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Digital Technologies Developed for Enhancing Physical Activity Among Youth: A 20-Year Umbrella Review and Systematic Review*

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Abstract

The impact of digital technologies on physical activity, sedentary behavior, energy expenditure, and weight loss has been a subject of long-standing investigation. While numerous studies have been conducted, their findings often lack the consistency needed to provide a comprehensive understanding. This has led to a surge in systematic reviews aimed at compiling primary studies to deliver more objective and holistic insights. An umbrella review covering 20 years of systematic reviews on the influence of digital technologies on increasing physical activity identified significant gaps. Notably, no systematic review focused exclusively on youth aged 14-29, and existing reviews exhibited considerable variability due to differences in target populations, technologies used, study designs, and inconsistent findings. Building on the umbrella review, the systematic review adhered to the same framework in terms of research questions, study protocol, data selection, inclusion and exclusion criteria, and methodology, with the key distinction being the population criteria. Specifically, while the umbrella review included studies encompassing a range of age groups, the systematic review focused exclusively on studies recruiting participants within the 14-29 age range. The umbrella review analyzed 22 high-quality systematic reviews encompassing a broad spectrum of digital interventions. Using the categories established by the umbrella review, the systematic review synthesized findings from 108 studies targeting youth exclusively. These findings revealed emerging insights into the potential of digital technologies for promoting physical activity. The analysis highlighted the need for robust, theory-driven interventions and longitudinal studies to establish sustainable behavioral changes in this age group.
Keywords: Digital technologies, Sport, Physical activity, Youth, Sedentary lifestyle

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INTRODUCTION

Previous studies have explored various digital technologies, including mobile apps, social media, chatbots, exergames, and wearable trackers, to assess their effectiveness in promoting physical activity (PA) and reducing sedentary behavior among different age groups (Au et al., 2024; Bi et al., 2024). For instance, recent studies emphasize digital behavior interventions designed to foster PA and healthy lifestyle using strategies such as goal setting, self-monitoring, feedback, and reminders (Zhu et al., 2024). Benítez-Andrades et al. (2024) argued that gamified social-network-based eHealth interventions have demonstrated improvements in physical activity and BMI. On the other hand, Ibrahim et al. (2023) suggested that reliable assessment methods, such as ecological momentary assessments (EMAs), have proven to be more accurate than traditional retrospective surveys for measuring PA. Despite extensive research, however, findings remain inconsistent, highlighting the need for systematic reviews to synthesize existing studies and provide more comprehensive insights (Higgins et al., 2021). Moreover, the targeted age ranges in existing systematic reviews often vary due to the diverse recruitment criteria used in primary studies. Some reviews focus on younger school-aged children (Sousa et al., 2023), while others concentrate on adults aged 18 and above (Bi et al., 2024; Bravata et al., 2007). Despite numerous reviews including youth aged 14–29, specific evidence about the effectiveness of digital interventions within this demographic remains unclear, particularly regarding sustained increases in PA and reductions in sedentary behavior. Recent evidence indicates that wearable activity trackers effectively increase daily step counts but have limited effects on moderate-to-vigorous physical activity (MVPA) in adolescents and young adults (Au et al., 2024).

Despite the rapid growth in research investigating technology-driven interventions for physical activity/healthy lifestyle promotion, recent systematic reviews and meta-analysis shows that there remains a lack of consensus regarding their overall effectiveness and the most optimal methods for implementation, and more systematic reviews are required (Ahraz et al., 2021; Bi et al., 2024; Kardan et al., 2024). Therefore, this study seeks to fill these existing gaps by conducting an umbrella review that synthesizes prior relevant systematic reviews, followed by a new systematic review informed by the findings of the umbrella review. Indeed, umbrella reviews, which aggregate findings from multiple systematic reviews, offer an effective way to consolidate and contextualize existing evidence (Aromataris et al., 2024; Russell et al., 2025). This umbrella review specifically focuses on systematic reviews that encompass the youth age group, defined as individuals aged 14 to 29. In this context, the following research questions explore key digital technologies promoting youth physical activity, their impact measurement, and connections to behavior change, reliability, validity, and usability.

1.What types of digital technologies are commonly utilized by young people to enhance their physical activity, and how do these technologies function?
2.How is the impact of these digital technologies on young people's physical activity participation assessed?
3.What is the relationship between these technologies and behavior change, and how are reliability, validity, and usability aspects evaluated?

METHOD

This section outlines the methodological procedures adopted in the umbrella review and the subsequent systematic review. Both reviews were designed to capture research published over the past two decades, ensuring a focus on contemporary developments in the field. A consistent search strategy was employed across both reviews, including the use of identical databases, keywords, and inclusion/exclusion criteria, all of which were developed through a peer-reviewed process. To guide the reporting process, the PRISMA flowchart methodology was applied (Tricco et al., 2018), which are presented in Figure 1 and 2.

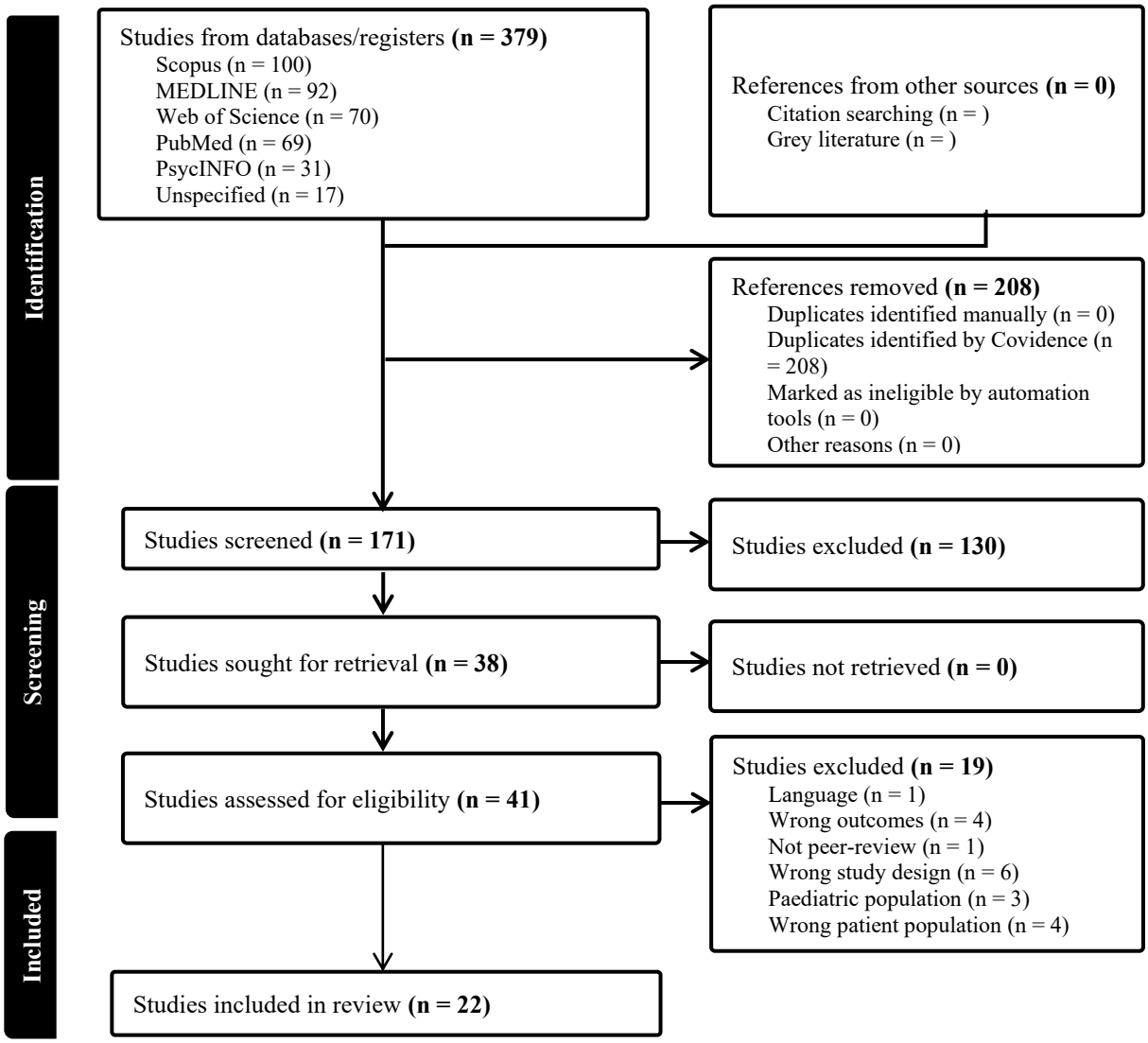

Figure 1. PRISMA flowchart for umbrella review

Methodology for Umbrella Review (UR)

The AMSTAR tool—a validated instrument designed to assess the methodological quality of multiple systematic reviews—was used for quality appraisal (Shea et al., 2007). Database searches were conducted in APA PsycInfo, MEDLINE, PubMed, Scopus, Web of Science, and SPORTDiscus, targeting publications from 2004 to 2023. The complete list of search terms can be found in Supplementary Material 2. After database queries were completed, the identified

records were imported into Covidence. A systematic review management tool. Duplicates were removed, and the remaining studies underwent a two-phase screening process: first by title and abstract, then through full-text assessment. Eligibility was limited to studies conducted in partner countries (Türkiye, Italy, and Slovakia) and those published in English. Studies that were irrelevant to the topic, methodologically incomplete, not peer-reviewed, or presented in the form of editorials, books, opinion pieces, or traditional (non-systematic) reviews were excluded to maintain methodological rigor. The umbrella review aimed to deliver a consolidated overview of systematic reviews addressing the use of digital technologies to enhance physical activity among youth (Belbasis et al., 2022). This review enabled a broad analysis of the methodologies employed in primary studies, systematic reviews, and meta-analyses, regardless of whether they followed qualitative or quantitative approaches (Aromataris et al., 2024).

Data Analysis and Synthesizing for Umbrella Review

As recommended in the literature, systematic reviews of low methodological quality were excluded (Aromataris et al., 2024). The AMSTAR tool, consisting of 11 items, was used to assess quality (Shea et al., 2007). All selected systematic reviews and meta-analyses were of high quality (see Supplementary Material 2). Included studies varied in design and in how they measured the impact of digital technologies on physical activity (PA), sedentary behavior (SB), and energy expenditure (EE). The umbrella review served as a foundation for the systematic review, identifying recurring patterns and core dimensions regarding digital technologies' influence on PA behaviors among youth. Five key dimensions emerged: 1. Types of Digital Technologies Used, 2. Design and Functional Characteristics, 3. Impacts on PA, SB, and EE, 4. Integration of Behavior Change Theories, 5. Credibility, Reliability, and Usability of Technologies. The review began with 379 studies (post-duplicate removal). Of these, 171 were screened by title and abstract. Forty-one full texts were assessed, and 22 studies were included in the synthesis (see PRISMA Flowchart in Supplementary Material 3). Due to time and funding limitations, a narrative synthesis approach was used. This method is suitable for descriptive findings reported in systematic reviews and the results are organized around the five thematic dimensions.

Methodology for Systematic Review (SR)

Following the umbrella review, a systematic review was conducted due to the number and heterogeneity of studies on digital technologies promoting PA. Given intervention diversity, tools, and aims, a narrative review was used instead of a meta-analysis. This review was pre-registered in PROSPERO (CRD42024530066), followed by Cochrane Handbook standards, and adhered to PRISMA guidelines (Tricco et al., 2018). Research questions matched those in the umbrella review. Searches were conducted in six databases (APA PsycInfo, MEDLINE, PubMed, Scopus, Web of Science, and SPORTDiscus) for the last 20 years. Search terms are in Supplementary Material 1. After deduplication, a multi-phase screening was conducted. Inclusion/exclusion criteria were consistent with the umbrella review, except this review included only participants aged 14–29.

Data Analysis and Synthesis for Systematic Review (SR)

AMSTAR was used in the umbrella review (Shea et al., 2007). For this review's primary studies, the CASP checklist (2018) was used for quality appraisal (CASP, 2018; please see Supplementary Material 4). A narrative synthesis was applied, using umbrella-derived themes: 1. Types of Digital Technologies, 2. Design and Functional Features, 3. Impacts on PA, SB, and EE, 4. Use of Behavior Change Theories, 5. Credibility, Reliability, and Usability. This thematic consistency was maintained due to the overlap between reviews and resource limits. No significant divergence in conceptual frameworks requires new categories. This systematic review covered more studies than the umbrella review. After duplicate removal, 5,935 articles remained. Title/abstract review identified 427 for full-text review. Of these, 108 met all criteria and were synthesized, as shown in below PRISMA Flowchart.

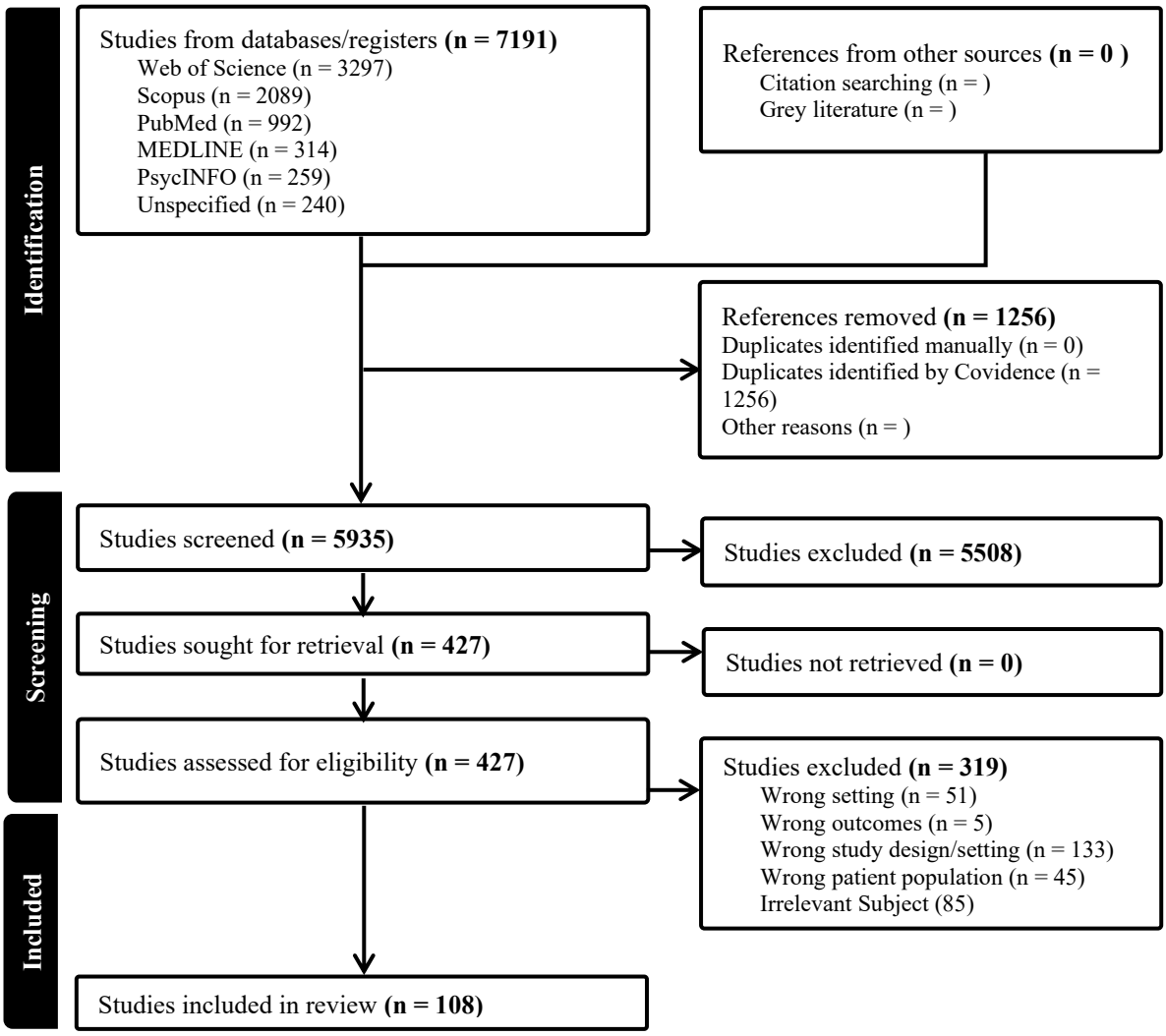

Figure 2. PRISMA flowchart for systematic review

FINDINGS and DISCUSSION

This section outlines the findings in two main parts, accompanied by a discussion that incorporates recent literature: the Results of the Umbrella Review and the Results of the Systematic Review.

Results of Umbrella Review

The umbrella review was conducted through a thorough, peer-reviewed screening process. An initial search of selected databases identified 379 systematic reviews. Following the removal of 208 duplicates, 171 records underwent screening, resulting in 22 reviews that met the inclusion criteria. These 22 reviews collectively encompass findings from 489 primary studies, with each review including between 5 and 60 studies. This wide range underscores the necessity for more comprehensive analyses of digital technologies (DTs) in promoting physical activity (PA). Accordingly, the findings were organized into five key dimensions:

1. Types of Digital Technologies
2. Design and Functional Characteristics
3. Effects on PA, Sedentary Behavior (SB), and Energy Expenditure (EE)
4. Use of Behavior Change Theories (BCTs)
5. Credibility, Reliability, and Usability

1. Types of Digital Technologies

The diversity of digital technologies was large in the compilation of identified systematic reviews. Furthermore, the use of such technologies is not only aimed at PA but also at improving health, well-being, sleep quality, weight loss, and more. In this context, Included systematic reviews focused following technologies: 1) Text Messages or Emails [#33, #39, #56, #153, #173], 2) Smartphone applications [#31, #32, #39, #45, #56, #72, #79, #85, #86, #147], 3) Social media [#10, #64], 4) Wearable Devices #2, #45, #64, #72, #85, #160, #173], 5) Chatbots[#113], 5) Exergames [#20, #43, #69, #79, , #81, #148] and 6) Web-based interventions #25, #39, #72, #79, #81].

2. Design and Characteristics

6 included systematic review studies (#33, #32, #45, #147, #148, #64) focused on the design, and characteristics of the DTs which aim to increase PA. Only study #64 directly addressed barriers and facilitators regarding digital technology use for PA. Eaton et al. (2024) identified significant limitations in the literature, especially the substantial inconsistency in the conceptualization of user engagement. This aligns with the findings of Schwarz et al. (2023), who highlight that applications exhibit various types of incompatibility in this context. The findings of this umbrella review back up these observations and highlight the need for standardization, as well as the establishment of a clear agenda for developers, grounded in user feedback.

3. Impact on PA, EE, and SB

Previous systematic reviews included one or multiple digital technologies such as social media, digital apps, chatbots, exergames etc. While only study #10 focused on social media, study #113 synthesized findings of chatbots-based PA interventions. Similarly, only study #153 compiled data from text-messaging interventions that aim to increase PA. In return, this UR found a few of systematic review that synthesized exergame-related PA studies (#43, #69, #81). Lastly, study #64 and #79 synthesized findings of multiple digital technologies such as social media, digital apps, chatbots, exergame etc. Similarly, we found that systematic review #86 was related to the utilization of digital apps for PA. Further details on the impact on physical activity (PA), energy expenditure (EE), and sedentary behavior (SB) are provided below, respectively.

PA: Study #10, #113, #69, #153, #43, #39, #81 and #64 found an increase in PA while study #86 results were trivial for total PA and, the pooled effect of MVPA size is moderately positive. On the other hand, study #79 and #113 finding were mixed. There is clear evidence showing that any kind of digital technology potentially increase the amount of PA but often short or moderate level. Moreover, Daniels et al. (2025) recently report that such interventions impacts are highly variable. As such, the more study and updated systematic review may be useful to show the longitudinal impact of such technologies

EE: Both study #20 and #43 synthesized findings of active video games. While study 10 identified an increase in EE, study #20 findings were contradictory. Notwithstanding, this systematic review found that cross-sectional studies results were slightly positive, compared to longitudinal Studies. França et al. (2024) propose that these technologies just serve as supplementary tools alongside traditional physical activities, rather than being the primary means to enhance energy expenditure. Consequently, a broader and more comprehensive systematic review is warranted to encompass various types of digital technologies and compare their effectiveness.

SB: While study #86 and #81 brought together outcome of studies that investigated the impact of digital apps on SB, only study #43 synthesized the impact of exergame on SB. Lastly, study #64 amalgamated study's findings of several type of digital technologies rather than focusing on only one. Having said that, Study #86, #43, #64 found a decrease in SB while #81 found a mixed impact. Iwakura et al. (2025), in their recent comprehensive review, found that digital technologies produced small but statistically significant reductions in sedentary behavior. However, since their focus was on workers, these findings may have limited applicability to young people. Nonetheless, it is reasonable to conclude that digital technologies—especially exergames—are likely effective in helping young people reduce their sedentary behavior.

4. Behavior Change Theories

Only one study among included SR (#86) particularly focused on the amalgamation of studies regarding use of behavioral changes theories. Other systematic reviews (#39, #64, #81, #153, #160) partially addressed these BCTs. These were goal setting, instruction on behavior performance, self-monitoring and social support, information about health consequences, the

transtheoretical model of behavior change, stage of motivational readiness for change model, self-determined theory, Behavioral economics, Social cognitive theory, theory of planned behavior, behavior change technology, transtheoretical model, Whole Person Wellness Model, theories of perceived value, fun theory, socio-cognitive learning theory, and the health action process approach. The WHO's (2022) Global Status Report on PA highlights the importance of digital platforms in facilitating behavior change regarding PA, EE and SB. However, existing research has yet to identify the specific theories that can enhance our understanding of how digital technologies are used to promote physical activity. Consequently, there is an urgent need that particularly focus on how behavior change theories are used in these interventions and whether there are specific theories that provide a comprehensive lens to understand users` behaviors towards such technologies. Notwithstanding, other systematic reviews (#64, #81, #39, #153, #160) partially addressed these BCTs.

5. Reliability, Validity, and Usability

More than half of included systematic reviews provided information about the one or multiple of validity, Reliability and usability issues for Digital Technologies (#160, #33, #86, #2, #113, #31, #160, #32, #45, #148, #81). Study #160, #2, #31, #33 and #86 focused on the validity of digital technologies including ecological validity. While some studies (#2, #31 and #32) evaluated the reliability of such technologies. Study #113, #160, and #45 explored the usability (i.e. feasibility, acceptability). Notwithstanding, it is vital to point out that majorities of such digital technologies are commercially developed. Fuller et al. (2020) contend that commercial technologies generally demonstrate higher reliability, validity, and usability compared to non-commercial technologies. Conversely, Benzo et al. (2025) highlight that variability among devices and the absence of standardized evaluation methods pose significant challenges in assessing the reliability, validity, and usability of these technologies. Accordingly, it is safe to say that although there is sufficient data to evaluate reliability, validity and usability of DT for PA, reporting system of these studies, which often aimed developers and researchers may not be clear for users, who are not expert in the field. Therefore, there is an urgent need for comprehensive and clear guideline for users, moreover, this will probably increase the impact of these technologies, accordingly, the physical activity levels of target group.

Results of Systematic Review

The present systematic review synthesized evidence from 108 peer-reviewed studies examining the impact of digital technologies on the promotion of physical activity (PA). These studies exhibited considerable heterogeneity in terms of sample size (ranging from 10 to 1,600 participants), geographic distribution, types of digital interventions, methodological approaches, research designs, and reported outcomes. The duration of the intervention varied widely, from as short as one day to as long as 52 weeks, with an average duration of approximately nine weeks. A temporal analysis of the included studies reveals a marked increase in research activity between 2011 and 2024, highlighting growing scholarly interest in the intersection of digital technologies and physical activity promotion.

The included studies are geographically distributed across 31 different countries. Notably, the majority of the studies, with 47 investigations, were conducted in the USA, followed by eight studies from Australia, and five studies from the UK. The remaining studies are spread across various other countries, with one to four studies conducted in each. A detailed breakdown of these distributions can be found in the Supplementary Material 2.

Across the included studies, digital technologies were deployed either as standalone interventions or in combination with other tools. Specifically, 57 studies employed smartphone applications, 33 utilized wearable technologies, and 16 implemented virtual reality (VR) systems. Social media platforms were integrated in 11 studies, while both short message service (SMS) and web-based applications were each featured in 7 studies. Additionally, 3 studies incorporated exergames, and 2 studies each employed accelerometers and global positioning system (GPS) technologies. A comprehensive breakdown of these distributions is provided in Supplementary Material 2.

A total of 14 studies adopted a mixed-methods approach. In these studies, the quantitative phase typically employed a pre-test–post-test design with randomized control groups, while the qualitative component included observational methods such as content analysis (n=6), semi-structured interviews (n=2), and focus groups (n=6). In contrast, 84 studies followed a purely quantitative research design. Among them, 72 studies utilized a pre-test–post-test model with control groups—37 of which were randomized and 35 non-randomized. The remaining quantitative studies employed relational survey and causal-comparative methods. Lastly, 12 studies applied qualitative designs, incorporating in-depth semi-structured interviews (n=3), focus groups (n=6), and observational techniques (n=3). Detailed methodological characteristics are presented in Supplementary Material 2.

As previously highlighted, prior systematic reviews examining the relationship between physical activity (PA) and digital technologies (DTs) typically included an average of 22 studies, with the highest number reported being 60. In contrast, the current systematic review incorporates 108 studies, which nearly doubling the most comprehensive previous effort. This considerably broader scope enhances the inclusivity and depth of analysis, providing a more robust understanding of how digital technologies influence PA.

The findings emerged from a meticulous search strategy conducted across multiple databases, which yielded 5,935 unique records after duplicate removal. Titles and abstracts were then screened through a blinded peer-review process, resulting in 427 studies eligible for full-text evaluation. Following this process, 108 studies met the inclusion criteria and were systematically analysed.

To maintain consistency and comparability, the synthesis of findings was structured using predefined categories established in a prior umbrella review. This approach was deemed appropriate, as the included studies aligned closely with the existing thematic classifications

and did not necessitate the development of new analytical categories. Accordingly, the narrative synthesis is organized under the following five predefined categories:

1. Types of Digital Technologies,
2. Design and Characteristics of These Technologies,
3. Effects of DTs on Physical Activity, Sedentary Behavior (SB), Energy Expenditure (EE),
4. Behavior Change Theories (BCTs),
5. Credibility, Reliability, and Usability of Digital Technologies for PA.

1. Type of Digital Technologies used to increase PA

This systematic review synthesized evidence from 108 studies encompassing a total of 10,530 participants, aiming to evaluate the effectiveness of various digital technologies (DTs) in promoting physical activity (PA). The included studies varied widely in terms of publication year, sample size (ranging from 10 to 1,600; M ≈ 100), geographical context, technological approach, research design, and reported outcomes. Intervention durations ranged from 1 day to 52 weeks, with an average length of 9 weeks. Considering the duration of the intervention, this result holds significance for the sustainability of behavioral changes. Research indicates that while short-term interventions can produce changes in individuals, long-term and well-structured interventions tend to be more effective in achieving lasting behavioral modifications (Stephens et al., 2017a; Biddle & Mutrie, 2007). Around 60% of the participants were female and 40% male. Prior studies suggest that women tend to engage with digital technologies more frequently (König et al., 2018). Therefore, the predominance of female participants highlights the need to incorporate gender-sensitive approaches when designing interventions.

Geographic and Demographic Distribution: The studies were conducted across 31 countries, with the United States (n = 47) being the most represented, followed by Australia (n = 8) and the United Kingdom (n = 5). An increase in research from Asian countries was also observed. In terms of ethnicity, around 50% of participants were White, 25% Asian, and the rest from other ethnic backgrounds. Supplementary Material 5 illustrates the year-by-year distribution of studies between 2011 and 2024. In general, ensuring geographical and demographic diversity in systematic review studies increases the generalizability of the results (Michie et. al., 2011).

Types of Digital Technologies: The studies employed a range of digital technologies, either as standalone interventions or in combination. The frequency of use across technologies was as follows: Smartphone applications: 57 studies, Wearable technologies: 33 studies, Virtual reality (VR): 16 studies, social media platforms: 11 studies, SMS and web-based applications: 7 studies each, Exergames: 3 studies, and Accelerometers and GPS: 2 studies each. The differences between types of digital technology vary according to the benefits and objectives expected by users (Lewis et al., 2015). Wearable technologies such as wristbands and smartwatches that provide instant feedback to users have been found to be effective in promoting behavioral change, such as PA (Brickwood et al., 2019). Among the various types of technologies such as exergames, those incorporating gamification demonstrated a longer-lasting positive effect compared to those without it. While there is a growing research interest in wearable technologies, virtual reality, and social media, SMS and web-based applications have gradually received less attention in the literature.

Methodological Designs: Mixed-methods approaches were used in 12 studies, featuring pre-test/post-test models with randomized control groups at the quantitative stage, and the following techniques in the qualitative component:

- Content analysis: 6 studies
- Semi-structured interviews: 2 studies
- Focus groups: 4 studies

Quantitative-only designs were most dominant methods, and were employed in 84 studies:

- Pre-test/post-test with control groups: 72 studies (37 randomized, 35 non-randomized)
- The remaining studies applied relational survey and causal-comparative methods

Qualitative methods were used in 12 studies:

- In-depth semi-structured interviews: 3 studies
- Focus groups: 6 studies
- Observational techniques: 3 studies

Most studies included in the review utilized quantitative research approaches. Among these, randomized controlled trials are regarded as one of the most trustworthy methods for assessing intervention effectiveness, offering robust evidence of causal links (Moher et al., 2010). Other studies mainly employed correlational surveys and causal comparative designs, which are non-experimental methods that help observe the impact of digital interventions on physical activity (Creswell & Creswell, 2018). Conversely, qualitative methods are essential for gaining detailed insights into aspects such as the process of adopting digital technologies, user experiences, motivations, and encountered challenges (Tong et al., 2007). For instance, factors like users' perceptions of a digital application and its sustainability significantly influence the application's overall success, alongside its technical performance (Greenhalgh et al., 2017). Therefore, it is advisable that future research increasingly adopts mixed method designs that integrate both qualitative and quantitative techniques to more comprehensively evaluate the effectiveness of digital interventions.

2. Design, and Characteristics of Digital Technologies

An essential factor in evaluating the impact of digital technologies on PA—particularly among younger populations—is the consideration of both technological design and the functional features these platforms offer. Several studies collected user feedback to iteratively enhance their platforms, ensuring alignment with participant needs and expectations (&24, &50, &57, &69, &80, &91, &97, &104, &108)

Desing: Research consistently highlights that user-centered design is critical for successful engagement in PA interventions Study (&3, &7, &18, &19, &20, &31, &61, &79, &88). Other essential design features include:

- Cost-effectiveness and portability (Study &7 and &17),
- Quality (Study &49),
- Enjoyment (Study &61 and &19),
- Customizability and privacy (Study &20 and 36), and
- Consistency (Study &21 and &78).

The literature consistently emphasizes that digital solutions that take into account user needs, expectations, and usage habits increase participant engagement and the impact on behavioral change (Perski et al., 2017; Yardley et al., 2015). Additionally, practical features such as cost-effectiveness and portability (Case et al., 2015), personalization, enjoyment, social interaction opportunities, or reward systems can make digital solutions more motivating (Edney et al., 2020). These findings indicate that digital health interventions should focus not only on technological innovation but also on human-centered design principles.

Characteristics: The characteristics of digital technologies such as sociability, motivation, goal setting, self-regulation (Study &3, &9, &17, &20, &31, &33, &49, &90), social support, decision making, problem solving (Study &22), and self-confidence, mindfulness, imagery, attention and concentration (Study &9, &10, &23, &36, &44, &61) were found to positively impact participants' mental well-being and engagement with these technologies. Only one study included in this review suggest that the positive effects of digital technologies on physical activity may stem from the incorporation of features such as single and multi-level tasks with escalating difficulty, reward systems, and individualized performance feedback mechanisms (Study &17). These elements appear to enhance user motivation and engagement by fostering a sense of progression and personal achievement.

However, several potential drawbacks were also identified. Notably, there is a risk of bodily injury associated with momentary lapses in attention, particularly among individuals with physical mobility limitations (Study &10 and &19). Additionally, the emergence of obsessive behaviors and social isolation has been observed in some users (Study &9), alongside performance-related anxiety (Study &31) and concerns over data privacy in web-based applications (Study &20). In summary, digital physical activity technologies play a crucial role not only in supporting physical health outcomes but also in enhancing mental and cognitive resilience (Bailey et al., 2020; Huberty et al., 2019). Nonetheless, research has pointed out that users may sometimes adopt a passive role within digital settings. These insights underscore the need for further research exploring the multifaceted impacts of digital interventions.

3. The Impact of Digital Technologies on PA, EE, and SB

An analysis of 43 studies focusing on digital technologies such as websites, mobile devices, wearable technology, smartphone applications, and SMS revealed that these tools generally promote physical activity (PA) and foster positive engagement (Study &1, &5-7, &12, &15, &17, &28-32, &36, &55, &60, &63-67, &70, &73, &75, &77, &78, &82, &86, &94-98, &100-102, &104, &105, &108, &108). Among the technologies reviewed, virtual reality (VR) emerged as a standout for its ability to immerse users, thereby encouraging higher levels of physical activity compared to traditional methods (Study &8, &11, &19, &41, &59, &62). Indeed, as suggested, VR is especially effective in supporting the early stages of physical activity and sport participation by enhancing participant motivation (Sattar et al., 2019), including motor skill acquisition (Namli et al., 2025). If so; it can be argued that, especially in the context of experimenting with various sports for physical activity, enhanced motor skill acquisition facilitates both participation and sustained involvement.

Energy Expenditure (EE): Among the 108 studies included in this review, only eight explicitly investigated energy expenditure in relation to digital technologies. Of these, four studies primarily assessed the validity of EE measurements, revealing some inconsistencies but generally indicating estimation errors (Study &21, &76, &78, &99). Conversely, Ulas and Semin (2021) reported a decrease in EE when digital technologies were employed for physical activity compared to traditional methods. In contrast, studies by Cellini et al. (2016), Nathan et al. (2020) and Szary et al. (2020) documented an increase in EE associated with the use of digital technologies, suggesting that the impact may vary based on the type of technology and intervention design.

Sedentary Behavior (SB): A limited number of studies emphasized the potential of digital technologies to positively affect sedentary behavior, particularly among young people. These benefits were largely attributed to the integration of behavior change techniques (BCTs) that enhance users' self-efficacy and motivation to reduce sedentary time (Study &1, &12, &13, and &81).

4. Behavior Change Theories

Of the 108 studies analyzed, 38 employed behavioral change theories to examine the effectiveness of digital technologies on PA, while 70 did not utilize such frameworks. Among these, frequently employed theories include goal setting (Study &12, &15, &20, &22, &28, &29, &31, &38-40, &49, &55, &58, &68, &71, &74, &79, &81, &96), self-monitoring (Study &20, &22, &27, &29, &32, &35, &38, &40, &44, &49, &55, &70, &81, &86) social support (Study &15, &20, &22, &27-29, &31, &35, &38, &40, &51, &70, &79, &81, &101, &105), rewards (Study &9, &17, &39, &40, &51, &62), social cognitive theory (Study &20, &27, &41, &62, &89, &95) and self-determination theory (Study &6 and 67), along with other less rarely utilized theories (Study &9, &15 and &22). Indeed, there has been an increasing trend to utilise multiple theoretical frameworks to better comprehend the behavioral impacts of these technologies (Cotie et al., 2025). However, the existing literature does not provide direct comparisons among these theories to identify which best explains behavior change in physical activity through digital technologies, making it difficult to ascertain the most effective one. Nonetheless, studies using these frameworks generally achieve greater clarity in explaining outcomes and behavioral processes.

5. Reliability, Validity and Usability of Digital Technologies for PA

With the increasing variety of digital tools, assessing their reliability, validity, and usability has become critical.

Validity and Reliability: Numerous studies have evaluated the reliability of wearable technologies such as accelerometers, pedometers, and smartwatches. Validity assessments have covered various activities, including water activities (Study &98), ball games (Study &98), running, walking and orientation exercises (Study &21, &24, &26, &45, &57, &69, &80, &91, &97, &99, &102, &108), cycling exercises (Study &64), daily life (Study &24, &36, &67, &78) and sleeping observation (Study &43). In these measurements, various factors were commonly evaluated including sleep quality (Study &43), energy expenditure (Study

&26, &43, &67, &76, &78), heart rate (Study &78, &91, &99, &102), step count (Study &24, &26, &45, &57, &69, &91, &99, &108), MaxVO2 consumption (Study &99), and body position (Study &24, &26, &45, &57, &69, &99). In the reliability studies of these technologies, a generally accepted motion sensor-based activity tracker, devices like GPS, heart rate monitors, laboratory-based energy expenditure estimation devices, VO2 Max tests, video recordings, self-reports were used to track the consistency of the data gathered from these devices. In these reliability tests, variables such as the placement of the device, exercise intensity, and individual differences have influenced the consistency of the results obtained (Fuller et al., 2020). Nonetheless, Benzo et al. (2025) highlight that variability among devices and the absence of standardized evaluation methods pose significant challenges in assessing the reliability, validity, and usability of these technologies.

Usability: Wearable devices are generally regarded as user-friendly, and their usability improves when integrated with mobile applications (Study &97). However, their effectiveness often falls short of smartphones equipped with widely popular apps due to limitations in size and features. (Study &67 and &97). Additionally, while smartwatches are the most preferred wearable technology, they have been reported to offer moderate validity compared to accelerometers and pedometers (Study &21, &24, &67, &76). The findings indicate that personalized messages and applications have been found to enhance the usability of digital technologies (Study &28, &33, &36, &49, &90, &106). However, technical errors in the applications (Study &49) and feelings of pressure, which increase anxiety related to body image (Study &31), are cited as obstacles to usability. Overall, these results support Fuller et al.'s (2020) conclusion that commercial technologies tend to be more user-friendly than non-commercial ones.

CONCLUSION

This systematic review synthesized findings from 108 studies, exceeding the scope of any individual review included in the umbrella analysis. While the umbrella review offered a broader contextual framework, this comprehensive synthesis—spanning two decades—provided a more granular and robust understanding of the evolving role of digital technologies (DTs) in promoting physical activity (PA) among young individuals. Consistent with prior literature, this review confirms the overall positive influence of DTs; however, the impact observed is generally moderate and predominantly short-term. Only 14 studies explicitly addressed long-term effects or retention, highlighting a critical gap in the literature and underscoring the need for longitudinal investigations. although such technologies prove effective in the short term, they fall short in sustaining physical activity over longer periods, partly due to factors like psychological influences. Existing literature and industry practices do not adequately produce solutions for long-term motivation. Nevertheless, before drawing definitive conclusions, it is important to await further studies that specifically examine the long-term impact of psychological factors.

Geographically, the research landscape was dominated by studies from the United States, Australia, and the United Kingdom, with increasing contributions from Asian countries in

recent years. Despite such increase in studies from Asian countries, it is difficult to claim that the findings adequately reflect global perspectives. Therefore, further research from other regions is necessary. Participant demographics reflected a female majority (60%) and a diverse ethnic representation, primarily White and Asian populations. A variety of digital technologies were employed, with several studies combining multiple tools. Despite this diversity, comparative evaluations between distinct technologies remain absent, representing another avenue for future exploration.

The findings suggest that for DTs to effectively support PA among young people, they should exhibit the following characteristics: 1. Ease of use and intuitive design, 2. Affordability, portability, and accessibility, 3. High quality and enjoyable user experience, 4. Customizability to individual needs, and 5. Privacy-conscious infrastructure.

Overall, a significant portion of the reviewed literature (n = 44) supported the role of DTs in enhancing PA levels. Notably, virtual reality (VR) and exergames demonstrated high efficacy, likely due to their immersive and interactive nature. However, findings regarding energy expenditure (EE) were inconsistent—ranging from increases and decreases to issues of measurement reliability—emphasizing the need for standardized assessment tools. Furthermore, a subset of studies indicated that DTs could help reduce sedentary behavior (SB), particularly when behavior change techniques (BCTs) were employed to boost motivation and self-efficacy.

Despite growing interest, the literature still lacks comparative studies of behavior change theories (BCTs), and little is known about their relative effectiveness in guiding DT-based interventions. The short- and medium-term outcomes are well established, yet the mechanisms behind sustained behavioral change over time remain underexplored.

As DTs continue to evolve, their evaluation has become increasingly rigorous, particularly concerning reliability, validity, and usability. Tools such as accelerometers, pedometers, and smartwatches generate valuable data on physical activity, but their precision can be affected by user behaviors and device placement. Most tools are considered user-friendly, especially when integrated with mobile applications that offer tailored features. Nevertheless, limitations such as technical malfunctions, competition from more engaging smartphone apps, and potential impacts on body image present challenges to widespread adoption.

Future research should prioritize improving measurement accuracy across varied conditions, integrating behavior change models more effectively, investigating long-term impacts, comparing multiple DT platforms, and fostering innovation in functionality and design. As digital technologies increasingly converge in features, strategic differentiation will become essential for advancing user engagement and effectiveness. Finally, at the time this study was initiated, no eligible research on AI-based physical activity was available; therefore, it was not included. Future studies should place greater emphasis on these emerging technologies.

Strengths and Limitations

This review offers several notable strengths. First, a comprehensive search strategy was implemented across multiple databases, covering studies published over the last 20 years. This strategy, collaboratively developed and peer-reviewed, ensured the broad and systematic identification of relevant literature. Second, the inclusive search terms and flexible eligibility criteria enabled the capture of a substantial number of pertinent studies (see Supplementary Material 1). Third, the inclusion of 108 studies allowed for an in-depth synthesis and alignment with PRISMA guidelines, enhancing the methodological rigor of the review.

However, some limitations must be acknowledged. The review was limited to studies published in English, Turkish, Italian, and Slovak, potentially excluding relevant research in other languages. Moreover, the review process involved 13 contributors from an Erasmus+ project, many of whom were not academic researchers. Although this may raise concerns regarding reliability, several measures were adopted to mitigate these risks. Reviewers received structured training, standard protocols were used to reduce bias, and the corresponding author served as the lead supervisor and conflict resolver throughout the process. In addition, comprehensive supplementary materials have been provided to ensure the transparency and reproducibility of findings.

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