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Review

Promoting Sustainable Mobility: To What Extent Is "Health" Considered by Mobility App Studies? A Review and a Conceptual Framework

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Abstract: Promoting cycling and walking in cities improves individual health and wellbeing and, together with public transport, promotes societal sustainability patterns. Recently, smartphone apps informing and motivating sustainable mobility usage have increased. Current research has applied and investigated these apps; however, none have specifically considered mobility-related health components within mobility apps. The aim of this study is to examine the (potential) role of health-related information provided in mobility apps to influence mobility behavior. Following a systematic literature review of empirical studies applying mobility apps, this paper (1) investigates the studies and mobility apps regarding communicated information, strategies, and effects on mobility behavior and (2) explores how, and to what extent, health and its components are addressed. The reviewed studies focus on environmental information, especially CO_2-emissions. Health is represented by physical activity or calories burned. The self-exposure to air pollution, noise, heat, traffic injuries or green spaces is rarely addressed. We propose a conceptual framework based on protection motivation theory to include health in mobility apps for sustainable mobility behavior change. Addressing people's self-protective motivation could empower mobility app users. It might be a possible trigger for behavior change, leading towards healthy and sustainable mobility and thus, have individual and societal benefits.

Keywords: mobility app; smartphone app; mobility behavior change; health; protection motivation theory; literature review

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1. Introduction

Urban mobility is still strongly relying on motorized transport, causing adverse impacts on people's health and has well known societal impacts such as climate change [1]. Motor vehicle exhausts from motorized transport contain harmful air pollutants, engines cause noise and vehicles require land for infrastructure (e.g., reducing green spaces) [1]. As a result, urban dwellers are exposed to high levels of air pollution and noise, injuries related to traffic crashes, and adverse health impacts due to urban heat islands [2,3]. A lack of urban green spaces and the effects of sedentary mobility cause additional individual health problems in the long-term [2,3]. Even though the concept of healthy cities has been on policy agendas since 1988 and the European Healthy Cities agenda 2014–2018 highly prioritizes transport, many cities still face the aforementioned negative health impacts of increasing urban traffic [2,4,5].

Meanwhile, awareness about healthy lifestyle choices is growing and smartphones are increasingly used to promote (individual) health: monitoring one's health is defined as part of the "quantified-self movement" [6,7]. Health-related smartphone applications help the user self-monitor their behavior and receive feedback on how to improve health, focusing, e.g., on weight loss, diet, physical activity, or illness monitoring [7,8]. "Mhealth" (mobile health technologies) are increasingly used in health research to provide the user with information about their health—including aspects such as air pollution [6]. These technologies have radically increased in recent years and can result in behavior changes towards healthier lifestyles [8,9].

As shown, approaches which digitally inform people about a healthy lifestyle are growing, meanwhile, mobility-related health components receive attention in transport research. However, only recently these two fields are integrated. This study addresses this by analyzing mobility apps applied in recent studies with regard to the addressed informational dimensions, focusing on the mobility-related health dimension and its components [1–3]. We investigate the mobility apps' intervention strategies and discuss the (potential) effects on mobility behavior. We examine the following research question: "To what extent and how is the 'health dimension' (and its components) considered in mobility apps applied in mobility behavior change studies?"

The research comprises three steps:

(1) Reviewing the current state of empirical studies using mobility apps for mobility behavior change and investigating the applied mobility apps regarding their informational dimensions, intervention strategies, and their effect on mobility behavior.
(2) Highlighting the existence and effects of the components of the "health" dimension in mobility apps in empirical research.
(3) Suggesting a theory-based inclusion of "health" components and intervention strategies to support mobility behavior changes through mobility apps.

We intend to examine the interrelation between health and sustainable mobility. For this purpose, we use a systematic literature review that focusses on empirical studies that deal with mobility-related smartphone apps to promote mobility behavior change (i.e., towards sustainable mobility). In Section 2, we provide the theoretical context of the literature review by defining the health concept and locating it in the sustainable mobility discourse and give an overview of mobility behavior change apps. Section 3 presents the methodological approach and the data used. In Section 4 the results of the literature review are presented. Section 5 presents the discussion and introduces a conceptual model to include health in mobility apps. Finally, in Section 6, the conclusion sums up the findings.

2. Background: Defining Health in the Sustainable Mobility Discourse

Recent studies have built conceptual models to define the interrelationship of health and transport, defined by physical activity (including calories burned as part of preventing obesity and prevent cardiovascular diseases), safety and traffic injuries, green space provision, air pollution exposure, noise pollution exposure, extreme weather (e.g., heat), and subjective wellbeing [2,3,10,11]. Concerning the social dimension, transport impacts on health equity, e.g., local pollution of air pollutants or noise, are part of the interrelationship of sustainable transport and health [11].

We argue that addressing these health components can influence people's mobility behavior, their mode/route choices and have co-benefits for sustainability (Figure 1). Following Figure 1, communicating the risks and protective actions regarding each health-component to the individual can address their self-interest in healthy living: If people perceive the severity of a risk and their vulnerability towards one of these health components as high and they feel that they are able to cope with the health risk easily and successfully, they may be motivated to change their behavior towards healthier modes or routes (referring to protection motivation theory (PMT), [12]). As for promoting cycling and walking or public transport, drawing on people's interest in leading a healthier lifestyle may encourage or act as a motivator for using healthy modes of transport or routes with more greenery or less motorized (less polluting) transport. Hence, addressing people's self-interest in health can positively influence sustainability on the societal level.

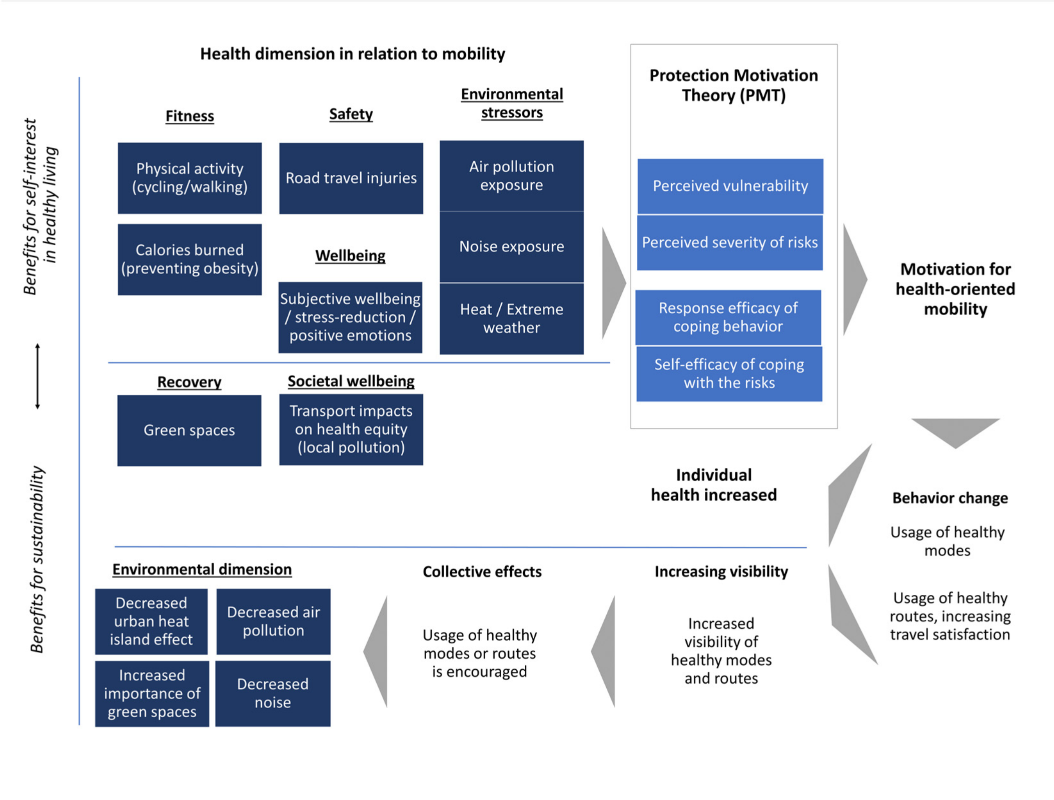

Figure 1. Nexus between mobility behavior and health and its potential to encourage sustainable mobility choices through PMT [12], including important components of transport-related health dimensions. Own illustration, mobility-health components defined by [1–3,10,11], PMT by [12].

For example, knowledge about air pollution can impact cyclists' route choice [13] and the knowledge about available safe cycling routes motivates bicycle usage [14], in turn reducing air and noise pollution. Additionally, increased bicycle usage can enhance the visibility of cyclists as common road users, which may encourage non-cyclists to cycle [15,16]. Not only active mobility promotes physical activity, public transport also has opportunities to improve fitness because people need to walk to the station [10]. Improving wellbeing in public transport by lowering travel time through appropriate travel plans can promote public transport usage [9]. Hence, providing information addressing mobility-health components can have co-benefits in lowering pollution levels, increase importance of greenspaces and a reduction of the heat island effect, i.e., benefits sustainability (Figure 1). Providing information and communication measures, e.g., about health-related factors, can help form intentions to change behavior and support the acceptance of travel demand measures [17].

In this paper we want to examine whether adding health-related information in sustainable mobility communication has the potential to draw on both healthy and sustainable mobility choices and triggers behavior changes. Therefore, we review mobility app studies that intend to change mobility behavior towards sustainable mobility.

The role of mobility apps in supporting route and mode choice has received increased attention in recent years [18]. Mobility apps introduce new possibilities to easily organize one's trip by providing access to information about different modes (shared or public transport), route-characteristics, payment possibilities, real-time trip information (e.g., departure/arrival time, duration), and supplementary information such as CO_2-emitted or kilometers traveled [19]. Thus, they address different informational dimensions [20].

To support sustainable mobility choices, recent studies have increasingly applied smartphone applications to intervene in current mobility behavior. Most studies employ mobility-apps to inform about sustainable trip options or persuade or nudge the user to use sustainable mobility modes through behavioral change strategies, persuasive technologies, or gamification approaches [19,21,22]. Intervention strategies can be education, persuasion, or incentivization (among others) [23]. More specifically, education involves descriptive information and can be achieved through increasing knowledge regarding mobility choices [23]. People are often not aware of the impacts of their mode-choice on the environment and mobility apps with supplementary information can educate [24]. Persuasion is common in mobility behavior change interventions and uses behavior feedback, social influence, comparison or personal suggestions [25]. Giving feedback is supposed to raise awareness about one's (probably undesirable) behavior and activate personal norm/responsibility [26]. Awareness raising is an important step in changing behavior [24]. Moreover, monitoring behavior can be used to compare previous behavior with present behavior and show one's relative performance [27]. As argued in recent literature, the differences in personal characteristics demand personalized information and suggestions [28]. For a comprehensive literature review on persuasive technologies in mobility apps see [25]. Incentivization uses the expectation of rewards as stimulus for behavior change [23] and together with gamification it supports users to achieve their goals [25]. Approaches with monetary incentives often draw on gamification strategies [29]. In competition, users can compare their mobility patterns or goals with others.

Comprehensive reviews regarding the sustainability aspects in mobility app studies were conducted by [30] or [9]. However, there is a gap in the literature concerning whether or to what extent and how the aforementioned mobility related health components (Figure 1) are included in mobility app studies to promote mobility behavior change. This is of concern with regards to the interrelationship and adverse impacts of transport on health and the co-benefits for sustainability. Research is missing which investigates the opportunities of health-related information for sustainable mobility, which appeals to one's self-interest and thus, enhance the possibilities for mobility behavior changes [31]. We draw attention to that applying a systematic literature review as presented in the following.

3. Method: Literature Review

A literature review was conducted focusing on empirical studies that developed or applied a specific mobility app and tested its impact on mobility behavior change. The PRISMA guidelines were used for the literature review [32]. Relevant databases for conference papers and complete articles were searched (Figure 2). Specifically, literature was considered that deals with the effects of mobility-related smartphone applications on mobility behavior change. Following an initial unsystematic paper search to familiarize with the research field, we then used a systematic combination of the following keywords: "behavio* change" AND "mobility" AND "smartphone app*" OR "behavio* change" AND "smartphone" AND "mobility app*". In order to ensure a consistent understanding of mobility as the act of being mobile which recognizes the social and cultural aspects of mobility alongside the mere physical aspects of moving, the focus was placed on literature which used the term "mobility". Therefore, and based on the definition of [33], literature was targeted that acknowledges the needs and abilities of the individual on-the-move and takes the social and psychological questions of being mobile into account. We considered literature on all modes of transport; however, the app should refer to mobility with a destination (e.g., route planning or route tracking for everyday activities) and not mobility as an activity in itself (e.g., cycling/walking for fitness purpose, vacations). To make sure only to include research with apps that have current technological options, the timeframe 2015–2020 was set. However, one article dated before 2015 appeared in our search and was included due to its relevance. The number of retrieved articles was 784. Subsequently, the articles were filtered by screening titles and abstracts were reviewed for eligibility. Only empirical studies were included in which a sample tested/used an existing or developed mobility app and which researched the effects of the mobility app on participants' mobility choices or mobility behavior. Fitness tracking apps or healthcare apps (e.g., hospital patients) were excluded. The reference lists and previous review articles were screened for additional relevant articles. Figure 2 shows the flow diagram of the literature review process based on the PRISMA guidelines [32].

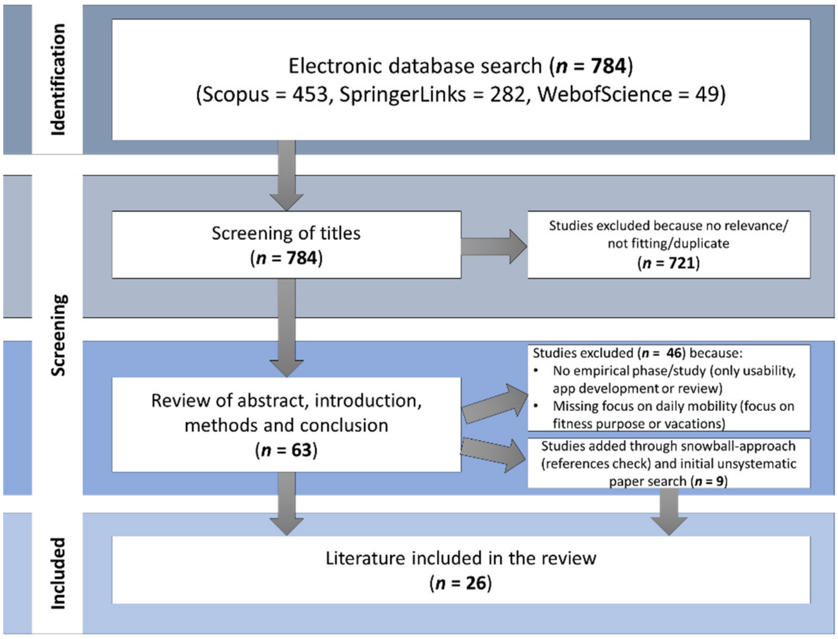

Figure 2. Systematic literature review proceeding according to PRISMA flow diagram [32].

After the literature review process, 26 studies were included in the review. They were analyzed in an inductive-deductive approach: we defined the informational dimensions they could address beforehand (environmental, social, organizational, health). The health specific components were defined based on current literature on the interaction of health and mobility (Figure 1). Moreover, intervention strategies used, and desired effects were based on literature on persuasion strategies in mobility app studies (e.g., [25]) as well as inductively retrieved during the review process. In this study, we specifically draw attention to the informational dimensions of the applied mobility apps.

4. Results

Figure 3 shows the defined four informational dimensions and their specific information given through the mobility apps, which we identified during the review process. The health dimension was subdivided into the health and mobility components derived from the literature (as presented in Figure 1). Ultimately, we investigated the studies regarding their behavior change strategy and effectiveness of the app regarding (intentions of) behavior change, derived from literature and during the review process. Figure 3 displays a summary of the dimensions and app characteristics.

4.1. Overview of the Studies

Table 1 presents an overview of the reviewed empirical studies and the effects of their behavior change interventions. The methods of the empirical studies vary from qualitative to quantitative, having a sample testing/using the respective mobility app. Table 1 represents the results as presented in the studies, describing main findings regarding the effects on mobility behavior change (or intentions) or a possible awareness raising for using more sustainable or healthy modes/routes. A summary of each study is provided in, Appendix A, Table A1.

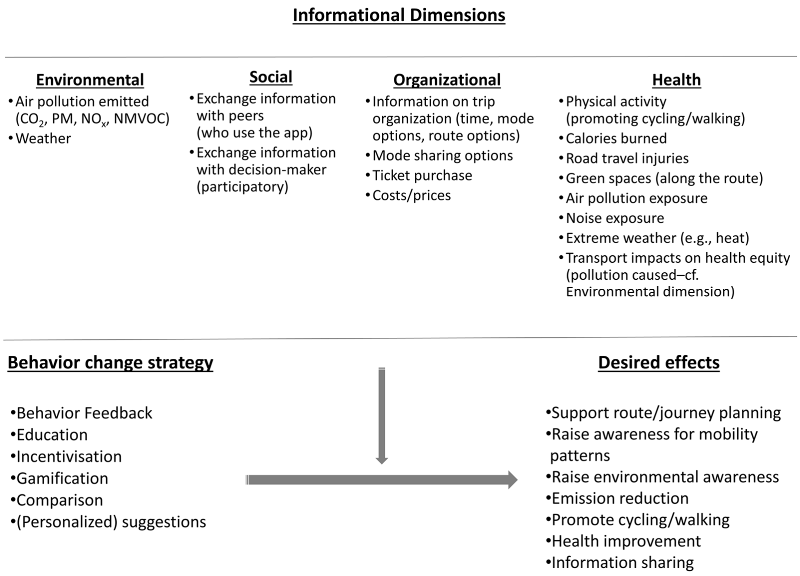

Figure 3. Categories and dimensions for analyzing the literature, defined both deductively based on current literature (mobility-health components [1–3,10,11] and mobility behavior change strategies [9,25]) as well as inductively through the literature review process. Health dimensions defined deductively beforehand for assessment of health dimensions in the apps. Own illustration.

Table 1. Overview of the reviewed studies, the methods applied and their measured effects on mobility behavior.

Study and Name of Mobility App	Method of Empirical Study/Field Trial: Qualitative		Quantitative			Measured Effects of Mobility App (According to the Respective Study) ((Intentions of) Behavior Change; Increased Awareness of Sustainable and Healthy Mobility)
	Interview	**Focus Group Workshop**	**Survey/Ques-tionnaire**	**Assessment of Recorded Routes/Mode**	**Simulation or Modelling**	
[34] OPTIMUM	X		X	X		• Ranking of routes influenced transport choice • Messages raised awareness to change mode/route
[35] PEACOX		X		X		• Positive educational impact that encouraged sustainable travel • Emission information did not produce significant behavior changes (lack of motivation or barriers)
[36] BikeRider		X	X	X	X	• Simulated data shows an increased bike mode share for entire Berlin population and significant decrease for motorized trips (daily purpose)
[37] Cyclers			X	X		• Small monetary rewards (financial incentives) can increase cycling frequency • Gamification does not show an effect on commuting cycling frequency
[38] Move			X	X		• Varying impact of alternative route suggestion incentives on mode choice for different attitudinal profiles
[39] PEACOX		X	X	X		• Increased awareness of unsustainable behavior by providing CO_2 information (especially for car-drivers) • Small and short-term changes in mobility behavior measurable; long-term behavioral change prevented by habits and social conditions

Table 1. *Cont.*

Study and Name of Mobility App	Method of Empirical Study/Field Trial: Qualitative		Quantitative			Measured Effects of Mobility App (According to the Respective Study) ((Intentions of) Behavior Change; Increased Awareness of Sustainable and Healthy Mobility)
	Interview	Focus Group Workshop	Survey/Ques-tionnaire	Assessment of Recorded Routes/Mode	Simulation or Modelling	
[27] PEACOX	X	X	X			• Challenges raised awareness and rethink current mobility behavior
[40] Bellidea		X				• Participants felt empowered, sharing knowledge and discussing with local stakeholders • Increased awareness of available possibilities which support mobility behavior change • Increased political and public communication about transport planning
[41] TrafficO2			X	X		• Sample of students (test sample) showed an increase in sustainable preference for their commuting trip from home to university • Monetary rewards are beneficial, but also environmental consciousness is triggering sustainable mobility choices
[42] GoEco!	X		X	X		• Statistically significant impact (decreased CO_2 emissions) in highly car-dependent urban areas for regularly travelled routes • No statistically significant effects in urban areas with high quality public transport
[43] Bewusst-Mobil		X	X	X		• Increased awareness of causes/effects of mode choice related to health or environment • Small changes in mobility behavior • Unintended effects of the game on the use of non-environmentally friendly modes
[44] UbiGo	X	X	X			• Less private car use and increase in public transport, walking and cycling • Development of negative feelings towards private car use, positive feelings towards public transport • Reported changes in mode choice
[29] BetterPoints			X	X		• 79% of every-day car users stated they have reduced their car usage • 89% tracked sustainable/active travel behavior; 47% showed visible long-term behavior changes throughout the project
[45] SUPERHUB		X				• Environmental concerns are not for all users a motivational factor • Personalized behavior change trigger, e.g., personal health • Sharing mobility data accepted when important for sustainable mobility
[46] Love to Ride			X	X		• Gamification campaigns potentially generate ridership or interest in cycling • Small variations of the game incentive have significant effects on a changed mobility behavior
[47] CarbonDiem	X		X	X		• No significant difference in intention to change before/after study • Qualitative interviews show influence on opinions and intentions to change mobility behavior • Identified barriers to change mobility behavior: weather, distance, child drop-offs, cycling safety

Table 1. *Cont.*

Study and Name of Mobility App	Method of Empirical Study/Field Trial					Measured Effects of Mobility App (According to the Respective Study) ((Intentions of) Behavior Change; Increased Awareness of Sustainable and Healthy Mobility)
	Qualitative		Quantitative			
	Interview	Focus Group Workshop	Survey/Ques-tionnaire	Assessment of Recorded Routes/Mode	Simulation or Modelling	
[48] Viagga Roveretgoto				X		• Introducing gamification after 3 weeks lead to a significant shift towards less car use, significant increase in cycling and a moderately significant shift towards bike-sharing
[24] Quantified Traveler			X	X		• Significant decrease in car use and significant increase in walking, small (not significant) increase in train ride • Increasing awareness (environmental, health, financial, time), with the greatest impact on environmental
[49]	X		X			• Walking to near places increased
[26] Blaze			X			• Interventions to induce behavioral change are stage-depended: individuals in early and late stages need different interventions • App induces some progression and prevents regression in some stages of behavioral change • Car use reduces through the stages • App can change proximate implementation intention but not the distal goal/behavioral intentions
[50] Opti-mod'Lyon		X	X			• No influence on mode shift • No effectiveness on daily trip organization due to strong habitual behavior
[51] Metropia				X	X	• Effectiveness of behavioral incentives for peak hour travelers which promote a departure at non-peak hour times • Incentives need to be tailored considering the travel purpose and the time of the day
[52] SMART Mobility			X	X		• Stated preference experiment to choose between usual route and a route with slightly higher travel time that contributes to a certain societal goal led to differences in travelers' compliance behavior • Travelers' compliance with received information significantly depends on the framing of the information, its societal goal and the size of the travel time sacrifice
[53]			X	X		• Survey data showed emotional persuasive strategy of content priming as an effective way to change detour intention and behavior of car users
[54] RideScout (moovel)			X			• Strong shift from driving towards walking and cycling
[55]			X			• Motives for using a mobility app are based on trip efficiency improvement, enjoyment, social interactions and environmentally-friendly travel promotion

4.2. Informational Dimensions and Intervention Strategies of Mobility Apps

The main aim of our review is to investigate the respective informational dimensions the studies address (and their mobility apps comprise), as well as the behavioral change strategies they used. Most apps applied in the studies comprise several informational dimensions, and only some address specific health components, as will be presented in the following (see Table 2 for an overview).

Table 2. Overview of the mobility apps in the reviewed studies (same order as Table 1), categorized according to the informational dimensions they address (E = Environmental, H = Health, S = Social, O = Organizational), specifically covering transport related health components.

Study and Name of Mobility App	Dimension				Transport Related Health Components								
	E	H	S	O	Physical Activity—Actively Promoting Cycling/Walking	Calories Burned	Safety/Road TravelInjuries	Green Spaces along the Route	Air Pollution Exposure	Noise Exposure	Weather (e.g., Heat)	Transport Impact on Health Equity	Well-Being
[34] OPTIMUM	X	X		X	X						X	X	
[35] PEACOX	X	X		X	X						X	X	
[36] BikeRider	X	X			X		X						
[37] Cyclers	X	X	X	X	X		X						
[38] Move	X	X	X	X	X	X						X	
[39] PEACOX	X	X		X	X							X	
[27] PEACOX	X	X		X	X							X	
[40] Bellidea	X	X	X		X							X	
[41] TrafficO2	X	X	X	X	X	X					X	X	
[42] GoEco!	X	X	X		X							X	
[43] BewusstMobil	X	X										X	
[44] UbiGo	X	X		X	X								
[29] BetterPoints	X	X			X	X						X	
[45] SUPERHUB	X	X	X	X		X						X	
[46] Love to Ride	X	X	X		X	X						X	
[47] CarbonDiem	X	X	X		X							X	X
[48] Viagga Roveretgoto	X	X	X	X	X	X						X	
[24] Quantified Traveler	X	X	X	X		X						X	
[49]		X			X	X							
[26] Blaze			X	X									
[50] Optimod'Lyon				X									
[51] Metropia				X									
[52] SMART Mobility	X		X	X	X								
[53]		X		X	X							X	X
[54] RideScout (moovel)				X									
[55]	X	X	X	X	X	X						X	

4.2.1. Environmental Information

The environmental dimension of transport is primarily expressed through the calculation and presentation of emitted CO_2 per mode/route. As already discussed, many mobility apps provide the user with individual baseline mobility patterns including CO_2 emissions [24,38,42]. Other studies monitor and present the CO_2-emissions of different modes through the app [40,47,55]. Most trip planning and trip assessment apps rank alternative routes and modes and highlight their CO_2 emissions. Some even add the user's preferences [34,35,39]. Sustainable/emission-free alternatives, such as bike-sharing services or park and ride solutions, are also included [48]. These studies use the apps to "nudge" the user to both environmentally friendly and personally beneficial mobility choices by ranking the possibilities based on CO_2-emitted and including personal mobility requirements [34] or contribute to congestion reduction in the region [52]. Other apps applied in the studies include personal goals for a behavior change, which are closely linked to environmental topics (e.g., GoEco! with goals such as "reduce CO_2 emissions") [40,42]. These gamification apps also provide users with rewards, such as vouchers or virtual currency, if sustainable modes are used or routes with less CO_2-emissions are chosen [29,36,40–42,44,55]. Some also cooperate with local shops, where the rewards can be exchanged with prices, and support local businesses (e.g., [41]). The app used by [36] also included the possibility to plant real trees in the city of Berlin when obtaining a certain amount of so-called "green credits". Another comparison strategy was sharing the CO_2-emissions saved on social media [55]. Other studies support social interaction through challenging friends with the app to walk more during the week and thus reduce their CO_2-emissions [38].

Mobility pattern changes as a result of environmental feedback have proved successful in the case of systematic routes in car-dependent urban areas [42]. Other studies, however, report only small behavior changes which may be limited to short-term effects, but report increased environmental awareness [39]. Comparing the emitted CO_2 with others proved to be important in 'understanding the numbers' of CO_2-emissions [39]. One study [41] shows that the gamification app, which provides rewards when choosing sustainable modes (incl. CO_2-emissions or calories burned), was effective in increasing sustainable preference for daily commuting trips. Other studies argued that pro-environmental attitudes are not primary incentives for behavioral changes, hence, incentives should rather introduce environmental choices as the "practical choices" rather than the "idealistic" ones [44].

Other negative environmental impacts such as pollutants are rarely included. The authors of [43] developed a gamification app which includes NO_x, NMVOC and PM2.5 emissions alongside CO_2-emissions as highly weighted indicators. The smartphone app in [38] monitors particulate matter (PM) emissions produced.

Weather information was incorporated into three apps. The authors of [39] included information from the publicly accessible weather service in the backend of the app. The authors of [41] added factors to the rewards received per km walking or cycling on rainy days or days with clouds. Further, [34] included weather as a persuading factor to use bike and ride, suggesting a combination of the bicycle with public transport to save CO_2-emission, drawing attention to the "sunny" weather.

4.2.2. Social Information

The social dimension and the influence of peer groups appears to be a very important aspect of mobility apps [24]. Many apps in the reviewed literature include social comparisons. Comparing daily emissions, calories burned, cost, or travel time with different groups such as "the average American", "the average resident of San Francisco" or "other study subjects" was included by [24]. Another study included the possibility to share information recorded by the app on CO_2 emissions saved or calories burned on social media [55]. Additionally, users could give feedback on infrastructure planning and traffic management related to their recorded trips. The study highlights the positive effects of encouraging a dialogue between decision-makers and citizens because it increases the users' perception of having a say in decision-making processes [55]. No other app included participatory approaches similar to that. In the apps studied by [40,42,48], users could compare their performance with other members through gamification such as "level achievements", "weekly leaderboards" or "badges obtained". Further, [41] made it possible to challenge friends in order to increase the virtual currency. Community challenges, in which participants cooperate for increasing their bicycle usage, were applied by [40]. This collective learning, which was the center of the living lab experiment in their study, highly encouraged participants [40]. The authors of [46] explored whether challenges between different teams (e.g., a company against another company) such as riding a bike "for at least 10 min" increased bicycle usage. Challenges between organizations were also included in [29].

One app [47] allows users to view others' experiences of different modes and their written comments (e.g., "feel ready for the day after that walk" [47]). Sharing knowledge was included in another app [45]: users could localize and share sustainable mobility services on a map, compare scores with friends, include mobility related knowledge (e.g., trip plans), and view suggestions from others. Another app also included sharing bicycle route experiences with peers within the app [37]. An app [52] was used to nudge or recommend an alternative "social" route to contribute to congestion alleviation in the region to help others drive faster due to less congestion. The social dimension was often addressed in the reviewed studies and presents good results in supporting mobility behavior changes (Table 1).

4.2.3. Organizational Information

Most apps also address organizational dimensions to support trip planning, especially integrating different modes and sharing options. One app [54] primarily helps users compare transport options with regards to departure and journey time or mode, integrating

MaaS (mobility-as-a-service) approaches such as ride-sourcing, carpooling, or car-, scooter-, and bike-sharing. Real-time multimodal trip organization was also the aim of the app applied by [50]. Cycling route planning and navigation, where users can set preferences, was combined with public transport in [37]. In another app, one could see the possible routes based on different modes of transport, focusing on sustainable modes, and focusing, i.a., on time and economic costs (next to CO_2 emitted and calories burned) [41]. Two apps focusing on organizing car-driver's departure time were tested by [51,53], including information on travel time and current congestion predictions and suggestions how to avoid congestions via alternative routes.

Many apps integrate payment possibilities or give an overview of the prices of different transport modes. The apps studied by [44,55] include the possibility to buy tickets or, in the case of [54], support payment for sharing options and cost comparisons within the app. Additionally, users requested the possibility of comparing the prices of different modes, receive feedback on the costs, and receive information on the prices of alternative mode-choices [44]. This was also integrated into the app by [24]. This app (integrating time, CO_2, and calories alongside costs) lead to significant behavioral shifts towards sustainable travel [24]. The financial dimension was also addressed in a gamification approach by which the trip which saved most money was awarded with scores (in addition to CO_2-emission saved and calories burned) [29]. The organizational dimension mainly comprised multimodal-trip information, costs/tickets and included new mobility services.

4.3. Health Information and Health Components

Many applied mobility apps in the reviewed studies include information about health (Table 2). However, most refer to physical activity by encouraging the user to cycle, which is closely linked to the environmental dimension of decreasing CO_2-emissions. Others provide information on calories burned. The latter is included in the apps in [24,38,47,55] and in two studies with gamification apps [29,41]. The gamification app by [43] also included health benefits from walking and cycling in terms of physical activity as highly weighted indicators to receive rewards. However, they stated that due to already high environment and health knowledge in the area, young people did not increase their knowledge, nor did they make any significant changes to their mobility behavior [43]. In contrast, other gamification apps which included "health points" based on km cycled/walked in a competition achieved an increase in the share of private cycling trips [48]. Encouraging cycling with gamification, i.e., badges obtained, was performed by [37], but did not show effects on cycling frequency. Financial incentives for cycling, however, did motivate bicycle usage [37].

Safety was addressed by two apps [36,37], which pay particular attention to safe and comfortable bicycle routes.

Even though subjective wellbeing is considered a part of health in relation to transport [3], this aspect is rarely addressed. One app [47] included the possibility of entering subjective experiences and ratings of specific modes and trips in the app and provided the possibility to view other user's answers. Hence, the app incorporated aspects of subjective wellbeing. This resulted in a higher consideration of active and sustainable modes as well as in a better understanding of travel experiences of other mode-users [47]. The authors of [53] successfully integrated an emotional persuasion strategy and thus the intrinsic motivation to avoid stress using pictures of upset co-travelers or small children to activate detour behavior.

Recent literature on exposure to air pollution has argued in favor of developing tools which integrate avoiding exposure as an incentive for individual route planning [13]. The inhalation of CO_2, PM or NO_x is reported to have an impact on human health [56,57]. While emitted air pollution of a mode is included in some apps, especially CO_2 (see Section 4.2.1), two apps also included the emission of other traffic-related pollutants (PM, NO_x) [38,43]. However, none include information on personal exposure to or inhalation of air pollution and related health impacts, which could result in behavioral changes regarding departure time or route-choices [13]. Nonetheless, including the produced PM, NO_x or CO_2-emissions in the app, as in many studies (see Section 4.2.1), does address health equity.

Moreover, none of the mobility apps included exposure to noise and only one [39] included aspects regarding extreme weather in route-planning/mode choice, setting the distance of walking or cycling below 15 min during extreme temperatures. The incorporation of green spaces along the route was not addressed by the reviewed apps. Summarizing, we can clearly see that health is addressed in terms of encouraging physical activity, which is also closely linked to the environmental dimension. However, other health related components are missing. We will discuss this lack of health-related information in mobility behavior change apps in Section 5.

5. Discussion

In this paper, we conducted a literature review of recent empirical studies which explore the possibilities of mobility apps to change mobility behavior. We investigated the informational dimensions their applied mobility apps include. Our results provide evidence that certain health aspects, as presented in the introduction, are lacking in mobility apps applied in mobility behavior change research.

5.1. CO_2-Emission Predominant in Studies That Employ Mobility Apps

The results indicate that there is a trend towards including environmental information in mobility apps to support a behavioral change. Environmental information is generally represented as reducing CO_2-emissions. Most research includes the emitted CO_2 of a certain mode/route choice, leading partly to an increase in active modes or public transport, which have great potential to support sustainable mobility (Figure 1). However, other pollutants resulting from traffic, such as NO_x or particulate matter (PM), are rarely included. The emission of CO_2 causes global problems related to climate change and is therefore important to consider for sustainable mobility. However, other traffic-pollutants have severe health impacts on a local level, i.e., affecting health equity. It is argued that these should be considered more [57]. Hence, not only CO_2-emission information should be provided, but also the emission of other pollutants. This could not only support the usage of bicycles, walking or public transport, but also of electric vehicles or micromobility offers (e.g., e-scooters), which rarely cause local pollution. Since the latter are a comparably recent development, few of the reviewed studies have taken them into account.

While the effects of CO_2-emissions are usually perceived as geographically distant, informing citizens about local pollution (NO_x, PM and noise) and mitigation benefits can incentivize environmentally friendly mode usage [58]. Moreover, noise is not included in any of the studies, even though a constant high noise level is among the top environmental health risks in urban areas [59]. The results of the reviewed literature show that environmental concerns may not be a sufficient motivation for mobility behavior change for all users (Table 1) [31]. Some do not want to change their mobility behavior "just for the sake of the environment", thus, additional information may be more convincing [60]. Addressing personal concerns is a possible trigger for behavioral change and applying healthy living interventions in mobility applications would be recommendable [31,60]. CO_2-emissions are the most frequently addressed factor in our reviewed studies, while other pillars of sustainability, such as health or equity, are addressed less. Yet, health is specifically regarded as part of sustainability and the third sustainable development goal (SDG), which explicitly addresses the severity of air pollution among other health-related issues [61]. We argue that there is a need to refine the term sustainability with regards to mobility app studies and incorporate health components more explicitly.

5.2. The Health Dimension and Subjective Wellbeing in Mobility Apps

Urban and transport planning research could further investigate the possibilities that new technologies offer to improve citizens' subjective wellbeing and health in traffic [20]. Generally, providing mobility-information can positively influence subjective wellbeing because it increases the feeling of self-control [62]. However, our literature review shows that mobility apps are lacking which inform about mobility-related health impacts en route and healthier route options. For example, none of the reviewed studies provided the option of searching green spaces or non-polluted (noise and air pollution) routes in their app. As recent research showed, cyclists would be willing to take a less polluted route if it did not add more than about 4 min to their travel time [13]. Other studies also stress the need to communicate information about exposure [63–65], one also using smartphone apps [66]. Studies similar to these are important to understand what impact digitally provided exposure information has on route choices and how that information should be designed. While CO_2-emission feedback addresses the collective dimension, addressing the self-interest of individuals can support sustainable mobility choices as well [60].

After all, communicating personal exposure and health impacts should be considered carefully. As [67] point out, the perception of air pollution and the related health risk can cause negative effects through stress-induced physical reaction and thus cause actual symptoms of sickness. Moreover, information aiming at people's self-interest should not result in an unsustainable outcome at the societal level, e.g., information on pollution levels for open air activities should not result in the usage of private cars, especially as car drivers are not necessarily less exposed to air pollutants than cyclists or pedestrians [68]. Unintended and undesired consequences of mobility behavior interventions have to be considered before intervening in people's daily mobility choice processes [69]. A more holistic view of behavior changes, in which the individuals themselves can change their moral values and not passively follow suggestions from an app, should be considered [52,69]. Strongly pointing out the health benefits of non-motorized transport (e.g., see [68]), additionally incorporating information of the organizational, environmental and social dimension while supporting individual's own decision-making process is crucial. After all, the knowledge of health risks can lead to a change in attitudes and beliefs, and motivate behavior changes [67].

5.3. Limitations of the Reviewed Studies

Many of the reviewed mobility app studies are short-term, have a rather small sample size and are missing evidence that behavioral change lasts (also argued by [45]). Seven of our studies had a field phase which was between 3 months and 1 year, and only two were longer than 6 months. Moreover, the characteristics of the user group have a strong impact on what effect the app has, hence, different user-groups respond to dimensions/arguments in different ways [34,70]. Future research should therefore acknowledge the limitations of the reviewed studies. Researching the impact of mobility apps when incorporating health components would be of interest. Based on the research gap as shown in our findings, we now present our conceptual framework for a mobility app focusing on the health dimension.

5.4. Conceptual Model for Including Health in Mobility Apps

Mobility apps in behavioral change studies mostly address health by means of CO_2-emitted, physical activity, or burned calories. Yet, the latter two do not feature prominently in the apps herein. We argue that health-related information should be given more attention. Improving personal health in addition to enabling contributions to wider global challenges, such as climate change through CO_2-emission reduction, could be an incentive to change mobility behavior [71]. Health should be understood in a broader way in the context of mobility apps: not only physical activity, but also personal exposure (to air and noise pollution, heat), green space provision, or safe routes affect health while traveling in the city [1–3].

As shown in our review, mobility apps including these components, supplementary to persuasion, incentivization, or other informational dimensions, are missing and the effect on mobility behavior changes vary (Tables 1 and 2). Informing about environmental dimensions partly leads to sustainable mobility choices, e.g., people increasingly use active modes or public transport or mobility apps support combinations of cycling, walking and public transport instead of private car usage (Table 1).

However, other studies report rarely any increase in sustainable modes (Table 1). This raises the question whether the altruistic motivation of environmentally friendly mobility is enough or—as we propose—if supplementary information on personal health is needed. As shown in this review, the effects of healthy mobility choices can improve the city's sustainability and urban health situation (Figure 1). We propose a stronger consideration of people's self-interest in protecting themselves from health risks en route and take the protection motivation theory (PMT) [12] as a framework. The PMT is a common theory for explaining health behavior and was even applied for physical activity promotion [72]. According to the PMT, protection motivation is based on four cognitive beliefs, which determine whether a person is motivated and has the intention to protect oneself: (1) threat appraisal (are the current outcomes of a behavior regarded as severe and harmful for oneself) and (2) coping appraisal (is one capable of undertaking protective actions (self-efficacy) and exist possibilities to prevent the risks (response efficacy) [12,72,73]. For promoting healthy and sustainable mobility and increasing physical activity (cycling/walking) or public transport usage, it is important to focus on people's threat appraisal and connect it with coping appraisal. We propose the protection motivation theory (PMT) [12] as a framework for further including health in mobility apps (Figure 4).

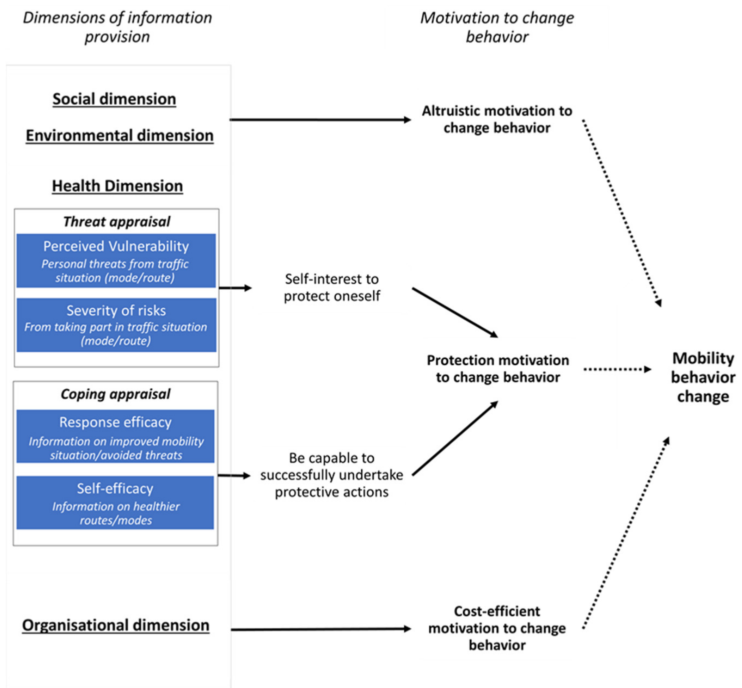

Figure 4. Inclusion of transport and health-related components (taking the protection motivation theory as a framework) to support healthy mobility choices through protection motivation, alongside cost-efficient motivation and altruistic motivation to change behavior. Own illustration, applying the PMT [12].

According to Figure 4, firstly, awareness could be raised for personal vulnerability during daily mobility (defined as threat appraisal) and included in a mobility app by presenting:

- Level of route-specific exposure to harmful air pollutants, noise, or temperatures;
- Traffic injuries on/in specific routes/areas;
- Number of non-active km travelled;
- Percentage of green-space areas on a specific route.

Secondly, the severity of the risks could be communicated by providing general information regarding:

- Health impacts of air pollutants, noise, or temperatures;
- Risk of traffic injuries;
- Risk of obesity/non-active mobility;
- Positive influence of green spaces on health.

Thirdly, providing information on how to protect oneself is part of people's self-efficacy (coping appraisal) and crucial for supporting behavior changes. A mobility app is especially suitable to provide information about:

- Healthier route options (less polluted, greener, safer, cycling/pedestrian friendly (incl. subjective experience (e.g., aesthetics) and wellbeing));
- Healthier mode options (bikeability/walkability, sharing bicycles, intermodal trip planning, i.e., connecting cycling and public transport).

Ultimately, the success of possible mobility behavior changes is of importance (response efficacy) and could be communicated by:

- Avoided pollutants (noise, air pollution), related positive health impacts (e.g., lower blood pressure, less chance of cardiovascular diseases);
- The distance in km travelled close to greenery/water/aesthetic urban form, related positive health impacts (e.g., relaxation, improved wellbeing, lower blood pressure);
- The distance in km cycled/walked, fitness level improved, related positive health impacts (e.g., improved wellbeing, lower blood pressure, higher fitness level).

People's self-interest in protecting oneself combined with healthy alternatives suggested by mobility apps may be a promising method to support healthy mobility behavior, supplementary to other informational dimensions and behavioral change strategies.

However, two aspects should be considered. Firstly, a health-related mobility app should not be overloaded with information, which could lead to difficulties for the user to choose a route or travel mode. It has to be carefully considered which information will be included in a specific app and how it is presented. Exposure-related information should address both threat and coping appraisal. It needs to be relatable/understandable, actionable, relevant to the user, connect with his/her emotions and increase a feeling of collective engagement [74]. Only then it may encourage and sustain fully sustainable (environmentally friendly and healthy) mobility behavior. Consulting a variety of stakeholder with different backgrounds for co-creation is required [74].

Secondly, it has to be considered that the here proposed protection motivation has to compete with other motivations to change behavior, e.g., the cost-efficient motivation (Figure 4). Traditional utility theories argue that travel mode and route choices are based on travel cost, time and effort (among others) [75,76] and longer travel times can decrease travel satisfaction [77]. However, recent studies argue that varying experience factors (e.g., directness, reliability congestion, comfort or even noise, scenery and weather) promote travel activities and influence perceived value of travel time [76]. As for mode choice, non-instrumental factors are also decisive, such as symbolic or affective motives (e.g., for car use) or environmental factors (e.g., weather, land use) and psychological factors (e.g., attitudes, social norms) for cyclists [75,78]. People need to balance the received health information against other decisive factors. Individual's mode or route choice may not follow app-based protection-motivation suggestions straightforward, but when knowing them, they might be considered among other factors.

6. Conclusions

In this paper, we have shown that health components are missing in mobility-related smartphone apps which aim at promoting sustainable mobility. We have investigated which dimensions are addressed and found a strong focus on CO_2-emissions, addressing sustainable mobility in terms of emissions reduction. Incorporating health-related components in mobility communication (e.g., mobility apps) may be just as or even more effective in changing people's mobility behavior towards sustainable and healthy mobility. That could be investigated in future research. Considering the severe impacts of urban mobility on individual health, including health information other than physical activity seems crucial.

It has to be considered that the market for mobility apps is growing and that, as a result, mobility services and possibilities for data generation/provision are changing fast. Nevertheless, our review paper provides new directions for future research agendas. Firstly, we recommend drawing more attention to how people perceive their health, exposure and environment en route and explore how they want to be informed via mobile technologies. Secondly, the effect of providing information on personal exposure, green spaces, or traffic injuries en route needs to be understood to effectively develop information strategies. Especially the effect of giving feedback about personal exposure on behavior is still scarce and needs to receive attention [79]. Exploring the impact of exposure information on mobility behavior through ex-ante and ex-post studies could be beneficial.

Considering that the desired effects on mobility behavior were not always reached in the reviewed studies, the question arises to what extent mobility planning and policy should focus on mobility apps as a suitable measure for sustainable urban mobility. It is important not to lose sight of good urban design, urban governance in planning, and urban dwellers actual needs: mobility apps can be used as a supplement to planning and political strategies, as long as they address the users' needs [80]. Only if healthy and sustainable alternatives exist, i.e., adequate public transport option or cycling/walking infrastructure, a mobility app has the chance to induce sustainable mobility behavior. To understand the user's needs, they have to be actively involved in research and practice regarding information and communication technologies (ICT), such as mobility apps [81]. Mobility apps should empower, inform and enhance the responsibility of urban dwellers to make their own healthy and sustainable mobility decisions, rather than just being passive consumers [69]. The fact that only one of the reviewed apps made successful use of participatory approaches (users sharing experiences with decision-makers) shows the lack of attention that citizen participation receives in mobility apps. Having said that, we finally argue that promoting mobility apps as a tool for sustainable urban governance, healthy urban design, or education could increase awareness for and the actual use of healthy mobility options and healthy routing. The resulting improved wellbeing of urban dwellers may lead to increased satisfaction regarding the institutional planning decisions and is thus desirable for urban policy. With an enhancement of people's environmental health literacy regarding mobility choices, sustainable and healthy mobility can become the center of individual as well as policy-oriented attention.

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Appendix A

Table A1. Overview of the reviewed literature.

Study and Name of Mobility App	Summary of Approach, Aim and Method of the Reviwed Mobility App Studies
[34] OPTIMUM	Approach: User persuadability profiles are developed based on people's mobility behavior and their personality. Personalized interventions, suiting to the persuadability profile of the respective user, are created. Aim: Interventions are part of a route planning app (multimodal route planning) which aims at nudging the user to using sustainable routes. Method: Tested in a pilot study (30 participants, 6 weeks).
[35] PEACOX	Approach: Development and testing of a smartphone-based journey planner, which aims at presenting environmental information for each searched trip to the user ("environmentally themed journey planning app"). Aim: Users reduce their CO_2-emissions and simultaneously receive the required trip information for undertaking their journey. Method: Field trial testing the app in Dublin.
[36] BikeRider	Approach: Users were introduced to new mobility services. Aim: Try to persuade to change their mobility behaviour and leave their comfort zone and behold the impact of these changes via different categories, like traffic system performance and carbon emissions. Method: Gamification approach, with three individual pilot sites, the Berlin STREETLIFE App and the game "BikeRider".
[37] Cyclers	Approach: Try to improve the "Cyclers" smartphone app through evaluating the financial and non-financial motivational features. Aim: To gain a more sustainable and healthier lifestyle, they try to increase regular commuter cycling via the "Cyclers" app in combination with motivational features. Method: Randomized experiment (4 different groups based on different motivational treatments).
[38] Move	Approach: Understand the role of smartphones as mobility behaviour sensors and their ability of various settings profiles to respond to personalized route suggestions incentives offered through smartphones. Aim: Showing user profiles who are likely to accept such incentives and who will more likely choose a more sustainable mode choice. Method: Mobile sensed data collection of real life (n = 3400, 6 months).
[39] PEACOX	Approach: Incorporate persuasive strategies (supported by a choice architecture approach) into a smartphone application (route-planning assistant) for everyday usage. Aim: Providing users with information and solutions while planning a route. Try to influence the user to consider the environmental friendliness of travel modes. Method: Evaluation of the modified route-planning assistant (24 participants, 8 weeks).
[27] PEACOX	Approach: Using the PEACOX system (mobile travel planning application) for analysing the effectiveness and perception of challenges. The challenges are in context of the personal mobility and their influence. Aim: Through which aspects users are willingly participate in these challenges and is there a potential to keep the user interested in using behaviour change support systems. Method: Field study (2 months).
[40] Bellidea	Approach: Exploring information and communication technologies and actively engaging users in co-creating innovative urban services. Aim: To co-create a behaviour change app for reducing car use and in this case reduce car-based traffic. Method: "Living" lab experiment.
[41] TrafficO2	Approach: Investigation of new smartphone and app technology, which promoted a more sustainable choice via mobility modalities. Aim: Change the mobility behaviour while using applications and game rewarding for more sustainable trips. Method: Smartphone app tested by university commuters' group
[42] GoEco!	Approach: Designing and testing a smartphone application named "GoEco!" which contains automatic mobility tracking, eco-feedback, social comparison and gamification elements. Aim: Reducing car use, related CO_2 emissions, energy consumption und enhance/persuade people to make sustainable mobility choices. Method: Randomized controlled trail (one year) in the regions: Cantons Ticino and Zurich (Switzerland).
[43] BewusstMobil	Approach: Concept for a competitive app for students which collects the player's travel data for the game. Aim: Increase environmentally friendly active travel modes during scores and real-life rewards (e.g., shopping vouchers). Method: Iterative process of design, prototyping, and evaluation of the game, three schools in Austria, 57 Students, age 12–18.
[44] UbiGo	Approach: Testing the UbiGo transport broker service and the regarding incentives for users to adopt the new travel services. Aim: Using the service from the UbiGo and obtain a better understanding how to establishing this kind of service. Method: Questionnaires, interviews and travel diaries, 6-month field operational test.
[29] BetterPoints	Approach: Users registered in the app "BetterPoint" obtain different behavioral categories proposed based on engagement etc. for better understanding the data and to tailor future intentions. Aim: Using gamification and rewards for increasing active travel and reduce car journeys. Method: 667 participants, transport project.
[45] SUPERHUB	Approach: Prototyping, testing, and refining of motivational features for environmentally friendly mobility with social influence strategies while using social media. Aim: Behaviour change, better mobility solutions for citizens, guidance for sustainable mobility choice. Method: Three parallel and complementary user studies.
[46] Love to Ride	Approach: Compare different users: smartphone application versus those relies on manual entry. Aim: Users with higher encouragement in digital and/or gamification campaigns are more engaged/have an increased attention. Collecting data can help for urban planning and improve infrastructure. Method: Three large-scale recurring annual encouragement campaigns (66,762 participants).
[47] CarbonDiem	Approach: Using a smartphone application as an intervention tool, the participants must reflect their own and/or others' subjective experiences (SE). Aim: Users should reflect their behavior while using transport modes and make better choices. Method: Automated capturing of data via app and automated reflection, previous self-report study.
[48] Viagga Roveretgoto	Approach: Presenting a service-based gamification framework. This should be an extension to existing services and systems in a smart city. Aim: Behavior change towards sustainable mobility solutions. Method: Testing the gamification framework in the city of Rovereto.

Table A1. *Cont.*

Study and Name of Mobility App	Summary of Approach, Aim and Method of the Reviwed Mobility App Studies
[24] Quantified Traveler	Approach: Presenting a computational travel feedback system using a mobile phone app to gather travel data and give personalized information on carbon, exercise, time and cost footprint to participants. Aim: Learn if participants accept travel data collection, use computed travel information and if this results in attitude or travel behaviour shifts. Method: Travel data collection, questionnaire, 135 participants.
[49]	Approach: Developing an app-based mobility management (MM) which uses step counting and score/ranking functions. Aim: Increase walking and therefor change behavior of the participants. Method: Case study.
[26] Blaze	Approach: Testing Blaze, a mobility behaviour change support system and their influence on travel behaviour. Aim: Obtain a better insight view on the potential role of technology interventions in mobility management and how to achieve behavioural changing in travel. Method: Longitudinal data from a social experiment (over a month).
[50] Optimod'Lyon	Approach: Using Optimod'Lyon (multimodal real-time information navigator for smartphones) and assessing the effects on travel behavior. Aim: User behavior shift from car driving to environment-friendly modes of travel. Method: Quali-quantitative approach, questionnaire, focus groups (50 participants in Lyon).
[51] Metropia	Approach: Analyzing the impact of incentives for main trips and obtain a personal incentive scheme to get an optimal manner at the system wide level. Aim: A behavior shift from peak hour travelling to non-peak hour travelling. Method: Compare two consecutive incentive schemes (1-year), data collected by the Metropia App (2270 users, 364,966 trips, May 2015–May 2018).
[52] SMART Mobility	Approach: Investigate determinants of travelers' compliance with social routing advice. Aim: Obtain a better view on how travel information can be used to obtain system-optimal routes, to obtain a better network efficiency. Method: Stated choice experiment, revealed choice experiment.
[53]	Approach: Applying an emotional persuasive strategy to examine the change of intention and behavior on route decisions. Aim: To keep users from using the Tohoku expressway to use the Joban expressway. Method: Two sets of interventional experiments, track location information (12 days within four weeks), longitudinal online survey.
[54] RideScout (moovel)	Approach: Applying a survey with users of a multi-modal information app to examine the impact of information provision on travel behavior shifts. Aim: Understand how a multi-modal information app may shift travel behaviour. Method: Survey with 130 app users.
[55]	Approach: Investigate motives and use intention for a municipal travel information system. Aim: Understand drivers travel decisions when using the multimodal travel app including type of travel information, integrated services, social and persuasive features. Method: Web-based survey with 822 participants.

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