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SYSTEMATIC REVIEW

Promoting active transportation through technology: a scoping review of mobile apps for walking and cycling

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Abstract

Background Incorporating active transportation (AT), such as walking and cycling, into daily routines is a promising solution for meeting the World Health Organization's physical activity recommendations and contributes to reducing the risk of many noncommunicable diseases. Smartphone apps offer versatile platforms for embedding health behavior promotion strategies to encourage AT.

Objective This scoping review aimed to provide an overview of how mobile apps are being used to promote AT through reviews of the academic literature and commercial app stores.

Methods We searched six academic databases (Embase, Medline, Web of Science, PsychINFO, Transport Database, and Google Scholar) for academic literature. The literature was included if it presented a developed app to promote AT behaviors. AT promotion strategies and theories were extracted and analyzed for their impact on changing behaviors and behavioral intentions toward AT. Commercial apps were searched in two app stores (the Apple App Store and the Google Play Store) across six countries, one per continent. Apps were included if they promoted and encouraged AT behavior. We evaluated the apps on the basis of user engagement and their quality and potential to change behaviors, as assessed via the Mobile App Rating Scale (MARS) and the App Behavior Change Scale (ABACUS).

Results The academic literature search identified 38 articles, presenting 29 apps. All the studies that evaluated behavioral intentions reported success in raising awareness and changing behavioral intentions. A promising strategy to motivate behavior involves providing multiple relevant feedback (calories burned, money saved, time saved, and CO2/particulate matter emissions) on behavioral impacts alongside action plans (route recommendations and personalized travel plans). Only two apps from the literature search were publicly available. The commercial app search identified 78 apps. Apps with high-quality engagement, functionality, aesthetics, and information presented greater user engagement than those that did not; therefore, they were more likely to succeed.

Conclusion Mobile apps have great potential to motivate changes and be part of a comprehensive system to promote AT. Given the rapid growth of app-based interventions, leveraging mobile apps to encourage AT warrants further exploration. Upon development, these apps should be maintained and made publicly accessible.

Keywords Active transportation, Mhealth, Mobile apps, Behavior change, Travel behavior, Scoping review

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Background

The World Health Organization (WHO) recommends that adults should engage in at least 150–300 min of moderate-intensity physical activity (PA), or 75–150 min of vigorous-intensity PA per week to reduce the risk of noncommunicable diseases such as coronary heart disease, type 2 diabetes, obesity, hypertension, and certain types of cancers [1–3]. In a joint report, the Organisation for Economic Co-operation and Development (OECD) and the WHO Europe estimated that if everyone in the 27 EU member states met the minimum PA guidelines, 10,000 premature deaths could be prevented annually, and by 2050, millions of cases of depression, cardiovascular diseases, and cancer could be avoided [4]. Despite robust evidence of these health benefits, insufficient PA has been increasing and now concerns almost one-third (31.3%) of adults globally [5]. The incorporation of active transportation (AT), such as walking and cycling, into daily routines is a promising solution for people to reach the recommended 150–300 min of moderate intensity per week. AT can also contribute to the reduction of air pollution in the transportation sector when it replaces personal motorized vehicles [6]. However, even though the benefits are evident, convincing people to change their travel behavior to favor more sustainable and active modes of transportation is complex and challenging.

Systematic reviews have shown that mHealth programs may be useful in achieving changes in health behaviors, such as PA and weight loss [7–9]. The term mHealth is defined by the WHO and the Global Observatory for eHealth as "the use of mobile and wireless technologies to support the achievement of health objectives" [10]. With the wide reach of smartphones (7 billion users in 2021 [11]), mHealth has great potential to improve population health. Smartphone apps offer flexible platforms with the ability to incorporate tailored theory-driven interventions in their design. In particular, a scoping review revealed that versions of theory-driven behavior change techniques (BCT) [12] have been incorporated into numerous app-based PA promotion interventions, with promising results [13]. Providing information about others' approval and prompting self-monitoring were effective for children and adolescents. Findings on the effectiveness of BCTs in the general population are inconsistent and inconclusive [13]. Gamification, i.e., the use of game design elements in a nongame context [14], has shown some success in PA-promoting smartphone apps. This is the case for example of Pokémon Go [15], which integrates persuasive strategies (closely related to behavior change principals) with a playfulness approach [16].

Apps developed specifically to promote AT, however, have not consistently been shown to improve PA. A wide variety of such apps have been developed in recent years. Some, but not all, have been theory driven. Some studies have incorporated gamification features, as reviewed in [17]. Others provided health information, as reviewed in [18].

However, the extent of academic research on the use of apps to promote AT behaviors and the quality of commercial apps that are available to the public has not yet been reviewed. The objective of this scoping review was to provide an overview of how mobile apps are being used to promote AT through reviews of both the academic literature and commercial app stores.

Methods

The following scoping review followed the recommendations from the Preferred Reporting Items for Systematic Review and Meta-Analysis extension for Scoping Review (PRISMA-ScR). This review was conducted on both the academic literature and commercially available apps.

Literature database

Following the recommendations of Bramer et al. [19] for biomedical and health-related literature, we searched Embase, Medline, Web of Science, and the first 200 literatures on Google Scholar, supplemented with subject-specific databases, PsychINFO and Transport Database. The Ovid platform was used to search Embase, Medline, PsychINFO, and Transport Database at the same time.

The search terms included variations in two subjects: mobile application and AT (Table 1). Nearby operators (e.g., searching "mobile" and "application" within two words from each other) were used to avoid missing articles that may have used other wording. The search was conducted on December 1, 2023. The identified articles were imported into Covidence [20], a web-based collaboration software platform for systematic and literature reviews, where they were screened. The inclusion criterion was that the article presented a developed app aimed at promoting AT behaviors. The exclusion criteria were as follows:

- The app solely promoted recreational PA or tourism.
- The app considered only public transport behaviors without AT.
- The study presented intervention frameworks or app designs but not implementation.
- The study presented apps that only tracked travel behavior (e.g., for an observational study).
- The paper was written in a language other than English or French.

Table 1 Search terms used in the six academic literature databases

Academic literature databases	Search terms
Ovid (EMBASE, Medline, PsychINFO, Transport Database)	(((smartphone adj2 app*) or (mobile adj2 app*) or (smartphone adj2 intervention)).ab,kf,ti.) AND (((active or soft or sustainabl* or green) adj1 (mobility or transport* or commut* or travel*)).ab,kf,ti.) OR (((walk* or bik* or cycl* or pedestrian) and (transport* or commut* or travel*)).ab,kf,ti.)
Web of Science	(TS = (smartphone NEAR/2 app* OR mobile NEAR/2 app* OR smartphone NEAR/2 intervention)) AND ((TS = ((active or soft or sustainabl* or green) NEAR/1 (mobility or transport* or commut* or travel*))) OR (TS = ((walk* or bik* or cycl* or pedestrian) AND (transport* or commut* or travel*))))
Google Scholar (first 200 results)	((smartphone AROUND (2) app*) OR (mobile AROUND (2) app*) OR (smartphone AROUND (2) intervention)) AND (((active OR soft OR sustainabl* OR green) AROUND (1) (mobility OR transport* OR commut* OR travel*)) OR ((walk* OR bik* OR cycl* OR pedestrian) AND (transport* OR commut* OR travel*)))

Journal articles and conference proceedings were included. Editorials, conference abstracts, master's and PhD theses, review articles, comment articles, book chapters, posters, and government reports were excluded. When the search was completed, NS and AV screened the titles and abstracts to be included for full-text review and data extraction. Conflicts were discussed with AdN until they were resolved.

First, irrelevant articles were excluded during the title and abstract screening. The remaining articles subsequently underwent a full-text review, during which additional exclusion occurred due to missed duplication by the software, incorrect publication types, incorrect population samples, and incorrect outcomes. The remaining articles were included, from which the following were extracted:

- Title, author, date of publication
- Study location
- Name of the mobile app
- Target population
- AT promotion strategies integrated into the app
- Theory base, if available
- Experimental design, if available
- Effectiveness of changing behavior, if available.

The data were then analyzed to determine which strategies were employed to promote AT and, if evaluated, were effective in achieving behavior change. The strategies were coded via the most up-to-date version of the BCT, the BCTTv1 [12]. We further reported methods to address self-selection bias and differentiate between increased cycling and changes in travel behavior.

Mobile app stores

A mobile app search was conducted to assess the range of publicly available AT apps, describe their features and AT promotion strategies, and evaluate their quality. As the most commonly used mobile operating system, we completed our search on the Apple App Store and Google Play Store.

With the aim of obtaining a global view of the existing apps, the search was performed in six countries: Australia, Brazil, France, South Africa, Thailand, and the United States, one country per continent. The following keywords were searched individually because the search engines of both app stores did not allow an OR search operator. Notably, the exact phrase search, which searches multiple terms in precise order, was only available in the Google Play Store.

- "Active transportation"
- "Active mobility"
- "Active travel"
- Active commute
- Transportation walk
- Transportation bicycle
- Commute walk
- Commute bicycle

Two MIT-licensed node.js packages, google-play-scraper [21], and app-store-scraper [22], were used to perform the search. Node.js is an open-source JavaScript run-time environment. In contrast, previous reviews of mobile apps typically searched local app stores via computers or smartphones, which require user accounts; thus, the results could be influenced by personalization, where app search results are provided based on the user profile. The two packages enable rapid searches in multiple countries without requiring user accounts or a virtual private network (VPN). On January 31, 2024, searches were conducted on the Google Play Store, followed by a search on the Apple App Store on February 1, 2024. The identified apps were compiled into a Microsoft Excel spreadsheet, and duplicates were removed via app identification codes. To compile results between both platforms, incomparable fields (e.g., app identification codes and app versions) and irrelevant fields (e.g., content rating, notes of latest updates) were removed, and related fields were retained (i.e., titles, descriptions, app categories (store-defined sorting based on the app's function, purpose, or content), URLs, pricing, app review scores (out of five), number of reviews, and country availability).

NS and AV screened the titles, descriptions, and URL webpages to be included in the review. We included apps that promoted and encouraged AT behavior. Apps that were not related to transportation, were only recreational, and focused on tourism were excluded. General transit (public transportation) apps were included only if they included active modes. Once selected by NS and AV, the spreadsheets were analyzed for discrepancies, and discussions were held until an agreement was reached.

To analyze user engagement, app review scores and the number of reviews in app stores were examined. An estimate of app installations was only available in the Google Play Store; therefore, it could not be used as a determinant of user engagement. Locally available apps in French app stores (where the search was conducted) were evaluated further. They were downloaded onto Android (Samsung Note 20 Ultra) and iOS (Apple iPhone 6) smartphones and tested for 10 min each. The quality of health apps and their potential to change behaviors were assessed by a single reviewer, NS, via two scientifically developed scales: the Mobile App Rating Scale (MARS) [23] and the App Behavior Change Scale (ABACUS) [24]. The MARS evaluates the quality of an app on a five-point scale based on four categories: engagement with the target audience, functionality, aesthetics, and the quality of information. The ABACUS assesses behavior change potential by quantifying strategies aligned with BCTs (out of 21), categorized into knowledge and information, goals and planning, feedback and monitoring, and actions. Both scales have demonstrated high interrater reliability, with intraclass correlation coefficient of 0.79 for MARS [23] and 0.92 for ABACUS [24], as well as strong internal consistency, with Cronbach's alpha value of 0.90 for MARS [23] and 0.93 for ABACUS [24]. Additionally, the MARS training materials indicated that the scale can be reliably applied by a single trained rater, ensuring objective and consistent evaluations [25]. The evaluated scores were then compared with user engagement data from the app stores. Finally, the apps identified in the literature were searched in app stores to determine whether they were publicly available.

Results

Overall, we identified 116 unique apps, including 28 from the literature search and 88 from the commercial app search. We describe this in turn below.

Literature search

Overview

Shown in Fig. 1, a literature search of the Embase, Medline, PsychINFO, and Transport Database on the Ovid platform resulted in 201 unique articles. Web of Science

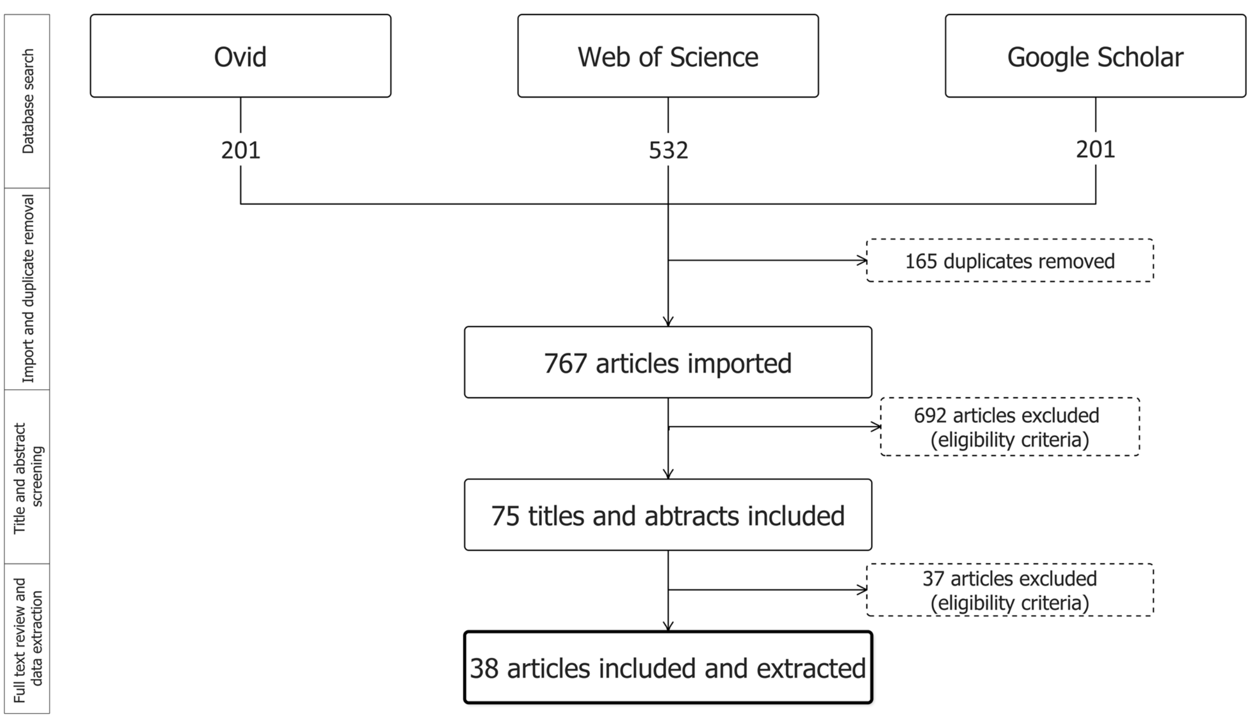

Fig. 1 PRISMA flow diagram of the academic literature search

resulted in 532 articles, 122 of which were duplicates. The first 200 articles found on Google Scholar contained 43 duplicates. In total, 767 unique articles were identified. Among the initial 767 articles, 692 were excluded during title and abstract screening, and an additional 37 were excluded during the full-text review. The 38 remaining articles were included and extracted for details.

The 38 articles from academic journals and conferences were published between 2012 and 2023. These articles presented 28 unique apps, describing either the developmental process and product testing or solely the app evaluation. The studies were conducted mainly in Europe (21 studies), four in North America, one in Asia, one in South America, and one in Australia. Some of these papers were different aspects of the same study; for example, Cellina et al. developed the Bellidea app and published three papers about the co-creation and testing of the app with a living lab [26], the design and development of the reward point system [27], and a study to evaluate the self-selection bias and attrition rate of app users [28].

The common goal of these studies was to deliver an app intervention to reduce personal motorized vehicle usage (cars and motorcycles) and promote sustainable transportation, some of which focused only on AT and some also included public transportation. The AT promotion strategies, identified as BCTs and gamification, applied in each app are listed in Table 2.

The most common BCT used (over nine times each) was *feedback on behavioral outcomes*, such as CO2 emissions avoided and calories burned, *social comparisons* (e.g., leaderboards), and *material rewards* (e.g., financial incentives). Gamification was incorporated into almost half (46%) of the apps, with *points* and *challenges* being the most common features. Combinations of strategies are typically incorporated into app interventions.

Theories

Multiple behavior change theories were employed to inform app intervention designs and guide the evaluation frameworks (Table 3). The predominant theories used to shape the intervention designs were: The Social Cognitive Theory [64], Theory of Planned Behavior [65], and Transtheoretical Model of Behavior Change [66]. The latter two were also most frequently used to guide evaluation designs. Other theoretical frameworks used to design the intervention included: Social-Ecological principles [67]; Self-Determination Theory [68, 69]; Norm Activation Model [70]; game-based theory [71]; random utility theory; and Prospect Theory [72]. Additionally, [26] and [47] implemented persuasive techniques, focusing on the psychological principles of persuasion rather than theories.

Some studies did not base their interventions on theories. For example, [37, 38] used a living lab to co-create their intervention building on the limitations of an existing app, GoEco!. They were guided by the literature evidence of effective persuasive elements for pro-environmental behaviors rather than a specific behavior change theory.

Participants

The interventions targeted adults, except for [43] and [42], who specifically targeted children and adolescents.

Self-selection bias is a common problem across studies, given the voluntary nature of participation and likely the engagement of people who are already interested in AT. For example, [43] and [36] reported that most of their participants were already engaging or knowledgeable about the target behavior, explaining the low levels of change in behavior and knowledge due to the intervention. The methods used to minimize this kind of bias included the following:

- Purposive sampling involves recruiting only or mainly car drivers to focus on the target population. Sottile et al. [39] included participants who mostly owned cars. The personalized travel plans provided through the app led to small shifts toward sustainable modes (walking, cycling, public transportation, and shared mobility). Ross et al. [33] exposed car drivers to the positive testimonial experiences of active travelers: survey results revealed no impact on the intention to change, but interviews revealed some potential to influence awareness and the intention to change.
- The participants' baseline travel data were compared with local mobility statistics to assess sample bias. Cellina et al. [28] and Di Dio et al. [59] reported that their participants' mobility behaviors were representative of those of their target population. Castellanos et al. (2016) reported underrepresentation in walking trips and overrepresentation of cycling and bus trips in their baseline data. Ciccone et al. [51] reported overrepresentation in participants who cycle year-round in Norway (not common due to snow).
- Pre-intervention surveys or monitored travel behavior at baseline were used to disaggregate participants' typical modes of transportation and the impact of the intervention. Eight studies [34, 36, 44, 48, 50, 51, 56, 59] distinguished the intervention impacts for specific travel groups. This mitigation method can also result in a low number of observations if the sample is highly biased.
- Location-based counting of target behavior pre- and post-intervention to observe objective changes

Table 2 Full list of included studies ($n=38$) and the app used ($n=28$), charted for AT promotion strategies and evaluation results (if applicable)

Apps	Ref studies	Behavior change techniques (BCT)										
		1.1 Goal-setting	1.4 Action planning	2.2 Feedback on behavior	2.3 Self-monitoring	2.7 Feedback on outcome of behavior	6.2 Social comparison	7.1 Prompts/cues	9.3 Comparative imagining of future outcomes	10.2 Material reward	10.4 Social reward	16.3 Vicarious consequences
Active Commute Tracker (ACT)	[29]			x		x						
Active Lions	[30, 31]	x	x	x	x	x						
Bellidea	[26–28]	x		x		x				x		
Bike Citizens	[32]									x		
CarbonDiem	[33]						x					
Cyclers	[34]		x				x			x		
CYCLIST	[35]											
EcoTrips	[36]			x		x						
GoEco!	[37, 38]	x		x		x		x	x		x	
IPET (Individual Persuasive Eco-Travel Technology)	[39]		x			x		x	x			
Muévete	[40]						x			x		
MUV app	[41]					x	x					
Mystic School	[42]											
App name not mentioned	[43]									x		
App name not mentioned	[44]		x	x		x	x					
App name not mentioned	[45]					x	x		x			
App name not mentioned	[46]	x		x				x			x	
Optimum	[47]		x					x	x			
OptimumPoints	[48]		x					x	x	x		
Play&Go	[49]						x			x		
Quantified Traveler	[50]					x	x					
Sense.DAT	[51]									x		
SMART Mobility Smartphone	[52–54]	x		x		x	x			x	x	
SocialCycle	[55]	x										
Swiss climate challenge (SCC) app	[56]	x				x	x					x
TrafficO2	[57–59]					x			x	x		
TravelVU Plus	[60–62]	x		x				x				
U-RIDE	[63]		x					x	x			

Table 2 (continued)

Apps	Ref studies	Gamification						Evaluation
		Points	Badges	Challenges	Avatar	Virtual game	Levels	△ – qualitative survey ● – quantitative survey ★- monitoring of behavior
Active Commute Tracker (ACT)	[29]	x						△—useful for monitoring travel behavior, encourages to become active commuter
Active Lions	[30, 31]							★—Increase in pedestrians and cyclists commuting to university campus ●—significant increase in percentage of AT trip for students, but not staff nor faculty of the university
Bellidea	[26–28]	x	x	x				Not evaluated
Bike Citizens	[32]							★- Both trials (individual benefits and community benefits) showed an increase in new users during the campaign. The "individual benefit" trial showed long-term increase in app usage and cycling behaviors
CarbonDiem	[33]							●—no difference in intention to change between the control and intervention group △—seeing other's subject experience initiated own reflection on behavior and potentially influence opinion and intention of AT
Cyclers	[34]	x	x	x				★- Combination of gamification and flat rate reward showed the most impact. All combinations of financial rewards had significant effects. Gamification alone did not differ from control group
CYCLIST	[35]			x				★—No statistically significant difference between the two trials. Collaborative condition recorded slightly more trips ●—higher enjoyment in cycling in collaboration condition than competition condition
EcoTrips	[36]							★—small and biased sample size, did not show difference pre- and post-intervention △—increased awareness of personal travel impact
GoEco!	[37, 38]							Not evaluated
IPET (Individual Persuasive Eco-Travel Technology)	[39]							●—Small shifts towards sustainable modes. Some tried suggested travel plans but did not maintain it
Muévete	[40]							★—Change in mode choice was observed but not statistically significant (small sample size)
MUV app	[41]	x	x	x	x	x		Not evaluated
Mystic School	[42]					x		Not evaluated
App name not mentioned	[43]	x				x		★—small (statistically insignificant) portions showed changes in mobility △—app brought awareness to environmentally friendly and health promoting mobility
App name not mentioned	[44]							★—"Car-free Choosers" are most likely to try new route suggestions. "Practical Travelers" and "Active Aspirers" had the most diverse travel modes and were open to trying route suggestions for wider trip purposes
App name not mentioned	[45]						x	Not evaluated

Table 2 (continued)

Apps	Ref studies	Gamification						Evaluation
		Points	Badges	Challenges	Avatar	Virtual game	Levels	△ – qualitative survey ● – quantitative survey ★- monitoring of behavior
App name not mentioned	[46]							★—Changes were seen during the weekend when there are fewer physical and time constraints. 14% adoption of sustainable transport behaviors. No analysis of statistical significance ●—increase percentage of participants moving to the "maintenance" stage of the Transtheoretical Model. Decrease percentage of participants in the "Precontemplation" stage
Optimum	[47]							●—comparison of impact between transportation modes has an influence on mode choice. No analysis of statistical significance △—providing a ranking of sustainable travel modes for trip planning influence mode choice. Positive feedback on persuasive messages
OptimumPoints	[48]							★—Optimum app service without the rewards (control) increased time spent in public transport. Those registered for the reward scheme showed an increase in travel time for public transport, biking and walking
Play&Go	[49]	x		x				●★—pre-test survey compared with monitoring indicated small impact on mobility behavior change, effective in encouraging participants to try new modes of transport
Quantified Traveler	[50]							★—significant decrease in driving and significant increase in walking (no changes for bike and bus), compared to baseline △—increase in awareness and changes in intention but not in sustainability attitudes
Sense.DAT	[51]							★—incentivized groups significantly increased their (mainly recreational) cycling activity compared to the control group. Flat rate incentive was most efficient
SMART Mobility Smartphone	[52–54]	x		x				★—Monthly choice challenges, offering rewards, led to reduced car use and increased bike trips compared to non-participants Public transport users and frequent walkers were more inclined to bike than car drivers Distance challenges proved more effective than trip frequency challenges with daily distance challenges being more motivating than weekly ones
SocialCycle	[55]	x	x	x			x	Not evaluated
Swiss climate challenge (SCC) app	[56]			x				★—No significant difference in mobility behavior between app users and control
TrafficO2	[57–59]	x		x				★—participants commuting > 3 km to < 5 km all increased in the number of trips made by walking and cycling and those living > 5 to < 10 km only improved in walking Reward and non-reward groups both showed improvement in target behavior. Main indicator of change is environmental consciousness

Table 2 (continued)

Apps	Ref studies	Gamification						Evaluation
		Points	Badges	Challenges	Avatar	Virtual game	Levels	△ – qualitative survey ● – quantitative survey ★- monitoring of behavior
TravelVU Plus	[60–62]							★—no effect during intervention but showed increase in PA 3 months after intervention △—participants were more aware of their behavior and inspired to change. Encouraging messages helped participants explore alternatives
U-RIDE	[63]							Not evaluated

Table 3 Theories used in the reviewed articles

Theory	Description	App studies
Social Cognitive Theory [64]	Learning occurs within a reciprocal interaction between the person, environment, and behavior	[30, 31, 33, 60, 61]
Theory of Planned Behavior [65]	One's behaviors are influenced by their intentions, which are derived from attitudes, subjective norms, and perceived behavioral control	[39, 44, 50, 63]
Transtheoretical Model of Behavior Change [66]	Individuals go through five stages of change from never thinking about the behavior to making the behavior a habit, and different stages require different interventions to move onto the next	[30, 31, 34, 37, 38, 46]
Social-ecological principles [67]	Multilevel interventions that target individuals, social environments, physical environments, and policies are needed to promote PA on a population level	[60, 61]
Self-determination theory [68, 69]	To motivate behavior change, individuals need to be satisfied in the three basic psychological needs: autonomy, competence, and relatedness	[49]
Norm Activation Model [70]	An individual's altruistic or pro-environmental behaviors are influenced by their moral norms, which are shaped by their awareness of the consequences of the behavior and their sense of responsibility to perform it	[36]
Game-based learning theory [71]	People learn through experiences. Well-designed games can provide these learning experiences	[43]
Random utility theory	People make choices based on goods' characteristics plus some degree of randomness	[48]
Prospect theory [72]	This theory stems from behavioral economics. It states that people prefer lower probability for higher gains (lotteries) than high probability for lower gains and that people prefer to make decisions that they would regret the least even though it might not be optimal	[51]
Persuasive techniques [73]	Techniques to apply psychological principles of persuasion using technologies	[26, 47]

in mobility patterns in the community. Before and after promoting AT (via an app) at a university campus, [30] observed the number of pedestrians and cyclists commuting to the campus and reported an increase in the number of people walking and cycling at the community level.

Evaluation approach

To determine the success of AT promotion, changes in behaviors and behavioral intentions were evaluated in 21 studies, 17 of which employed app-based monitoring and 14 of which used self-reports. Nine of these studies employed both methods. Seven studies did not evaluate the change but instead field-tested the usability of the app and its functionalities.

Various experimental designs have been used to evaluate app interventions. Specifically, 11 studies used control groups for comparison, including seven that also employed randomization. Additionally, ten studies used quasi-experimental designs in which the intervention groups were self-selected and there were no control groups or randomization. Fourteen longitudinal studies tracked participants over a period of multiple experimental phases to observe changes.

Changes in travel behavior

To distinguish between modal shifts and additional trips in assessing travel impacts, studies have used the following methods:

- Tracking and comparing multiple modes of transportation over time from the baseline. Tsirimpa et al. [48] and Ciccone et al. [51] reported that material rewards can significantly increase engagement in target modes but fail to show a reduction in other modes. This shows how incentives lead to increased trips of target modes but not necessarily by replacing other modes, such as cars. Jariyasunant et al. [50] reported successful modal shifts with an increase in walking trips accompanied by a decrease in car trips when participants received feedback about the impact (time spent traveling, cost, CO_2 emitted, and calories burned) of their actions.
- After the intervention, the participants were asked to self-report whether any increase in target behaviors replaced other modes of transportation. Following an intervention period with in-app challenges to encourage cycling, [52–54] reported that 40% of those who completed the challenge cycled more than usual, half of whom replaced car trips to complete the challenge, indicating some success in the modal shift.

Effectiveness

All seven self-reported qualitative evaluations (through interviews and focus groups) indicated that their app interventions were successful in influencing behavioral intentions. After using the apps, the participants expressed an increased awareness of the impact of their mobility choices and intentions to change their travel habits in favor of active and sustainable modes. Additionally, the participants reported that they were encouraged to try alternative transportation modes. Six of these seven studies also monitored travel behavior, four of which reported contradictory results, i.e., finding little to no impact on behavior change.

Many of the same BCTs and gamification features appeared in both apps that successfully influenced travel behavior and those that did not. For example, *leaderboards* used to provide social comparisons were part of the effective apps in [34, 44, 49, 50, 52] but not in [33, 40, 56]. Setting app-based *challenges* was found to be effective in promoting cycling [53] but not in reducing overall mobility-related carbon emissions [56]. Similar inconsistencies were observed for *material rewards*. Nine studies evaluated *material rewards* in the form of cash, credit, discounts, and lotteries. This results in increasing target behavior ranging from a large [32, 34, 51, 53] to a small impact [40, 43, 49]. Some studies have also reported an increase in target behaviors in both the intervention and control groups, indicating a possible effect of other incorporated features [48, 58].

Compared with those that provide only one type of outcome, apps that integrate multiple outcomes as *feedback on the impact* of travel behavior tend to be more effective in increasing awareness of behavioral consequences and shifting travel behavior. Five studies [30, 39, 44, 50, 58] that provided three to four types of outcomes (calories burned, money saved, time saved, and CO2/particulate matter emissions) reported increases in target behavior, including two that also showed a decrease in car usage, indicating a modal shift [39, 50]. Park et al. [36], who provided two types of outcomes (calories burned and CO2 emissions/avoided), reported no significant difference in behavior, but participants reported an increase in awareness of their mobility impact. Three studies provided only one type of outcome as *feedback*: [56] offered *feedback* solely on CO2 emissions and reported no significant difference in behavior; [53] were successful in promoting cycling with in-app *challenges* and *feedback* on CO2 emissions; [29] successfully encouraged AT behavioral intentions through an app that provided *feedback* on calories burned, in addition to mobility *monitoring* (modes of transportation, step counts, distance traveled).

Seven studies [30, 34, 39, 44, 47, 48, 63] incorporated BCT "*action planning*," in the form of route recommendations and travel plans (Table 2). While this feature is often combined with other features, making it challenging to isolate their specific effects, we observed that every app with this feature yielded positive outcomes and facilitated changes in travel behaviors [30, 34, 39, 44, 47, 48]. One study [63] did not evaluate for change. Even in cases where participants did not significantly change their travel behavior, these suggestions appeared to encourage participants to try alternative modes and routes [39].

App search

The commercial app search from six countries yielded 194 apps from the Google Play Store and 679 apps from the Apple App Store, 18 of which were available in both stores. The Apple App Store has a much broader interpretation of our search request, resulting in many irrelevant apps. After the apps from both stores were compiled and screened, the final selection included 78 apps (Fig. 2). Three apps had more than 10,000 reviews at the time of the search: Miles – Travel, Shop, Get Cash (score 4.7/5 stars); CityMapper (4.8); and Anywheel (4.2). Miles – Travel, Shop, Get Cash is an app based in the United States that rewards every mode of transportation with points, with greater compensation for sustainable and healthy modes (walking, cycling, public transportation), which can be redeemed for gift cards, raffles, and donations. CityMapper is a journey planner that allows users to compare the impacts (calories burned and cost) of different travel modes. Its services are available in many cities across Europe, North America, and several metropolitan areas worldwide. AnyWheel is an app that facilitates bike-sharing services and provides feedback on users' calories burned and carbon emissions avoided through this service compared to the same journey by car; it operates in Singapore, Malaysia, and Thailand. Five apps had between 1000 and 10,000 reviews, three of which were bike-sharing apps (BCycle, Donkey Republic, and Dott), with scores of 4.1, 4.4, and 4.5 out of 5, respectively. One app, Mappy, is a journey planner that compares the potential outcomes (time, cost, and CO2 emissions) of different modes and has a score of 4.3. Finally, Geovelo—Bike GPS & Stats is a bike journey planner app with a score of 4.5, which provides feedback on CO2 emissions avoided by cycling compared with the same journey by car. It also collaborates with local and regional authorities around France by providing usage data to inform the development of the cycling infrastructure in their territories and a platform to communicate with local cyclists. Seven apps had between 100 and 1,000 reviews (six bike-sharing and one bike campaign), with scores ranging from 4.1–4.6 (average = 4.3). Forty apps received fewer than 100 reviews, with scores

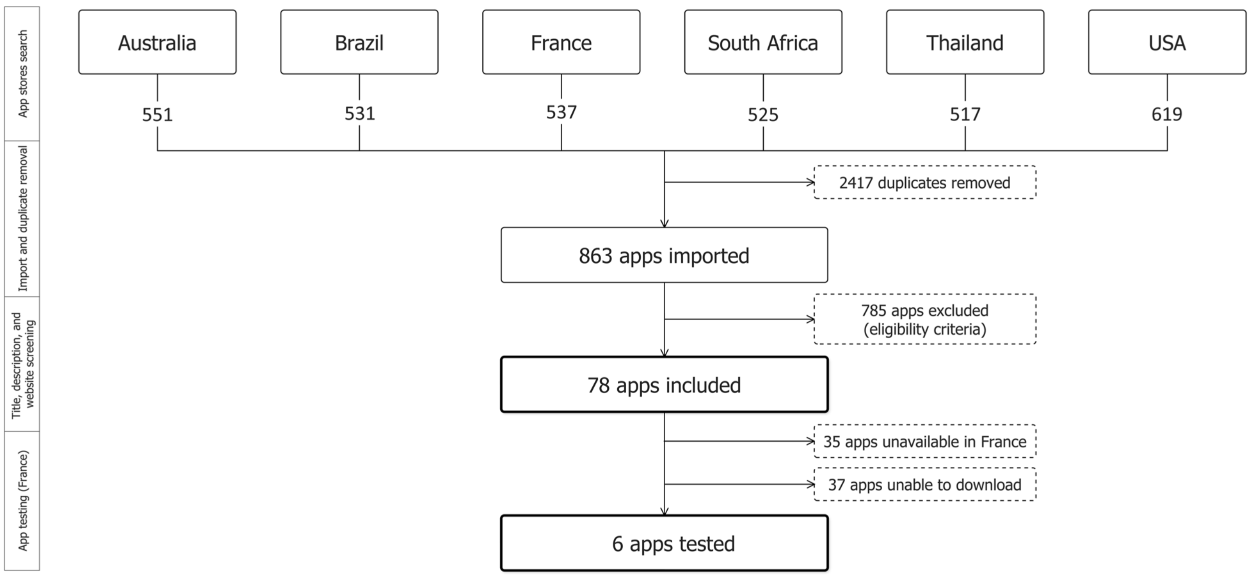

Fig. 2 PRISMA flow diagram of the mobile app search process on the Google Play Store and Apple App Store

ranging from 1–5 and an average of 3.8. The remaining 23 apps had neither scores nor reviews.

Of the apps we included, 43 were available in France, and most of them had very few user engagements on the app stores, more than half with fewer than 10 reviews. Among them, 23 facilitate bike-sharing and bike-parking services that provide useful information and access to physical opportunities for AT engagement. We did not test these apps because they required signing up and payments to access their products and features. The remaining apps consisted of eight reward apps, six journey planners, and six apps that tracked and provided feedback on behavior. Eight of these were not available on the testing devices (Samsung Note 20 Ultra and Apple iPhone 6) because of incompatibility; two were only available for organizations with specific codes, and four had software problems and could not run. Only six of the remaining apps were tested.

For the MARS assessment, we found that the six apps had an average score of 3.4 out of five (range: 2.5–4.2; SD = 0.57; Table 4). Comparing the scores between categories, we found that the apps, on average, scored highest in functionality, which looked at performance and ease of use. The lowest scores were for engagement with users, which focused on interactivity with users and whether the app was well designed for the target audience. The apps that scored above the overall average (3.4) were Citymapper, Geovelo, ActiveTravel, and Mappy. These apps are journey planners, with the exception of ActiveTravel, which tracks mobility and provides feedback on the behavioral impact. In terms of the apps' potential to change behavior, the ABACUS assessment of the tested apps revealed an average count of 5.8 out of 21 (range: 2–11; SD = 3.80; Table 4). The highest scores were 11 BCTs for both ActiveTravel and Geovelo. The tested apps scored highest in the feedback and monitoring category of BCTs, where the users could see the statistics of their trips taken and their impact, and lowest in the goals and planning category, only being provided in one app (ActiveTravel).

With respect to user engagement in app stores, three of the tested apps (ActiveTravel, Commute, and Kent Connected) did not have any scores or reviews in the stores of the six countries we searched, possibly because these apps did not service these locations. Therefore, to obtain user engagement data for these apps, additional app store searches were conducted in the countries in which they were developed, as italicized in Table 4. The apps that scored higher than average on the quality assessment (MARS), except for ActiveTravel, had much greater user engagement (more reviews and higher scores) than the other apps did. In contrast, ActiveTravel scored 3.6 on MARS and 11 on ABACUS, both above the average, but had low user engagement. No pattern could be observed by comparing the ABACUS behavior change potential scores to app store user engagement.

Revisiting the 29 apps identified from the literature search, we found that five were available in app stores (Bike Citizens, Cyclers, CarbonDiem, Play&Go, and TravelVU). Three of them, however, were the control or pre-modified versions of the apps used in the studies (Bike Citizens, Cyclers, and TravelVU). Cyclers (control)

Table 4 The MARS, ABACUS, and user engagement scores of the downloaded and tested apps

Apps	MARS (average out of 5)					ABACUS (count out of 21)					App stores		
	Engagement	**Functionality**	**Aesthetics**	**Information**	**Average**	**Knowledge and information**	**Goals and planning**	**Feedback and monitoring**	**Actions**	**Counts**	**Score**	**Reviews**	**Additional search**
ActiveTravel	3.4	4.5	2.6	4.0	**3.6**	2	2	5	2	**11**	*3.6*	*16*	*Sweden*
CityMapper	3.8	4.3	5.0	3.8	**4.2**	2	0	2	1	**5**	4.8	2941.8	-
Commute	2.0	3.8	3.3	2.2	**2.8**	0	0	3	1	**4**	*3.6*	*55*	*Denmark*
Geovelo	3.6	4.3	3.0	4.0	**3.7**	3	0	6	2	**11**	4.6	3172	-
Kent Connected	1.8	2.8	2.7	2.8	**2.5**	1	0	0	1	**2**	*3.6*	*18*	*Great Britain*
Mappy	3.2	3.8	3.7	3.8	**3.6**	2	0	0	1	**3**	4.3	6014	-
Average	3.0	3.9	3.4	3.4	3.4	1.7	0.3	2.7	1.3	6			

had the highest score (4.2) and number of reviews (272 reviews); three had decent scores (Play&Go = 4.2; Bike Citizen (control) = 3.6; TravelVU (control) = 2.8), but a small number of reviews (fewer than 100); and one (CarbonDiem) had no review. When attempting to download and test the apps, Play&Go was under construction, and CarbonDiem was unavailable in France. As the remaining three were controls in the literature, they were not tested here.

Discussion

This study aimed to provide an overview of how mobile apps are being used to promote AT through reviews of both the academic literature and commercial app stores (Android and iOS). The findings suggest that app-based interventions are being researched as a way to promote AT, but with mixed results, and good-quality supportive commercial apps available to the public are very limited.

Features and strategies to motivate behavior change

The most utilized behavior change strategy in the reviewed apps was providing *feedback on behavioral outcomes*, namely, calories burned, money saved, time saved, and CO2/particulate matter emissions. The Feedback Intervention Theory proposed by Kluger and Denisi [74] posits that feedback functions primarily to focus and shift attention. This theory supports our results, which show that providing feedbacks on the multiple impacts of behaviors was effective in increasing users' awareness of and actions toward healthy and sustainable travel behavior. Our findings are further supported by a review [75], who reported that feedback has the potential to disrupt undesired habits and can be a supportive component of any intervention that aims to change habitual behaviors. Control Theory [76], which emphasizes the importance of the relevance of feedback to individuals' goals, posits that individuals are motivated to change their behavior when there is a disparity between their current behavior and desired goals. Therefore, feedback must be designed to elicit behavioral reflections that bridge this gap. The inclusion of multiple types of impacts increases the likelihood of engaging individuals motivated by various goals.

The effectiveness of feedback has also been shown in previous research to be enhanced when coupled with clear *action plans* [77]. This is confirmed by our findings that providing route recommendations and personalized travel plans was successful in promoting behavior change or, at the very least, encouraging users to try alternative travel modes. This aligns with findings in other domains, such as air pollution communication, where actionable information has been shown to mitigate feelings of powerlessness and encourage positive shifts in public attitudes and behaviors [78]. By providing feedback that is aligned with individuals' goals and offering actionable recommendations, app intervention can effectively evoke a sense of need for change and facilitate a plan to do so. In reference to the Transtheoretical Model of Behavior Change [66] in Fig. 3, *feedback* provides awareness to facilitate progress from the precontemplation to the contemplation stage, and *action plans* can assist in the preparation stage and facilitate progress into the action stage.

We could not find apps that integrated health outcomes beyond the eight (seven of which were evaluated and shown to be successful in changing behaviors and intentions) that provided feedback on burned calories. This gap was also highlighted in a review [18], who reported that CO2 emissions, both as a consequence of past behavior and as a potential outcome of planned behavior, were the outcome most frequently addressed in transportation apps. Nevertheless, transportation has multiple impacts on health [79, 80], which can potentially be used as arguments to shift behaviors. For example, routes that maximize greenspace and minimize air pollution have been shown to reduce stress for cyclists and pedestrians [81]: providing information on greenspace and air pollution along alternative routes could help users identify healthier and more enjoyable solutions and could motivate individuals who may not be driven by altruistic environmental concerns alone [82]. Moreover, personal health benefits from physical activity accrued from modal shifts toward AT have been shown to dominate the benefits of transportation policies that address climate change and air pollution [6, 83], thus providing a strong rationale to support such changes. Furthermore, positive outcomes are more likely to be engaging than negative impacts are [78]; thus, practical information on how to improve health can provide helpful and engaging information to users rather than solely allowing them to reflect on the consequences of their behavior in the environment.

We found that *material rewards* and *challenges* provided through an app can increase extrinsic motivation and the time spent walking, cycling, and using public transportation. This increase did not always translate to a reduction in car use, but [53] reported that some participants replaced their car trips with cycling to reach their goals. In a review of five studies from various fields, [84] indicated that immediate rewards (e.g., financial incentives for time spent walking/cycling) were a stronger predictor of persistence of behavior than delayed rewards (e.g., improved health/environment). However, caution should be taken when approaching behavior change with externally mediated rewards because they can distract individuals and reduce their intrinsic motivation

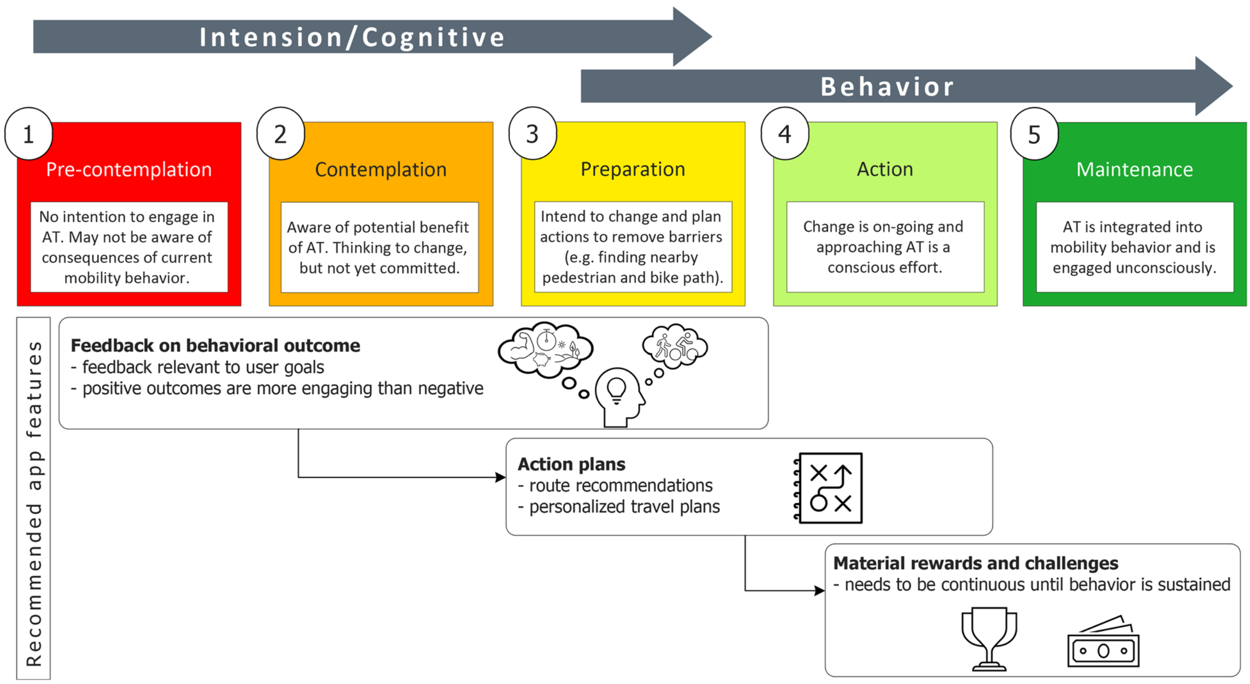

Fig. 3 Stages of change in relation to AT based on the Transtheoretical Model of Behavior Change, adapted from Prochaska and DiClemente (1982), and, based on current review, recommended app features to support user progression through the stages

(engaging in AT for the satisfaction of improving health and the environment) [85]. To create long-term changes with external rewards, engagement approaches need to foster internalization until the behavior is autonomous or transforms one's identity [86–89]. For example, the rewards app "Miles – Travel, Shop, Get Cash" has been providing, since 2018, continuous external motivation and immediate rewards for all users, with an emphasis on sustainable transportation, thus creating the potential to foster internalization; judging by its number of users and partnership with numerous industries and local authorities, it could be considered successful.

Maintaining app engagement

The attrition rate is a common challenge in mobile apps [90]. In a review of studies using mobile health apps, [91] reported that participants were more likely to drop out of the study than be retained. This challenge is attributable to networked individualism, where individuals' commitment to a network (e.g., an app) is limited because of their involvement in other online networks [92]. Garnett et al. [93] identified seven highly ranked strategies to improve app engagement: ease of use, design – aesthetic, feedback, function, design – ability to change design to suit own preferences, tailored information, and unique smartphone features. This is consistent with the MARS assessment used to determine the app quality [23]. We found that those with higher MARS quality scores tended to have better app store scores and more engagement than those with lower MARS scores.

External factors influencing the impact of the app intervention

The success of an intervention also depends on external factors beyond its scope. Based on the Transtheoretical Model of Behavior Change [66], even if an intervention successfully moves an individual to the contemplation stage (i.e., developing the intention to change), a lack of access to a safe environment for walking or cycling could limit the possibility of actual change. Progression to the preparation stage may be halted because one cannot plan to mitigate the barriers that lie beyond individual control. Perceived control is a significant factor that determines behavior according to the Theory of Planned Behavior [65]. This suggests that the efficacy of app features and strategies alone may be insufficient to determine app success. Consistent with the socio-ecological framework of behavioral change, an app that targets individual behaviors is limited in its ability to change behaviors if the social and physical environments do not enable them. Although not tested, apps could be designed to engage individuals to support action toward creating enabling environments (e.g., policy support), thus creating positive feedback effects toward systemic change [78].

Voluntary usage of apps

Often, app-based interventions operate within a voluntary, self-selected framework, which poses a risk of "preaching to the converted," that is, presenting the intervention to people who are already making changes or are motivated to do so. This self-selection bias not only skews the demographic composition of research participants but also undermines the generalizability of the findings to a broader target population [94]. The personalization algorithms used by app stores to promote apps can further increase this gap, as they aim to display content based on user interests [95]. Thus, behavior change apps require specific targeted recruitment to reach unengaged individuals.

Study limitations

The expansion and evolution of the mobile app sector is rapid. For example, 90,000 health apps were added in 2020, averaging approximately 250 apps per day [96]. The continuous influx of technological advancements and new applications means that our review may quickly become outdated as newer mHealth interventions emerge. However, it is imperative to comprehensively capture the current landscape and catalog the current works. Future research will need to continually update fast-paced developments in mHealth technologies to provide relevant and timely insights.

During the commercial app search, the accuracy of the app engagement was challenging. App stores do not have guidelines for where an app can be made available for download; therefore, it can be available in areas where it does not service. For example, a bike-sharing company operating in one city can have an app accessible worldwide. As a result, the app may not appear to be downloaded or used if the search is not performed in the operating country.

Additionally, the selection of countries for the commercial app search were made to ensure geographical diversity by including six countries from different continents. The selection was also influenced by practical considerations such as language proficiency within the research team. This approach may have introduced selection bias, and future studies could benefit from a more systematic approach to country selection based on objective criteria, such as regional app market size or AT trends and infrastructures.

Conclusion

Since the beginning of the century, the use of smartphones has increased significantly, and a wide range of mobile apps have been developed and made available to users on the go. App-based interventions provide an opportunity to promote sustainable and healthy modes of transportation, such as walking and cycling. A scoping review was conducted to provide an overview of how mobile apps are being used to promote AT through reviews of both academic literature and commercial app stores. BCTs and gamification strategies have been integrated into apps to encourage AT. Our study revealed that apps were successful in increasing awareness and changing behavioral intentions. To motivate behaviors, providing multiple relevant feedbacks on behavioral impacts and action plans is a promising combination. A variety of commercial apps are available; however, they do not have high rates of engagement, and only a few are of high quality. Apps that had high-quality engagement, functionality, aesthetics, and information were more likely to have higher levels of engagement than those that did not and were therefore more likely to be successful. With the fast-growing field of app-based intervention, the use of mobile apps to encourage AT should be further explored and rigorously tested. Well-designed, theory-based apps should be made commercially available and maintained for widespread dissemination. A successful app has the opportunity to not only promote the health of the population and improve the environment but also address and reduce social barriers within the community, creating healthier cities.

Abbreviations

WHO	World Health Organization
PA	Physical Activity
OECD	Organisation for Economic Co-operation and Development
AT	Active Transportation
BCT	Behavior Change Techniques
PRISMA-ScR	Preferred Reporting Items for Systematic Review and Meta-Analysis extension for Scoping Review
VPN	Virtual Private Network
MARS	Mobile App Rating Scale
ABACUS	App Behavior Change Scale

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Authors' contributions

NS developed the study design, acquired, screened, and analyzed the data, wrote the main manuscript, and prepared the figures and tables. AdN screened the data, revised the manuscript, and supervised the project. AV conceptualized the study, screened the data, revised the manuscript, and supervised the project. All authors read, reviewed, and approved the final manuscript.

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Data availability
The datasets of the included literature and apps generated by the searches during the study are be available in the Open Science Framework repository, https://doi.org/10.17605/OSF.IO/GJ5ZY.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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