adults be- tween 10 and 25 years old. By definition, participants who aged between 10 and 19 are defined as adolescents [13]. Moreover, young adults in this review are defined as individuals between 19 and 25 years of age. Studies involving broader age groups than 10-25 years old were excluded.

• The study must include relevant data to evaluate the effectiveness of the intervention on the parameter of sleep health outcome (e.g. sleep quality, sleep pattern, sleep duration). Review articles, study protocol articles, conference proceed- ings, and commentary articles were excluded.

2.4. Screening and selection of articles

The records retrieved from the databases were imported into a systematic online PDF management tool, Zotero. Zotero helped remove all the duplicate articles. First, the title and abstracts of all articles were screened in the initial screening phase. Articles were excluded if they did not describe any relevant information about mHealth technology or sleep im- provement. If the title and/or abstract could provide sufficient information, the articles' full text were reviewed in the next screening phase in order to determine whether the article fits the eligibility criteria. After the initial screening the title and abstract, the articles remaining were assessed for full-text screening process. The articles were further excluded if article did not meet the remaining eligibility criteria, including studies employing at least one type of mHealth intervention for sleep; reporting at least one evaluation parameter for sleep health; conducting experiments with participants aged 10-25 years old (Fig. 1).

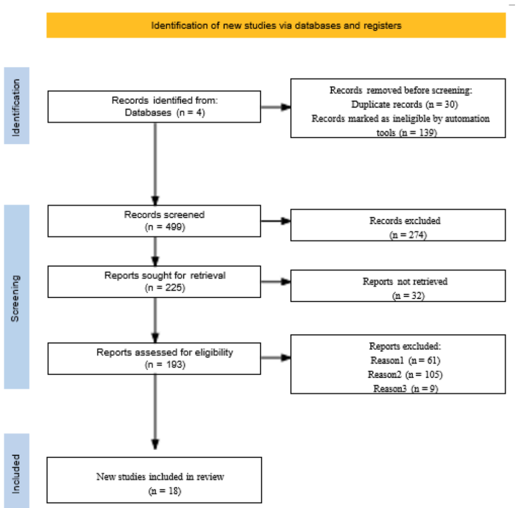

Figure 1. Flow diagram of article selection process

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2.5. Data extraction and synthesis

The following study characteristics were extracted from final set of eligible studies using data extraction worksheet (Table 1):

1). Study sample size: the total number of participants in each study.

2). Intervention time length: the length of time participants engaged in an intervention program with mHealth technology.

3). Types of mHealth technology used to intervene sleep behavior and improve sleep health: the categories of different mHealth technology, including applications, wearable devices, and other wireless technologies

4). Sleep health parameter: indicators of sleep outcome were extracted from each study, such as such as sleep duration (total sleep time per night), sleep efficiency (percentage of time in bed spent asleep), and sleep quality.

5). Sleep outcome measurement: methods or tools used to detect each sleep parameters reported were extracted, includ- ing the objective sensors and subjective questionnaires.

6). Evaluation metric(s): any metric that reports the effective- ness of mhealth intervention in changing or improving sleep outcomes. This included both objective numerical values (e.g., minutes of total sleep time, percentage sleep efficiency) and subjective scores (e.g., PSQI score, ISI score). For randomized controlled trials (RCTs), statistics such as p-values were also extracted in analyzing the statistical significance and the magnitude of the intervention effect.

2.6. Method of summarizing data

The data extracted were summarized using the descriptive synthesis approach, consistent with the objectives of a scoping review. All the study characteristics extracted, such as sample size, types of mhealth technology, were concluded using tables and charts. Furthermore, the reported sleep outcomes were categorized according to the types mhealth intervention employed, such as smartphone applications, internet-based platforms, and device-based intervention.

3. Result

3.1. Literature search

The literature search found 499 research articles, with 30 duplicates, resulting in 200 articles to be screened. After initial screening of all titles and abstracts, 86 full-text articles were further reviewed for eligibility. After removing articles that did not meet the inclusion criteria, 18 articles were included in the review.

3.2. Study characteristics

The reviewed studies were published between 2017 and 2025. The sample size of the studies ranged from 17 to 6,640 participants, with a mean of 1,288.47(SD = 2,394.62). The duration of interventions varied from 1 to 24 weeks. Details information of each study are presented in Table 1.

3.3. Parameters for sleep health

The majority of studies (N=9, 50%) used more than one parameter to evaluate sleep health. Seventeen different sleep- related parameters were identified in the 18 included studies, shown in

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Table 2. The most frequently utilized parame- ter was sleep quality, reported in 5 studies (N=5, 27.8%). The second most frequently utilized parameter was insomnia symptoms(N=4, 22.2%), followed by sleep disturbance(N=3), sleep efficiency(N=3), and Wake After Sleep Onset(WASO) (N=3). Bedtime, Waketime, sleep duration, Slow-Wave Ac- tivity (SWA), Daytime sleepiness were used in two studies. Lastly, sleep onset latency, difficulty falling asleep, Dysfunc- tional Beliefs and Attitudes about Sleep (DBAS), sleep hy- giene, Sleep-related impairment, REM sleep, sleep intentions and pre-sleep arousal were used in one study each.

3.4. Sleep outcome measurement

To evaluate the performance and effectiveness of mHealth in improving sleep health statistically, 19 different sleep- related outcome measurements were identified in table 3. The most frequently used measurement is non-standardized questionnaire or sleep diary (N=8, 44.4%). The second frequently used standardized measurement is Insomnia Severity Index (ISI) (N=5). Other moderately frequent measurement included the Cleveland Adolescent Sleepiness Questionnaire (CASQ, n = 3), the Patient-Reported Outcomes Measurement Information System (PROMIS, n = 3), and actigraphy (n = 3). Instruments such as the Pittsburgh Sleep Quality Index (PSQI), Fatigue Severity Scale (FSS), and Pediatric Daytime Sleepiness Scale (PDSS) were used twice. Moreover, Sleep-Related Behaviors Questionnaire (SRBQ), Pre-Sleep Arousal Scale (PSAS), Epworth Sleepiness Scale (ESS), Adolescent Sleep Hygiene Scale (ASHS), Karolinska Sleepiness Scale, Adolescent Sleep Habit Form, Sleep Condition Indicator (SCI), Dysfunctional Beliefs and Attitudes about Sleep Scale for Children (DBAS), and the Ruminative Thought Style Questionnaire (RTSQ) were only used in a single study each.

In the included studies, sleep outcome measurements could be categorized into subjective self-report questionnaires, objec- tive wearable measurements, and mixed-method approaches. Fourteen of the studies (N=14) measured sleep outcomes by using the self-report questionnaires or diary. Within this group, nine studies employed validated standardized instru- ments (e.g., ISI, PSQI, PROMIS, CASQ, PDSS), while five relied on non-standardized, such as simple self-report surveys, EMAs, or sleep diaries. Three of the studies (N=3) used mixed methods, combining objective wearable measurement and subjective questionnaire [14]. Lastly, one of the studies only used objective wearable measurement, actigraphy, collecting relevant data for sleep health.

3.5. Characteristics of the intervention

According to table 1, the majority of the included studies (N=15, 80.0%)) employed mobile applications as mHealth intervention, aiming to improve participants' sleep health. The designs and functions of these mobile applications varied con- siderably, which could be grouped into three main categories.

1) Health promotion–based applications (N = 8, 44.4%) :

These health promotion-based applications target the general population, including non-clinical group. The applications, like LIFEGOALS, Health4Life, and Happify for Teens, provide educational information articles about health behavior and behavior changes, guiding individuals to foster consistent healthy behavior and develop healthy habits rather than focus solely on sleep health [14-23].

2) Cognitive behavioral therapy for insomnia (CBT- I)–based applications (N=4, 22.2%) : These apps, such as Sleep Ninja and DOZE (Delivering Online Zzz's with Empirical Support), provided

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structured therapeutic content, including stimulus control, sleep restriction, relaxation, and cognitive restructuring in order to address sleep disturbances and insomnia disorder [24-27].

3) Self-monitoring and feedback applications : Three stud- ies (N=3, 16.7%) used applications that functioned as digital sleep self-tracking systems, enhancing the sleep health through sending text reminders or social media reminders. With the help of these reminders and motivational interviews, these apps can help adolescents and young adults reverse adverse outcomes, such as inadequate sleep and poor sleep patterns [28-30].

Table 1. Studies characteristic of included studies (N=18)

First Author, Year	Sample Size	Intervention Time length	mHealth Technology	Parameter of sleep health	Outcome measurement method	Outcome data
Carmen Peuters, 2024 [14]	279	12 weeks	A theory-based health promotion app (#LIFEGOALS)	sleep quality	Subjective web-based survey; Axivity accelerometer	Sleep quality improvement: χ^2 = 6.11, p = 0.01; Sleep routine: χ^2=1.21, P=0.27
Lauren S Weiner, 2024 [15]	73	12 weeks	Vira smartphone app	Sleep disturbance、Sleep-related impairment	Patient-Reported Outcomes Measurement Information System (PROMIS)	PROMIS Sleep Disturbance: Effect size = 0.27 (95% CI: –0.09 to 0.63); p=0.14PROMIS Sleep-related impairment: Effect size = 0.16 (95% CI: –0.19 to 0.58); p=0.37
Helene Høgsdal,2025 [16]	736	11 weeks	A universal mental health-promoting mobile application (Opp)	Sleep	Questions from Bergen Child Study	Sleep: p=0.258
Niranjan Bidargaddi, 2017 [17]	387	4 weeks	mobile app: "The Toolbox" consisting of 46 built-in health and well-being apps	Sleep quality	EMAs: how well did you sleep last night?	control: −2.34 (−3.16 to −1.52), P<.001; intervention: −.46 (−1.66 to 0.74), P=.15; difference between groups: 1.88 (0.43-3.34), P<.001
Katrina E Champion, 2023 [18]	6640	24 months	an eHealth Health4Life: six online cartoon modules + a companion smartphone app	Sleep duration	self-report surveys	sleep duration: OR = 0.91, 95% CI 0.72–1.14
E. M. Boucher, 2024 [19]	303	12 weeks	self-guided DMHI app: Happify for Teens	Sleep disturbance	PROMIS (Patient-Reported Outcomes Measurement Information System) Pediatric Sleep Disturbance Scale—Short Form 4a (questionnaire)	no significance difference of sleep disturbance: Ps>=.096
Siobhan O'Dean, 2023 [20]	6640	24 months	an eHealth Health4Life: six 20-minute online cartoon modules plus an optional companion smartphone app and internet-based feedback	Difficulty falling asleep, Daytime sleepiness	Self- report: sleep onset difficulty + PDSS (Pediatric Daytime Sleepiness Scale)	Difficulty falling asleep: OR = 0.72 (95% CI 0.51–1.01)

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Table 1. (continued)

Katrina E Champion, 2024 [21]	6639	24 months	six cartoon modules with web-based tailored feedback and an optional companion smartphone app	Sleep intentions	Self-report questionnaires on sleep for [9–11 or 8–10] hours per night on all or most days of the week with 4-point scale ranging from 0 (not at all true of me) to 3 (very true of me)	For intervention group, higher odds of changing to higher intentions to get the recommended amount of sleep from baseline to post-intervention follow-up (OR = 1.33, 95% CI = 1.16, 1.52, p < 0.001), but effects were again no longer significant at 12 or 24 months
Bethany Cliffe, 2020 [22]	39	8.5 weeks	Sleepio: a web-base CBT	Sleep efficiency, Sleep quality, Insomnia symptoms	Sleep Condition Indicator (SCI), Insomnia Severity Index (ISI), Sleep diary	Sleep efficiency (P=.005), sleep quality (P=.001), measures of sleep (SCI: P=.001 and Insomnia Severity Index: P=.001)
Gary Garcia Molina, 2025 [23]	17	2 weeks	Auditory stimulation during deep sleep	Slow-Wave Activity (SWA)	EEG; CASQ; Karolinska Sleepiness Scale	Slow-Wave Activity (SWA): +7.57%
Kara M Duraccio, 2021 [24]	167	1 weeks	iPhone's Night Shift	Sleep onset Latency, Sleep efficiency, Total sleep time, WASO	Actigraphy	Sleep onset latency: p=0.85, TST: p=0.59, WASO: p=0.81, sleep efficiency: p=0.59
First Author, Year	Sample Size	Intervention Time length	mHealth Technology	Parameter of sleep health	Outcome measurement method	Outcome data
Si-Jing Chen,2024 [25]	708	6 weeks	app-based cognitive behavioral therapy for insomnia (CBT-I)	Remission of insomnia disorder, Insomnia symptoms	Insomnia Severity Index (ISI)	Remission of insomnia disorder: relative risk [RR] 1.83, [95% CI 1.49–2.24]; p < 0.001 (Significant)Insomnia symptoms: −1.7 [95% CI −2.4 to −1.0]; d = 0.66; p < 0.001
Aliza Werner-Seidler, 2023 [26]	264	6 weeks	Ninja (an app-delivered cognitive behavioral therapy program for insomnia)	Insomnia symptoms, sleep quality, Pre-sleep arousal	ISI, PQSI, SRBQ, PSAS, ESS, FFS	Insomnia symptoms: post-intervention: 95% CI = –2.96 to –0.41, d = 0.41; follow-up: 95% CI = –3.34 to –0.19, d = 0.39Sleep quality: from baseline to post: 95% CI = –2.30 to –0.03, d = 0.39; follow-up: 95% CI = –2.45 to –0.16, d = 0.44Pre-sleep arousal: 95% CI: -8.05 to -2.42, d = .10
Nicole E Carmona, 2021 [27]	83	4 weeks	transdiagnostic sleep app called DOZE (Delivering Online Zzz's with Empirical Support).	Insomnia symptoms, Sleep efficiency	Insomnia Severity Index (ISI),Cleveland Adolescent Sleepiness Questionnaire (CASQ), FSS	Sleep efficiency (p=.001); Insomnia symptoms: [95% CI 2.82-5.17]; p=0.001
Sophie H. Li, 2023 [28]	264	6 weeks	Sleep Ninja: a CBT-I smartphone app for adolescents	DBAS	ISI, 20-item ruminative thought style questionnaire (RTSQ) for rumination, 10-item dysfunctional beliefs and attitudes about sleep scale for children (DBAS) for unhelpful beliefs about sleep	Dysfunctional Beliefs and Attitudes about Sleep Scale for children (DBAS-10): p=.04, d =1.24

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Table 1. (continued)

Ngan Yin Chan, 2019 [29]	203	4 weeks	SMS/push message	Bedtime, Sleep duration, Wake-up time, SOL, WASO	Sleep diary + Actigraphy (Philips Actiwatch Spectrum Plus) + Pediatric Daytime Sleepiness Scale (PDSS)+Adolescent Sleep Hygiene Scale (ASHS)	Weekday bedtime (sleep diary): 95% CI [12.64–54.46], p = 0.002 (Significant)Weekday bedtime (actigraphy): 95% CI [8.15 to 57.90] p = 0.009 (Significant)Weekday sleep duration at 3 months follow-up: 35.26 min longer, 95% CI [12.33 to 58.19], p = 0.003 (Significant)
Songül Çağlar, 2024 [30]	55	4 weeks	WhatsApp (social media reminder)	Sleep quality, daytime sleepiness, sleep hygiene, SWS, REM sleep, Total Sleep Time, Bedtime, WASO, Waketime	PSQI, CASQ, Adolescent Sleep Habit Form, Actigraphy	PSQI decrease p=0.01, CASQ decrease p=0.02, AHSF increase p=0.02no statistically significant different for bedtime, wake time, total sleep time, deep sleep time and light sleep time p>0.05
Yingfeng Zheng, 2021 [31]	954	2 weeks	REAP app: a peer to peer live-streaming app, prompted by SMS text messaging for each use.	Sleep disturbance	PROMIS Sleep Disturbance	Sleep disturbance: 0.05 (95% CI –0.03 to 0.13), p=.22

Table 2. Sleep parameter frequency

Sleep Parameter	Article	Count
Sleep quality	[14,17,25,29,31]	5
Insomnia symptoms	[15,25,26,31]	4
Sleep disturbance	[15,19,30]	3
Sleep efficiency	[23,26,31]	3
WASO	[23,28,29]	3
Sleep duration	[18,28]	2
Bedtime/Waketime	[28,29]	2
Total Sleep Time	[23,29]	2
Slow-Wave Activity (SWA)	[22,29]	2
Daytime sleepiness	[20,29]	2
Sleep-related impairment	[15]	1
Difficulty falling asleep	[20]	1
Sleep intentions	[21]	1
Sleep onset Latency	[23]	1
Pre-sleep arousal	[25]	1
DBAS	[27]	1
Sleep hygiene / REM sleep	[29]	1

Table 3. Sleep outcome measurement

Outcome Measurement	Article(s)	Count
non-standardized questionnaires or diary	[14,16-18,20,21,28,31]	8
ISI	[24-27,31]	5
CASQ	[22,26,29]	3
PROMIS	[19,25,30]	3
Actigraphy	[23,28,29]	3
PSQI	[25,29]	2
FSS	[25,26]	2

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Table 3. (continued)

PDSS	[17,20]	2
Accelerometer	[14]	1
EGG	[22]	1
Karolinska Sleepiness Scale	[22]	1
SRBQ	[25]	1
PSAS	[25]	1
ESS	[25]	1
DBAS	[27]	1
RTSQ	[27]	1
ASHS	[28]	1
Adolescent Sleep Habit Form	[29]	1
SCI	[31]	1

4) Internet-based interventions: One included study (N=1, 5.6%) implemented internet-based interventions. Although programs such as Internet-delivered CBT (WebMAP2) were originally designed as web-based platform, they can be ac- cessed not only on laptops but also on mobile phones and tablets. Therefore, the internet-based intervention was also categorized as mobile mHealth tool, aiming to improve the sleep health through wireless devices [31].

5) Device-based Interventions: Two studies (N=2, 11.1%) utilized device-based interventions to improve sleep health for adolescents and young adults. One studies delivered auditory stimulation during deep sleep, the other used the iPhone's built-in Night Shift function to reduce blue light exposure and wrist-worn devices integrated with mobile platforms for passive monitoring of sleep patterns [22,23].

3.6. Intervention outcomes

Most studies (N=10, 55.6%) reported statistically significant improvements in at least one sleep-related outcome, including sleep quality, sleep duration, bedtime/wake-up patterns, insom- nia symptoms and sleep efficiency. However, seven studies (N=8, 44.4%) showed no significant effect in sleep health and one study demonstrated only short-term improvements that were not sustained at longer-term follow-up.

Through categorizing intervention outcomes by different intervention methods, the CBT-I app-based mHealth inter- ventions have the most consistent improvement, reporting significant effects on outcomes such as sleep quality, effi- ciency, and insomnia symptoms. Two out of three studies using digital reminder approaches (SMS, WhatsApp) were also effective in improving sleep duration and bedtime patterns. In contrast, among the eight studies that employed general health-promotion or multi-component apps, only three (37.5%) reported significant improvements in sleep-related outcome (e.g., LIFEGOALS app improving sleep quality, the Toolbox app showing group differences $p < 0.001$, and Health4Life modules increasing sleep intentions, OR=1.33, $p < 0.001$). The remaining five studies (62.5%) did not demonstrated significant effects on outcomes such as sleep disturbance, duration, or sleep onset difficulty.

4. Discussion

The use of mHealth technologies for sleep intervention in a a real-world setting is an emerging field that offers various op- portunities for future public health research and applications. Previous

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literature reviews on sleep interventions have mainly focused on the adult populations and clinical settings. No review has directly examinedto which mHealth technologies have a significant impact on adolescents and young adults. Furthermore, the discussion of this review synthesizes the key parameters used to assess adolescent sleep, evaluate the ef- fectiveness and limitations of different mHealth interventions, and outline recommendations for future directions of public health stduies.

4.1. Summary of key findings

This scoping review included 18 studies that reported the effectiveness of mHealth technology in improving sleep for adolescents and young adults. The most commonly reported sleep health parameter was the sleep quality (N=5), followed by insomnia symptoms (N=3), sleep disturbance and sleep efficiency. To measure the sleep outcomes and improvement, the majority of studies utilized subjective self-report ques- tionnaires or diaries (N=14 of 18), whereas only four studies detected the sleep health via objective wearable sensors. More than half of the included studies (N=10 of 18) in this scoping review reported their mHealth interventions have significant impacts on at least one sleep health parameter. The CBT-I app- based mHealth interventions and digital reminder approaches have the most consistent improvement, reporting significant effects on sleep health outcomes such as sleep quality, effi- ciency, and insomnia symptoms.

4.2. Comparison with existing literature

This scoping review assessed the effectiveness of mHealth in improving sleep health for teenagers and young adults. The high effectiveness of CBT-I based application intervention aligns with the pervious review article, which shown the digital CBT-I application achieve larger effect sizes in both short- term and long-term outcomes when delivered to participants with clinically significant insomnia. The study explained that participants with higher baseline insomnia severity give out more room for improvement in sleep quality and insomnia symptoms compared with control groups [32].

On the contrary, health-promotion apps in our review showed little or no significant impact on sleep outcomes. This observation reflects the findings from a systematic review of sleep-related mHealth apps, which reported that most pro- grams draw on only a small portion of the health and lifestyle promotion only use behavior change techniques (BCTs) that related to goal setting and feedback. The limited use of BCTS and the lack depth in intervention design may explain why the health-promotion apps showed no significant improvement in sleep outcome in the review [33]. The finding also explains the reason why mHealth interventions have ineffective long-term impact is because people do not engage with the tracking apps in long term [33].

4.3. Limitation of the review

This scoping review maps and evaluates the effectiveness of different mHealth technologies in improving the sleep health targeted on adolescents and young adults. The review has a relatively small number of eligible studies that met our inclusion criteria, which makes the article hard to draw firm conclusion because of insufficient evidence. Secondly, many included studies relied heavily on these subjective and non-standardized outcome measurements, other than validated instruments such as ISI, CASQ or PROMIS. It limits the comparability across studies and reduce the generalizability of these findings. Finally, improving sleep health outcome might not be the primary intervention focus for many included studies, which means the results from these articles might lack reliability and sufficient evidence to demonstrate significant positive effects on sleep health improvement.

4.4. Future work

Since the article identifies many limitations of the review, future research on sleep health for adolescents and young adults and mHealth interventions should address these issues in several ways:

Firstly, future trials should adopt the standardized question- naires combined with objective measures, such as actigraphy or wearable sensors to improve the reliability of the result. In addition, further exploration could narrow the scope to one specific type of mHealth interventions to have an in-depth understanding and evaluation on its intervention effects.

Finally, future innovations should incorporate more behavior change techniques to enhance the long-term intervention effect through techniques like personalized feedback or gamification.

5. Conclusion

This scoping review mapped and evaluated the effectiveness of mHealth interventions for improving sleep in adolescents and young adults. While mHealth technologies have been recognized as vital tools for health intervention and sleep management, just over half of the included studies had significant improvements in at least one sleep health outcome. The CBT-I app-based mHealth interventions and digital reminder approaches have the most consistent improvement.

By focusing specifically on teenagers, this review fills the critical gap in the literature, as previous reviews always focused on adults and clinical groups as their target population. The findings underscore both the potential and the limitations of current mHealth approaches for adolescents and young adults, particularly regarding long-term effectiveness. How- ever, it is essential to acknowledge that the generalizability of the results might be limited, as the evaluation of mHealth technologies was measured by different measurements and tools.

Consequently, while mHealth technologies offer various opportunities to address adolescent sleep problems, it is im- perative to have greater consistency in measurement and more standardized study designs. Future interventions could build on the strength of CBT-I and integrate behavior change techniques and objective monitoring tools, ensuring that adolescent sleep health can be supported more effectively at scale in real-world contexts and situations.

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