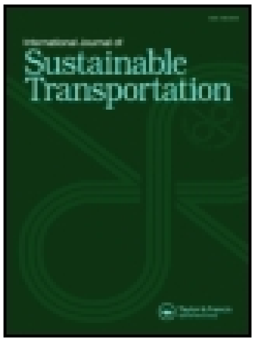

International Journal of Sustainable Transportation

ISSN: 1556-8318 (Print) 1556-8334 (Online) Journal homepage: http://www.tandfonline.com/loi/ujst20

Can we promote Sustainable Travel Behavior Through Mobile Apps? Evaluation and Review of Evidence.

Varsolo Sunio & Jan-Dirk Schmöcker

Can we promote Sustainable Travel Behavior Through Mobile Apps? Evaluation and Review of Evidence.

Varsolo Sunio and Jan-Dirk Schmöcker

Department of Urban Management, Kyoto University, Japan

Corresponding Author E-Mail schmoecker@trans.kuciv.kyoto-u.ac.jp

ABSTRACT

Mobile phone applications to monitor and influence one's behavior are numerous. Most developed appear to be health applications but in the past decade, "persuasive technology" has also been leveraged and applied to promote sustainable travel behavior. We discuss the health applications and review and evaluate existing behavior change support systems (BCSS) designed to promote sustainable travel behavior. We extract the persuasive features embedded in these systems and evaluate their persuasive potential by using the persuasive systems design (PSD) model that has been used to evaluate BCSSs in the health domain. Our evaluation reveals that some features crucial for successful travel behavior change, such as tunneling, rehearsal and social facilitation, are missing. Furthermore, we assess studies conducted to evaluate the effectiveness of these BCSSs in changing behavior and find indications that effect sizes are mostly small though methodologically robust studies are largely missing and hence no definitive conclusion yet can be derived. Based on these findings as well as literature related to public health where BCSSs appear to be further developed, we then derive three important suggestions on research needs and applications for further development of BCSSs in the transport policy realm.

Keywords: smartphone, behavior change support system, sustainability, travel behavior, persuasive technology.

1. INTRODUCTION

There has been a burgeoning interest in using technology to deliver interventions to change behavior ever since Fogg (2002) introduced his pioneering work on “persuasive technology.” This is defined as technology designed to change attitudes and behaviors of users through persuasion (Fogg, 2002). Recently, Oinas-Kukkonen (2010; 2013) coined the concept of behavior change support system (BCSS), which builds on this tradition of persuasive technology. Oinas-Kukkonen (2010) defines BCSS as an “information system designed to form, alter, or reinforce attitudes, behaviors or an act of complying without using deception, coercion or inducements.” In the design of the information system, a web- or mobile- based platform is often used. Here, smartphones as a medium of intervention are particularly noteworthy and promising. With their widespread adoption and pervasive use in society, smartphones can be leveraged to deliver large-scale and cost-effective behavior-change interventions (Lathia et al, 2013). Indeed, as Fogg and Eckles (2007) asserted, the future platform for persuasion and behavior change is mobile.

BCSSs have been implemented in domains such as healthcare/wellbeing (e.g. Lane et al, 2011), energy use conservation (e.g. Weiss et al, 2011), education (e.g. Mintz and Aagaard, 2012; Mintz et al, 2012), and travel (e.g. Froehlich et al, 2009), to name only a few. In the healthcare/well-being domain, extensive reviews have already been conducted. These studies include evaluations on the persuasiveness of the design features of the health/well-being BCSSs (Langrial et al., 2012; Lehto & Oinas-Kukkonen, 2010; Lehto & Oinas-Kukkonen, 2011); content analysis on the extent of inclusion of health behavior theory constructs (e.g. Cowan et al, 2012); characterizations of behavior change techniques implemented (e.g. Conroy et al, 2014; Yang et

 ACCEPTED MANUSCRIPT

al, 2015); and assessment of their effectiveness (e.g. Wang et al, 2014). Although a number of reviews like these have been done in the healthcare/wellness domain, we observe that, in the domain of travel behavior, no review of this kind has been carried out yet.

Moreover, in recent years, Fogg's (2002) framework has also been applied to the topic of environmental sustainability (e.g. Di Salvo et al, 2010). A broad range of environmental sustainability issues are being addressed or tackled, such as energy consumption, water and fuel use, indoor air quality and transportation (Brynjarsdottir et al, 2012). The primary aim is to promote environmental sustainability through persuasive technology.

In this paper, our interest is on persuasive technology, in particular BCSSs, designed to promote "sustainable travel" or "sustainable mobility." Technology -- or in particular, information and communication technology (ICT) -- can promote sustainable urban mobility in various ways by changing travel demand, travel patterns and urban forms (see, for example, Cohen-Blankshtain & Rotem-Mindali, 2016), but here we only consider ICT potential effect on travel behavior. Moreover, we use "travel" and "mobility" interchangeably. Definitions of sustainability vary in literature, but it is generally considered as encompassing environmental, economic and social dimensions. In this paper, we regard sustainability in its narrow environmental sense of simply minimizing the amount of car travel or carbon emissions. Unsustainability of travel is thus usually equated with car use.

To the best of our knowledge, work on sustainable travel BCSSs began with Ubigreen Transportation Display (Froehlich et al, 2009). Its purpose is to increase awareness about the user's sustainable travel behavior. Each time the user takes greener alternatives, Ubigreen senses this and feeds it back as ambient changes to the background graphics of the user's phone. Later

ACCEPTED MANUSCRIPT

on, other sustainable travel BCSSs were developed: Peacox (Schrammel et al, 2012), Quantified Traveler (Jariyasunant et al, 2015) and MatkaHupi (Jylhä et al, 2013).

Traditionally sustainable travel behavior has been promoted through various voluntary behavior change programs (VTBC) without extensive support systems. Examples include so called “Travel Feedback Programs” (TFP) in Japan (Fujii and Taniguchi, 2005). In a typical TFP, participants of the program are given feedback based on their reported travel behavior with the aim of modifying their behavior without coercion. TFPs come in several types, differentiated by the location, techniques, procedures and communication media used in their implementation (Fujii and Taniguchi, 2006). With respect to communication media, TFPs have relied so far only on traditional technologies, namely face-to-face communication, regular mail, telephone and email (Fujii and Taniguchi, 2006). This severely limits the potential of classical TFPs for scaling up (Jariyasunant et al, 2015). Nonetheless, as argued earlier, a new platform for persuasion has emerged recently -- the mobile platform -- which TFPs, or VTBC programs in general, appear to not yet have taken full advantage of. The mobile platform can broaden the applicability of VTBC programs while maintaining their effectiveness (Meloni et al, 2015). For instance, Quantified Traveler (Jariyasunant et al, 2015), mentioned earlier, is a mobile-based computational TFP.

Besides their potential in promoting sustainable behavior change, many of these systems also function as automated trip diaries, capable of generating travel surveys at large scale. Smartphones are equipped with sensors that can be used to collect trip data from individuals, often with minimal respondent burden. These data can then be processed to derive detailed information about mobility patterns (Roxas et al, 2016; Sadeghvaziri et al, 2016; Patterson and Fitzsimmons, 2016) and urban activities (Demissie et al, 2015).

In this paper, we aim to extract and evaluate the persuasive elements embedded in travel behavior change support systems by applying the Persuasive Systems Design (PSD) model (Oinas-Kukkonen and Harjumaa, 2009; explained below). We are motivated by the need to identify important persuasive design elements in these BCSSs. Davies (2012) observed that in non-technology-based VTBC programs, “little regard has been paid to the actual design of VTBC campaigns and their individual elements… However, there is also a need to understand and theorise the design of campaigns, both singularly and collectively, as part of overall policy to change travel behavior on a wide scale.” Hence, it is necessary to evaluate the design of the VTBC program itself, in addition to its impact in changing behavior. Finally, we conclude with some propositions and suggestions to advance the field.

2. METHODS

2.1. Eligibility Criteria

There are clearly a large number of studies aiming to change the travel behavior through various information feedback (Ampt, 2003; Fujii and Taniguchi, 2005; Richter, Friman, & Gärling, 2011). We limited our review by the following criteria: A study was included if (1) it aimed to change travel behavior by influencing the traveler’s trip, mode, departure time, or route choices; (2) the intervention used a mobile/smartphone application and/or website, and (3) it is published in journals or conferences. Studies that use smartphones as mobile sensors to automatically detect trip information or construct travel diaries, but do not (explicitly) aim to change behavior, are excluded. Moreover, those which use smartphones in designing behavioral modification interventions but have no corresponding publication are likewise excluded. For example, “in-Time”, “Wiewohin”, “Kongressnavigator” and “EcoWalk”, which are cited in Busch et al

(2012), are not included in this review because we could not identify sufficient material describing these.

2.2. Search Method

We conducted our literature search in several databases using keywords such as ‘‘smartphone”, “travel”, “behavior”, “change”, “persuasive” and “intervention.” We searched articles published between January 2005 and June 2015. We screened the articles based on their titles and abstracts, and those that seemed to meet the inclusion criteria were selected for further examination. After we verified that they indeed met the necessary criteria, they were then included in the final list. A snowball review was then conducted, in which selected articles that emerged from the literature search were screened and checked for potential eligible studies. In case when some papers obtained through this search method are only a part of a bigger study, supplementary papers are also obtained.

2.3. Evaluation Method

2.3.1. Persuasiveness

Several frameworks have been introduced to evaluate persuasiveness of design. The BCSSs included in the study were evaluated based on the framework introduced by Oinas-Kukkonen and Harjumaa (2009), known as the Persuasive Systems Design (PSD) model. The PSD represents an extensive conceptualization for technology-based persuasion and the most sophisticated evaluation method available (Lehto & Oinas-Kukkonen, 2011). In general, PSD can be used in a variety of settings: from evaluating the software design specifications to assessing the literature in some problem domain (Oinas-Kukkonen, 2013).

ACCEPTED MANUSCRIPT

The PSD model is a conceptualization for designing, developing and evaluating BCSSs. In evaluating BCSSs using PSD, we first analyze the persuasion context and then the persuasive system features. Persuasion context analysis includes identifying the intent (Who is the persuader? What type of change does the persuader target?), the event (use, user and technology contexts) and the strategy (message and route). Next, we analyze the persuasive system features. In the PSD model, there are four categories for the features: primary task support, dialogue support, system credibility support and social support. Primary task support helps the user achieve or carry out the primary task or target behavior by means of seven principles, namely reduction, tunneling, tailoring, personalization, self-monitoring, simulation, and rehearsal. Dialogue support enables user-system interaction to keep the user active and motivated in using the system. Praise, rewards, reminders, suggestion, similarity, liking, and social role are seven principles of dialogue support. System credibility support aims to make the system more believable and thereby more persuasive. It includes trustworthiness, expertise, surface credibility, real world feel, authority, third party endorsements and verifiability. Social support leverages social influence to motivate users and employs social learning, social comparison, normative influence, social facilitation, cooperation, competition and recognition (Oinas-Kukkonen and Harjumaa, 2009; Oinas-Kukkonen, 2010; Oinas-Kukkonen, 2013).

Two methodologies can be used to carry out BCSS evaluation according to the PSD model. The first, and the most rigorous, is to have two or more research scientists independently carry out feature-by-feature evaluation of the applications using the persuasive features specified by the PSD Model. After the independent review is made, the research scientists meet to discuss findings and to resolve disparities in their evaluations. In Langrial et al (2012), four scientists

 ACCEPTED MANUSCRIPT

carry out independent evaluations while in Lehto and Kukkonen (2010) and Kelders et al (2012), only two perform independent review. The second, which is less rigorous, consists of one research scientist preparing a comprehensive evaluation, which is then verified and commented by one or more research scientists. In Lehto and Kukkonen (2011), this is the methodology employed: one research scientist did the coding, which was then checked by the second scientist.

Moreover, feature-by-feature evaluation can be done by simply coding descriptions based on published literature without using the applications (e.g. Lehto and Kukkonen, 2011; Kelders et al, 2012) or by actually using the applications and performing representative tasks (e.g. Lehto and Kukkonen, 2010), or both (e.g. Langrial et al, 2012).

In our study, four research scientists performed the PSD evaluation. We first developed a common coding framework from the seminal paper on PSD by Kukkonen and Harjumaa (2009), and papers that use the PSD model to evaluate applications (i.e. Lehto and Kukkonen, 2010; Lehto and Kukkonen, 2011; Kelders et al, 2012; Langrial et al, 2012). This coding framework (see Table 1) was used by the first author to prepare a comprehensive feature-by-feature evaluation of the 9 BCSSs as described in the published reports. The resulting entries were then put in tabular form, and independently reviewed and commented by the second author and two other research scientists. Any disparity was then resolved by all the four evaluators through a rigorous discussion. It was agreed that persuasive features would only be reported if all four evaluators reached a consensus. Our evaluation is limited only to published reports, since many of the applications are not downloadable from the online stores, and if ever they are, they cannot be used in Japan. Lastly, in our evaluation, as in Kelders et al (2012), we omitted system credibility support because the published studies do not sufficiently report these principles, making any evaluation difficult to carry out in a manner that is as objective as possible.

Finally, we note that evaluating persuasiveness of design using PSD is based on “interpretive categorization” (Lehto and Kukkonen, 2011). In many articles cited in this review, their authors did not state explicitly the persuasive features; in few others, their authors clearly stated these features even though they did not necessarily use the same terminologies in the PSD. Hence, the authors of the present review, in extracting and categorizing persuasive features, had to use their subjective judgment -- and herein lies potential bias.

2.3.2. Effectiveness

We then characterize the evaluation studies conducted to assess the effectiveness of the identified BCSSs. In our characterization, we adapt parts of the framework used by Graham-Rowe et al (2011) to assess the efficacy of 77 car-use reduction interventions. In this framework, evaluation studies are characterized in terms of intervention strategy (structural, psychological), methodological quality of study design (high, low), and measure type (distance, mode change, trips/frequency, time/duration). Structural interventions involve modification of the structures surrounding travel behavior through physical and/or legislative measures (e.g. road pricing and bus priority lanes). Psychological interventions are designed to modify perceptions, beliefs and attitudes (Graham-Rowe et al, 2011). Since we are interested only in BCSSs, we only consider psychological intervention strategies.

Three study designs are considered of high methodological quality: experimental, quasi-experimental, and cohort-analytic (with control). In experimental designs (e.g., randomised controlled trials), individuals are allocated randomly to either intervention or control groups. In quasi-experimental designs, matched but not randomized control groups are used. In the cohort-analytic (with control) method groups exposed and unexposed to an intervention are compared. In this method, the investigator does not control the intervention exposure but only 'observes' (observational study design). These three designs are considered of superior quality because they provide strongest control of confounding variables.

Low quality study designs include case controlled/cross sectional and cohort uncontrolled. In case-control or cross-sectional between-group evaluation, two groups, without pre-intervention measures, are compared post-intervention. One group is exposed to the intervention, and the other is not. In cohort-uncontrolled, before- and after-intervention measures are recorded, but there is no control group for comparison. In the original framework by Graham-Rowe et al (2011), medium and medium/low study designs are also cited, but for our purposes, we deem it unnecessary to include them here.

The outcome measures are categorized as: (i) distance travelled, (ii) number of car trips or frequency or car use, (iii) time spent in a car and (iv) measures of modal shift away from car use or away from single car occupancy. Section 3.3 presents the results of our assessment of the efficacy evaluation studies of the BCSSs using this categorisation.

3. RESULTS

3.1. Overview of BCSSs

Our search method yielded nine unique BCSSs that met our inclusion criteria and that are listed and described in Table 3. We note that these BCSSs differ quite significantly in the size of the consortium involved and hence probably also in the amount of resources available for their development. Five out of these nine BCSSs (Peacox, SuperHub, Tripzoom, Matkahupi, iTour) are part of larger projects, sponsored by for example the European Commission. In addition PEIR is a collaboration between academics and industry. The remaining three BCSSs (IPET, Ubigreen and QT) appear to be smaller scale academic projects. Moreover, all nine BCSSs are from the developed countries in Europe (Italy, Finland and Austria) and the United States only, and none from developing countries.

3.2. Persuasiveness Evaluation Using PSD

3.2.1. Persuasion Context

The persuaders behind the BCSSs (*intent*) were either consortia of public and private partners, or stand-alone universities. All the BCSSs target some behavioral and attitudinal change (*change type*). The event contains the use, user and technology contexts. Some BCSSs explicitly identify the use scenarios (*use context*) though for all nine target users are assumed to be the population at large (*user context*). Further all nine use website and/or smartphones (*technology context*). The strategy in the PSD model includes two elements, the *message* and the *route*.

In so far as *message* is concerned, we observe that all the BCSSs use carbon emissions as one of the attributes for feedback/feedforward information to induce sustainable mobility behavior. We can observe the increasing popularity of utilizing carbon emission information also from other transport literature. While there is no conclusive evidence yet regarding the effect of carbon information on behavior change of a population at large (Avineri and Waygood, 2013), three experiments conducted by Gaker et al (2011) among UC Berkeley undergraduates suggest that presenting carbon impact of transport alternatives can influence transport decisions such as mode choice, and therefore, can potentially be used to promote sustainable transport behavior. In addition, other attributes are also used in BCSSs: time, cost, calories, environmental impact and exposure. Time and cost are associated with the utility of transport modes. Calories burned are increasingly being included to promote active transportation as a means to combat the global problem of obesity. The rest of the attributes are BCSS-specific.

The *route* of aiming to influence users is both direct and indirect depending on the BCSS: Some explicitly and directly ask the users to reduce carbon emissions (direct route) whereas others indirectly do this by simply providing carbon feedback, without explicitly asking the users to reduce their footprint (indirect route).

3.2.2 Persuasive Features

The distinctive persuasive features assimilated in the nine selected mobility BCSSs are described next. We begin with BCSSs that contain most of the persuasive features: PEACOX, SuperHub, IPET and Tripzoom.

PEACOX has 7 primary task support, 6 dialogue support and 6 social support features. It is a multi-modal navigation smartphone application that guides users through a step-by-step process of route searching (*tunneling*) and aims to help them travel with lower carbon impact. It is a route choice planner (*rehearsal*), which is able to provide prognosis of emitted carbon for each trip option (*simulation*). Routes which help users save more emissions are highlighted (*suggestion*, *reduction*). PEACOX also gives other tailored and personalized recommendations (*tailoring* and *personalization*) such as “We estimated that you could walk 29% of your car -- and 41% of your PT trips to save more CO2” or “Improve your Rank by reducing your CO2 Consumption. We recommend walking instead of using your car/PT for short trips.” PEACOX calls this “shift potential.” Feedbacks on user’s performance through detailed CO2 and PM10 statistics or a tree showing over-all CO2 status are also provided (*self-monitoring*). Users who saved carbon emissions or completed challenges are praised or given positive feedback (*praise*) and badges (*rewards*). They are also regularly reminded to save carbon emissions (*reminder*). Users also have their own personal accounts (*similarity*), with attractive features (*liking*). PEACOX allows comparison of one's performance with others (*social comparison*), especially with one's in-group (*normative influence*), and viewing the details of others' trips (*social learning*). It also calls for the best to win (*competition*) or for everyone to cooperate (*cooperation*). Finally, it displays statistics leader board (*recognition*).

SuperHub also includes many support features: 7 primary task support, 6 dialogue support and 5 social support. It seriously profiles the users in order to "tailor, customize and rank mobility offers" (*reduction*) so that the solutions are close to the users' needs (*tailoring*). It also allows users to self-monitor their progress through personalized statistics and charts (*personalization*) or track their behavior change status or past trips (*self-monitoring*). Moreover, it supports a multi-modal multi-criteria journey planner (*rehearsal*) and allows calculation of CO2-footprints using various transport modes (*simulation*). Once the user is close to achieving his goals (or has achieved them), s/he is congratulated (*praise*) or given incentives including discounts or concessions on travel or within local establishments (*reward*). He is also prompted to set and review his individual, mobility-related behavioral goals (*reminder* and *suggestion*). SuperHub continuously updates itself over time of user's preferences in terms of mobility options (*similarity*). One unique feature of SuperHub is its persuasive games, which offer the users opportunities to learn more about sustainability through games (*tunneling*). Its interface is also visually appealing (*liking*). Users can also compare their scores with their friends or others in the community (*social comparison*, *normative influence*, *competition*, *recognition*) and share trip plans (*social learning*).

IPET is embedded with 7 primary task support, 6 dialogue support and 4 social support features. Under primary task support, IPET guides the users through a process (*tunneling*), consisting of three steps: data collection of car users' actual behavior, construction of activity travel diaries and provision of a personalized travel plan (PTP). The PTP is a detailed plan which can be used to rehearse the target sustainable behavior (*rehearsal*). It also "simplifies the complex process of considering different alternatives of transport (*reduction*)" by identifying a prospective sustainable travel behavior that is "highly customized and based on the individual's particular needs and characteristics (*tailoring*)." Moreover, the PTP makes immediate comparison of the unsustainable car and the proposed sustainable alternative modes using four measures: travel time, cost, distance traveled, and calories burned or carbon emitted (*simulation*). Users can also "monitor their own behavior (*self-monitoring*) which allows them to view their movements and feedback quantities" in a personal website (*personalization*). Under dialogue support, IPET first identifies an alternative transport solution (*suggestion*) and then monitors and compares the actual behavior with the suggested behavior. If users follow the sustainable advise, they will be congratulated (*praise*) and given badges (*rewards*). If they continue to use car for their trips, they will receive regret messages, and hence will be continuously reminded to try traveling sustainably (*reminder*). In designing the messages and PTP, "persuasive graphics are used" in order to attract the participants (*liking*). All the information is displayed on a dedicated personal webpage (*similarity*). Finally, under social support, IPET automatically calculates the scores, so that participants can see the results of their performance and those of others (*social learning*),

ACCEPTED MANUSCRIPT

compare their scores (*social comparison*) and their rank with others (*competitio*n). The names of top-scorers can be seen by other users (*public recognition*).

Tripzoom embeds 4 primary task support, 6 dialogue support and 5 social support features. Tripzoom proposes a set of challenges to users (e.g. Take the bike to work, Go for a walk during your lunch break), which dare them to improve their regular travel behavior (*reduction*, *suggestion*, *tailoring*). Their performance is then translated in terms of saved money, CO2, health and collected points, which can serve as feedback (*self-monitoring*). TripZoom has a “Me” tab, where detailed information about the user’s mobility profile, including visited places, trails or statistics is provided (*personalization* and *similarity*). Users who master challenges are congratulated (*praise*) or given incentives (*rewards*). There are also illustrations -- which can be either positive or negative -- which can remind them of their goals (*reminder*). Tripzoom also exploits several social support features. Through the “Community Tab”, one can compare his performance with that of others (*social comparison*). Aggregated data and comparison with averages can also give clues about community norms (*normative influence*). In the “Friends Tab”, one can share their travel behavior with friends or obtain concrete and more detailed mobility behavior of others (*social learning*) or view ranking among friends (a source of *competition* and *public recognition*).

The next three BCSSs we describe have strong support in other features, but have very weak social support: iTour, MatkaHupi and Ubigreen.

iTour has 6 primary task support and 3 dialogue support features but only 1 social support feature. iTour is a personal multi-modal travel assistant. It guides users through a route selection search process (*tunneling*) using various visualization modes, which can be selected to identify the best route (*reduction*). The visualization mode is a visually attractive circular graph-like structure (*liking*) showing routes to final destination (*rehearsal*) that is dynamically adjusted depending on user preferences and other contextual information (*tailoring*, *personalization* and *similarity*), such as time, distance, cost or emission generated to reach the final destination (*simulation*). A recommended route option (providing fastest, most sustainable, shortest or cheapest solution) is highlighted, while less favorable options are not (*suggestion*). With iTour, one can also see if others are traveling by the same leg of a particular route (*social facilitation*).

MatkaHupi contains 5 primary task support, 5 dialogue support and no social support features. By means of automatic sensing of behavior and trips taken by the user, MatkaHupi targets behavior change through challenges that are tailored according to individual behavior (*tailoring*). The challenges are simple and direct (*reduction*), such as "walk 3km, cycle 3k and tram 3km." Through an appealing visual feedback (*liking*), the users can track their progress towards their goals/challenges (*self-monitoring*). Moreover, users can also view their trip history (*personalization* and *similarity*). After each detected trip, MatkaHupi checks if the same trip can be made faster and with lesser emission (*simulation*), and if so, proposes an alternative route plan for the future (*suggestion*). It also works as a journey planner for public transportation (*rehearsal*). After the user completes the challenges, he is congratulated (*praise*) and awarded a badge and some points (*reward*).

UbiGreen Transportation Display has 2 primary task support and 5 dialogue support features but assimilates no social support feature. It is a mobile phone application that provides iconic feedback about one's green transportation behavior (*self-monitoring*). The icon can either be a polar bear or tree, and the user can select which of the two he can use for his ambient display (*personalization*). Ubigreen tracks transport behavior of the user either through automatic sensing or self-report (*similarity*), and each time the user rides a green transportation such as bus or train, this green mode is emphasized with its corresponding benefits (saving money, getting exercise, etc.), thus serving as a suggestion for his next transport mode (*suggestion*). Moreover, the user also earns some small graphical rewards which culminates in a complete tree or bear (*praise* and *reward*). Since the ambient wallpaper represents a critical area of persuasion, care is taken to ensure it is visually attractive (*liking*).

The last two BCSSs, in addition to the just-described Ubigreen, have weak primary task support: PEIR and Quantified Traveler.

In PEIR, only 2 primary task support (but 4 dialogue support and 5 social support) features are present. Personalized estimates of environmental impact (carbon and sensitive site) and exposure (smog and fast food) are given as feedback (*self-monitoring*). The feedback can be viewed from a visually appealing interactive map (*liking*) and is broken down weekly or daily, as well as via a time browser, through a personal website (*personalization* and *similarity*). If one's impact and exposure are low relative to friends, green icons of trees appear; conversely, if they are high, smoky and smoggy icons appear (*praise*). These icons can also serve as reminders to travel sustainably (*reminder*). Users can also see the performance of others (*social learning*), and their ranking relative to their friends, encouraging competition (*social comparison*, *competition* and *recognition*). Aggregate statistics from friends can also provide information about norms (*normative influence*).

Quantified Traveler (QT) assimilates the least number of features: 2 primary task support, 1 dialogue support and 3 social support features. QT gathers data from users and automatically transforms such raw data into trip diaries and footprints (time, money, calories and CO2 emitted), which is then presented as personalized feedback to the user (*self-monitoring*) in his own personal website (*personalization* and *similarity*). QT also exploits social influences: QT users can view the average performances of other users (*social learning*), enabling peer comparisons (*social comparison*). The average statistics of these peer groups (SF Bay area, US average, Berkeley students) can provide clues to norms (*normative influence*).

3.2.3 Discussion

Table 4 summarizes the presence of support features in the nine evaluated BCSSs.

In Table 4, under the primary task support category, we observe that personalization (found in all applications), and self-monitoring (in eight applications) appear to be the most commonly utilized techniques. Personalization is easily implemented because of the capability of all the BCSSs to automatically sense travel footprints and present them in the personal accounts of the users. Self-monitoring enables tracking of behavior or performance with respect to certain measures (e.g. carbon emission, cost, calories burned, time spent, distance traveled per mode, etc.), aggregated in a variety of ways, such as by day, week or month. Only iTour does not support self-monitoring, as this is unnecessary, because this BCSS only promotes sustainable multi-modal routing options without checking or monitoring the user's actual behavior.

In the same table, we notice that tunneling is the least utilized feature (n = 4). Tunneling means guiding the user through a process or stages of behavior change. We revisit this point again in our recommendation and argue that to improve the effectiveness of BCSS, there is a need to incorporate formal behavior change models, especially those which explicitly take into account the temporal sequence of stages in a behavioral change process. Tunneling can be used together with tailoring (in the above table, tailoring is seen to be less utilized as well). BCSSs can guide users through appropriate stages in a process (tunneling) only if they are sensitive to the users' profile and characteristics (tailoring).

Moreover, simulation and rehearsal are also less utilized features (n = 5 for both). BCSSs which support rehearsal provide journey or trip plans to the users, while those that support simulation provide the means of observing the benefit or effect of following such a plan in the form of, say, prognosis or equivalent points. Later, we argue as a recommendation the need for more BCSSs to include these features of simulation and rehearsal in order to facilitate an effective behavior change.

Under the human-computer dialogue category, similarity and liking are supported in all or most applications. Persuasive technology places strong importance on the appeal of the design (liking). Since the applications also have sensing capability, it is easy for them to mimic their users in some way (similarity). Rewards are implemented in the form of badges, points/icon, discounts or concessions given as incentives every time the desired behavior is performed. Suggestions are recommendations to try alternative modes, routes, travel plans or pursue mobility challenges or goals. Reminders enable the user to continue pursuing their goal or to review them. Praises are congratulatory remarks as a form of approval for desired behavior. None of the applications supports a social role (i.e. it does not support communication between users and real agents offering advice). Lehto and Kukkonen (2011) also found that none of web-based alcohol and smoking interventions support social role per se.

Finally, the design principles that belong under the social support category are social facilitation, social comparison, normative influence, social learning, cooperation, competition, and recognition. Table 4 shows that some BCSSs (iTour, MatkaHupi, Ubigreen) do not have any social support features at all (or only have one). Moreover, social facilitation and cooperation (*n* = 1 for both) are not present in almost all applications. In our conclusions and recommendations, we also elaborate further how BCSSs can further enable social facilitation and cooperation, as they have a significant influence for behavior change.

3.3. Assessment of Efficacy Evaluation Studies

In the previous section, we carried out an evaluation of the persuasive features of the BCSSs to determine to what extent they assimilate the Persuasive Design Model. This gives us an idea of the "persuasive potential" of the systems. While it is true that for "achieving better outcomes from BCSSs, they should be designed by using persuasive systems design frameworks and models" (Oinas-Kukkonen, 2010), separate efficacy evaluation of these persuasive technologies needs to be carried out.

One of the issues with studies on persuasive sustainability systems (e.g. energy conservation, responsible resource consumption, etc.) is that they lack user evaluation (Brynjarsdottir et al, 2012). Many of them report system evaluation that addresses proof-of-concept, technicality and usability concerns, but they do not evaluate intervention-induced behavior change. A few studies have behavioral change evaluations, but these are run on small sample sizes, short-term field study durations, with limited evidence of lasting behavioral impact.

Of the nine mobility BCSSs reviewed in this study, seven include system usability evaluations. However, only three (QT, Peacox, SuperHub) attempt to evaluate the effectiveness of behavioral change interventions. We are aware that the development of these mobility BCSSs is still ongoing, with design issues as their foremost concern at the moment. We present in the table below some details of the behavior change evaluation carried out by these three studies.

The three studies are similar in many aspects. All assess not only changes in actual behavior but also in pro-environmental shifts in attitudes and motivations. Only QT reports a significant change in travel behavior (driving distance) as a result of the intervention, while Peacox and SuperHub report no significant change. Since QT's field study duration is short though (3 weeks), this raises doubts regarding the long-lasting impact of the intervention. Finally, as all employ cohort uncontrolled evaluations (e.g. before-after comparison, without adequate control groups), these must be considered of low methodological quality (Graham-Rowe et al, 2011; Fujii et al, 2009) and threatens the validity of any result.

It seems that there is, at this point, no possibility for a more robust evaluation of the efficacy of persuasive sustainability systems, as many are still in their early or ongoing stages of design development. In contrast, in the health domain, a number of BCSS studies include effectiveness evaluations, based on sufficient sample size with control groups (e.g. Wang et al, 2014).

4. CONCLUSION AND RECOMMENDATIONS

We considered in this review nine mobility BCSSs, and examined the persuasiveness of their design features using the Persuasive System Design Model. We also assessed the quality of the study conducted to evaluate the effectiveness of the BCSSs in changing behavior.

In assessing the quality of the studies, we find that of the three studies that include behavior change evaluations (QT, Peacox and SuperHub), two report no significant shift towards sustainable travel behavior as a result of the BCSS interventions. No definitive conclusion can be derived from these studies regarding the effectiveness of the BCSSs though since a robust evaluation was not conducted in the first place. Their study design employs only (1) a small sample size, partly because of large drop outs and (2) uncontrolled cohorts (before-after comparison, without any control group). Although the foremost concern of BCSSs right now is design development, we recommend proper evaluations of BCSSs using methodologically robust study designs such as Randomised Controlled Trial, Cluster Randomised Controlled Trial or Controlled Before and After studies as suggested by Arnott et al (2014) and Graham-Rowe et al (2011).

In the absence of proper evaluation studies of the efficacy of mobility BCSSs, it is instructive to look into studies on health BCSSs, where evaluation studies appear to be more developed. We find that, if the meta-analysis of health BCSSs is any indication, we can reasonably assume that, in general, the intervention effect size of BCSSs is significant but small (e.g. Bamberg et al, 2015). Hence, the challenge for future studies is to develop BCSSs in the domain of travel with greater intervention effect. In the following, based on our review, we suggest three propositions that can be pursued in future work, which address the small effect size of BCSSs. These recommendations will be further supported by empirical evidences from studies in the health domain.

First, we observe that tunneling and tailoring features are less utilized. Thus, as will be explained below, we suggest to incorporate a stage-based behavior change model in the design of the BCSSs. Stage-based models explicitly specify the stages in the process of behavior change that users will go through leading to the desired behavior. These models can be used to first determine the users' current stage membership (tailoring) and then to guide them to progress towards the next stages in the process (tunneling). Second, we also notice that the simulation and rehearsal features are underutilized. Behavior change in mobility requires formation of an implementation intention, which is greatly facilitated by a provision of an appropriate travel plan (rehearsal) with its corresponding benefits (simulation). Third, our persuasive design evaluation reveals that social facilitation and cooperation are least supported. We therefore suggest, following again findings from health BCSSs as well as other literature, to incorporate these social support features in the design of the mobility BCSSs. We discuss each of these recommendations further in the next sections.

4.1. Explicit Reference to a Behavior Change Theory

As pointed out by some authors, many BCSSs were developed using techniques solely drawn from persuasive technology literature (Klein et al, 2014; Arnott et al, 2014; Bamberg et al, 2015). Too little effort is given on grounding the BCSSs in an explicit behavior change theory. Among the mobility BCSSs included in this paper, we note that only one BCSS, the Quantified Traveler, is grounded explicitly on a behavior change theory.

In the literature, this seems to be commonplace though not only for transport applications. Klein et al (2014) notes that “intelligent support systems have become increasingly popular for the use of behavior interventions in recent years, [but] those systems are rarely based on models of behavior change.” A notable exception to this is the eMate system, an intelligent behavior change support system for therapy adherence for patients with type 2 diabetes, HIV and cardiovascular diseases (Klein et al, 2011; 2014). This health BCSS is based on an integrated model of human behavior change, called Computerized Behavior Intervention or COMBI (discussed below). Bamberg et al (2015) is also in the process of developing a BCSS of this type in the mobility domain, called "PrimaKlima Bielefeld."

Arnott et al (2014) suggests that developing a successful behavior change support system (BCSS) depends not only on the creative and appropriate implementation of the behavior change techniques, but also on explicitly grounding it on established theoretical constructs from behavioral theories. In the health sector, a few meta-analyses seem to support this conclusion (Bamberg et al, 2015). One significant meta-analysis is by Webb et al (2010), which finds that "the extent of a BCSS's theoretical foundation [is] positively correlated with its effectiveness." An example of a theory-based BCSS demonstrated to be effective through randomized controlled trial is Happy Ending, a digital program on nicotine withdrawal (Brendryen et al, 2008).

By using a formal behavior theory in the design of a support system, we can "understand the underlying mechanisms of behavior change and how these mechanisms can be influenced to establish the desired behavior" (Klein et al, 2014). This is especially important because empirical evidence increasingly shows that "modality styles" of individuals are very much influenced by deeply entrenched habits and ingrained lifestyles, and are therefore difficult to change (e.g. Vij et al 2013). In fact, this may be the reason why travel behavior change programmes to date have statistically significant but only small intervention effects (Fujii et al, 2009; Möser and Bamberg, 2008). Hence, by carefully understanding the possible mechanisms of behavior change, we can exploit them to increase the effectiveness of these programmes in changing behavior.

In addition, as pointed out by Brynjarsdottir et al (2012) in their critical review of 36 persuasive sustainability systems, many of these systems design their persuasion around a narrow understanding of sustainability as mere "optimization of simple [behavioral] metrics", and consequently, their common persuasion tactic is simply to “tweak behaviors with the goal of adjusting actions to be more in line with benchmarks of sustainability.” However, this may sidestep “difficult lifestyle choices that may in fact be necessary to work toward a more sustainable society.” By adopting a holistic model of behavior change, we can consider multiple metrics of sustainability that allow us to see the bigger picture.

QT, the only BCSS explicitly informed by a behavior change theory, is based on the theory of planned behavior (TPB). One criticism against this theory, however, is that it fails to take into account the time dimension of behavior change. As other models such as e.g. the “Transtheoretical Model” suggest, behavior change is a transition through a temporally-ordered sequence of different stages. Moreover, as Riley et al (2011) point out, static behavior change models, such as TPB, seem “inadequate to inform mobile intervention development as these interventions become more interactive and dynamic.” Recently, Bamberg (2013) introduced a cumulative theory that incorporated the dynamic stage concept, called the Stage Model of Self-Regulated Behavior Change Theory (SSBC). Because it is a dynamic theory, it may prove suitable in the BCSS platform. To date, however, except for the aforementioned “PrimaKlima” that appears to be under development, no mobility BCSS based on this theory has been developed so far to the best of our knowledge. Other models, such as the Computerized Behavior Intervention or COMBI (Klein et al, 2011; 2014), may also be suitable to be implemented in the BCSS platform. COMBI is a computational model of behavior change that integrates constructs from the most influential theories such as the Transtheoretical Model, Social Cognitive Theory, Theory of Planned Behavior, Attitude Formation, Self-Regulation Theory, Relapse Prevention Model and Health Belief Model.

4.2. Greater Integration with Shared Mobility Services Platform

It is well-known that goal initiation is not sufficient for a successful goal achievement. Formation of implementation intention is also important (Gollwitzer 1999). This is also true in a successful mobility behavior change (e.g. Fujii and Taniguchi, 2005). Implementation intention, which entails a plan for when, where and how to implement the target mobility behavior, mediates the effect of behavioral intention on behavior (Gärling and Fujii, 2002). Mobility BCSSs can facilitate the formation of implementation intention by exploiting the rehearsal feature, i.e. by providing people a trip/travel plan which they can use to rehearse the target behavior. However, as the previous section shows, very few mobility BCSSs have this feature: out of the 9 BCSSs we examined here, only five support the rehearsal feature in the form of personalized travel plans (iPET), journey planner (MatkaHupi) or dynamic trip plans (PEACOX, SuperHub and iTour). The rehearsal feature can be combined with the simulation feature by showing potential outcomes of the trip plan to the users.

In contrast, in health-based BCSSs, as pointed out by the review of Lehto and Kukkonen (2010), simulation and rehearsal are rather common features. In these health BCSSs, a typical example of simulation "was calculating how much calories a specific physical activity burns, or the type and duration of exercise needed to burn the calories from, e.g., a chocolate bar. The rehearsal feature was supported by providing workout plans and exercise ideas to the user. As a highlight, [two BCSSs] provided extensive video-based, customizable workout builders." In another review of mobile health applications for physical activity Conroy et al (2014) observed that most of them have features that "provide instruction on how to perform the behavior" and "model/demonstrate the behavior", which support the formation of implementation intention.

Moreover, there have been studies in the health sector showing the effectiveness of implementation intentions in changing behavior (e.g. Belanger-Gravel et al, 2013). As a consequence, one health BCSS recently developed for cardiac rehabilitation explicitly included “implementation intention” in the design approach (Antypas and Wangberg, 2014).

How can mobility BCSSs support further the rehearsal feature? Lately, due to advances in technology, both hardware and software, multi-modal integration -- or the seamless connection of various modes -- is becoming a reality. These technological advances, together with the ubiquity of internet-enabled smartphones, enable users to plan and organize their trips on a very short notice or even en-route. For instance, PEACOX, as a journey planner application, is able to provide cross-modal trip plans to users. Such provision of trip plans is akin to making implementation plans in the traditional VTBC programs. Tang and Thakuriah (2012) showed that mere provision of real-time bus information, through a system called CTA Bus Tracker, can increase transit ridership.

An important application are the recent developments in ridesharing, as reviewed by several authors (e.g. Agatz et al, 2012; Chan and Shaheen, 2012; Siddiqi and Buliung, 2013; Furuhata et al, 2013). In ridesharing, travelers are grouped together into common trips by car or van (Chan and Shaheen, 2012). In recent years, as ridesharing becomes more dynamic, i.e. real-time, it is being considered as one travel demand management (TDM) strategy that can alleviate congestion, while maintaining an acceptable level of service (Siddiqi and Buliung, 2013). In the United States, ridesharing is increasingly being discussed as a powerful strategy to reduce congestion, emissions and fossil fuel dependency.

Dynamic ridesharing is being touted as a promising and attractive alternative to private car usage because of its potential to provide immediate access to door-to-door transportation. Moreover, it allows users to share costs on car-usage. Furuhata et al (2013) summarize it best: "Conceptually, ridesharing is a system that can combine the flexibility and speed of private cars with the reduced cost of fixed-line systems." In other words, dynamic real-time ridesharing combines tailored trip and cost-sharing.

In the coming years, ridesharing is likely to take greater modal share as it tries to include greater technology interoperability and multi-modal integration (Chan and Shaheen, 2012). Interoperability here means "allowing open source data sharing among ride-matching companies, which will enable members to find matches across all databases." Integration means "seamless connection of ridesharing with other transportation modes, such as public transit and carsharing." Hence, with further technological advances, ridesharing can capture more market share, as it positions itself as a very attractive alternative to private car use.

In summary, a mobility BCSS is hypothesized to have a greater intervention effect if it includes provision of a dynamic, cross-modal trip planning tool (*rehearsal*), together with potential effects or outcomes (*simulation* feature). There is no available evidence yet for this, but if empirical data from the health BCSSs and the increasing adoption of ridesharing in the recent years are any indication -- a trend greatly facilitated by the fact that ridesharing has become more dynamic and cross-modal -- we can be confident that a mobility BCSS that supports cross-modal planning in real time may have greater chances of effecting behavior change.

4.3. Social Interaction

Various studies have already shown that social information drawn from one's social network can be a potentially powerful tool to trigger sustainable travel behavior change (e.g. Bamberg et al, 2011; Ettema, Arentze, Timmermans, 2011; Abou-Zeid and Ben-Akiva, 2011; Axsen and Kurani, 2012; Kormos et al, 2014; Zhang et al, 2015). This review, in fact, shows that the majority of the BCSSs have assimilated at least five of the seven social support features. Nonetheless, we also observe that two of these social support features -- social facilitation and cooperation -- are largely missing in most applications.

Social facilitation means facilitating social interaction among the users. In health-based BCSSs, the most common means of social facilitation are "asynchronous peer discussion forums and synchronous chat rooms", for example, discussion forum, peer-to-peer forum, chat room, online and support community (Lehto and Kukkonen, 2011). In contrast to mobility BCSSs, social facilitation is a widely used element in health BCSSs (e.g. Lehto and Kukkonen, 2010; Kelders et al, 2012). Nonetheless, these studies are inconclusive yet on whether social facilitation is effective in changing behavior (for instance, better adherence to interventions). Even though conclusive studies are not yet available, we consider social facilitation a promising direction to pursue as this offers social support, which is identified by Ploderer et al (2014) in their review as one of the key approaches for future work of BCSSs in general. Social facilitation by means of exchanges in online and offline communities can provide social support such as "esteem support, intimacy, companionship and validation" or "material aid as well as informational support like advice and help in problem-solving" (Ploderer et al, 2014).

In contrast to this, cooperation is largely not supported, not only in mobility BCSSs, but also in health BCSSs (e.g. Lehto and Kukkonen, 2010; Lehto and Kukkonen, 2011; Kelders et al, 2012) and therefore provides area for improvement. Ploderer et al (2014), in the same review, present some guidelines on how cooperation can be implemented in BCSSs. They note that many systems are designed for individual use, though some have partially collective orientation which facilitate interaction between individuals. They thus suggest developing BCSSs for collective, rather than the usual single, use. They cite as an example the Tidy Street project (Bird and Rogers, 2010), which focuses on the average electricity consumption of households in the street, instead of individual households, in order to foster cooperation and collaboration. In the domain of travel, users can register in travel behavior change or shared-use mobility programs in groups (e.g. as a family or co-workers) instead of merely as single participants.

5. SUMMARY AND FURTHER RESEARCH

There are numerous behavior change support systems (BCSS). Most developed appear to be health applications, but the last ten years also saw the development of BCSSs for travel behavior. Using the Persuasive Systems Design (PSD), we evaluate the persuasive potential of nine behavior change support systems designed to promote sustainable travel behavior. We extract the persuasive features embedded in these support systems and find that tunneling, tailoring, rehearsal, simulation, social facilitation and cooperation are not widely present. In contrast, in the health domain, these features, except cooperation, are commonly used. Furthermore, we assess studies conducted to evaluate the effectiveness of these BCSSs in changing travel behavior and find indications that effect sizes are mostly small though methodologically robust studies are largely missing and hence no definitive conclusion can be derived yet. We then propose three suggestions on research needs and applications for further development, especially addressing the small size of the intervention effects.

In proposing that smart devices be utilized as medium of intervention for promoting sustainable behavior change, a caveat must be mentioned. Aside from the expected bias towards a younger population group, there is some evidence that usage of these devices generates a negative effect against sustainable behavior. While many studies (e.g. Guo et al, 2015) suggest that usage of such devices can enrich use of travel time on public transport such as buses, bringing them positive utility, a study by Julsrud and Denstadli (2017) finds that active users of smart devices ("equipped travelers") tend to bear critical (negative) attitudes to public transport. Moreover, the amount of time spent in the usage of ICT may generate more motorized travel, including by car (Hong and Thakuriah, 2016). This is, however, beyond the scope of our present study and should be addressed in future research.

 ACCEPTED MANUSCRIPT

REFERENCES

Abou-Zeid, M. & Ben-Akiva, M. (2011). The effect of social comparisons on commute well-being. *Transportation Research Part A: Policy and Practice* 45.4, 345-361.

Agatz, N., Erera, A., Savelsbergh, M., & Wang, X. (2012). Optimization for dynamic ride-sharing: A review. *European Journal of Operational Research*, *223*(2), 295-303.

Ampt, E. (2003). Voluntary household travel behaviour change--theory and practice. In *10th International Association of Travel Behaviour Research Conference, Lucerne, Switzerland, August*.

Antypas, K., & Wangberg, S. C. (2014). Combining users' needs with health behavior models in designing an internet-and mobile-based intervention for physical activity in cardiac rehabilitation. JMIR research protocols, 3(1), e4.

Arnott, B., Rehackova, L., Errington, L., Sniehotta, F. F., Roberts, J. R., & Araujo-Soares, V. (2014). Efficacy of behavioural interventions for transport behaviour change: systematic review, meta-analysis and intervention coding. *International journal of behavioral nutrition and physical activity*, *11*(1), 133.

Avineri, E. & Waygood, E. O. D. (2013). Applying valence framing to enhance the effect of information on transport-related carbon dioxide emissions. *Transportation Research Part A: Policy and Practice*, *48*, 31-38.

Axsen, J., & Kurani, K. S. (2012). "Interpersonal influence within car buyers' social networks: applying five perspectives to plug-in hybrid vehicle drivers." *Environment and Planning-Part A* 44.5, 1047.

 ACCEPTED MANUSCRIPT

Bamberg, S., Fujii, S., Friman, M., & Gärling, T. (2011). Behaviour theory and soft transport policy measures. *Transport policy, 18*(1), 228-235.

Bamberg, S. (2013). Applying the stage model of self-regulated behavioral change in a car use reduction intervention. *Journal of Environmental Psychology*, *33*, 68-75.

Bamberg, S., Behrens, G., Bergmeyer, M., Brewitt, K., Papendick, M., Rees, J., & Zielinski, J. (2015). "Development of a Theory-Driven, Web-based Behavioral Change Support System for Environmentally Friendly Behavior." In Evans, D. (Ed.). Social Marketing: Global Perspectives, Strategies and Effects on Consumer Behavior (109-120). NY: Nova Science Publisher.

Baumer, E. P., Katz, S. J., Freeman, J. E., Adams, P., Gonzales, A. L., Pollak, J., Retelny, D., Niederdeppe, J., Olson, C.M. & Gay, G. K. (2012). Prescriptive persuasion and open-ended social awareness: expanding the design space of mobile health. In *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work*, ACM, February, 475-484.

Bélanger-Gravel, A., Godin, G., & Amireault, S. (2013). A meta-analytic review of the effect of implementation intentions on physical activity. Health Psychology Review, 7(1), 23-54.

Bird, J., & Rogers, Y. (2010). The pulse of tidy street: Measuring and publicly displaying domestic electricity consumption. In *workshop on energy awareness and conservation through pervasive applications (Pervasive 2010)*.

Brendryen, H., Drozd, F., & Kraft, P. (2008). A digital smoking cessation program delivered through internet and cell phone without nicotine replacement (happy ending): randomized controlled trial. *Journal of Medical Internet Research*, *10*(5), e51.

 ACCEPTED MANUSCRIPT

Broll, G., Cao, H., Ebben, P., Holleis, P., Jacobs, K., Koolwaaij, J., Luther, S. & Souville, B. (2012). Tripzoom: an app to improve your mobility behavior. In *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia*, ACM, December, 57.

Brynjarsdottir, H., Håkansson, M., Pierce, J., Baumer, E., DiSalvo, C., & Sengers, P. (2012). Sustainably unpersuaded: how persuasion narrows our vision of sustainability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, May, 947-956.

Busch, M., Schrammel, J., FLU, M. A., Kruijff, E., & Tscheligi, M. (2012). Persuasive Strategies Report. *CURE--Center for Usability Research & Engineering*.

Carreras, I., Gabrielli, S., Miorandi, D., Tamilin, A., Cartolano, F., Jakob, M., & Marzorati, S. (2012). SUPERHUB: a user-centric perspective on sustainable urban mobility. In *Proceedings of the 6th ACM workshop on Next generation mobile computing for dynamic personalised travel planning*, ACM, June, 9-10.

Chan, N. D., & Shaheen, S.A. (2012). Ridesharing in north america: Past, present, and future." *Transport Reviews* 32.1, 93-112.

Cohen-Blankshtain, G., & Rotem-Mindali, O. (2016). Key research themes on ICT and sustainable urban mobility. *International Journal of Sustainable Transportation*, 10(1), 9-17.

Conroy, D. E., Yang, C. H., & Maher, J. P. (2014). Behavior change techniques in top-ranked mobile apps for physical activity. *American journal of preventive medicine*, *46*(6), 649-652.

Cowan, L. T., Van Wagenen, S. A., Brown, B. A., Hedin, R. J., Seino-Stephan, Y., Hall, P. C., & West, J. H. (2012). Apps of steel: are exercise apps providing consumers with realistic expectations? A content analysis of exercise apps for presence of behavior change theory. *Health Education & Behavior*, 1090198112452126.

Davies, N. (2012). What are the ingredients of successful travel behavioural change campaigns?. *Transport Policy* 24, 19-29.

Demissie, M. G., Correia, G., & Bento, C. (2015). Analysis of the pattern and intensity of urban activities through aggregate cellphone usage. *Transportmetrica A: Transport Science*, 11(6), 502-524.

DiSalvo, C., Sengers, P., & Brynjarsdóttir, H. (2010, April). Mapping the landscape of sustainable HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, April, ACM, 1975-1984.

Ettema, D., Theo Arentze, and Harry Timmermans. "Social influences on household location, mobility and activity choice in integrated micro-simulation models." *Transportation Research Part A: Policy and Practice* 45.4 (2011): 283-295.

Fogg, B. J. (2002). Persuasive technology: using computers to change what we think and do. *Ubiquity*, December, 5.

Fogg, B. J. and Eckles, D. (2007). *Mobile Persuasion: 20 Perspectives on the Future of Behavior Change*. Stanford Captology Media, Stanford.

Froehlich, J., Dillahunt, T., Klasnja, P., Mankoff, J., Consolvo, S., Harrison, B., & Landay, J. A. (2009, April). UbiGreen: investigating a mobile tool for tracking and supporting green transportation habits. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1043-1052). ACM.

Fujii, S., Bamberg, S., Friman, M., & Gärling, T. (2009). Are effects of travel feedback programs correctly assessed?. *Transportmetrica*, *5*(1), 43-57.

ACCEPTED MANUSCRIPT

Fujii, S. and Taniguchi, A. (2005). Reducing family car-use by providing travel advice or requesting behavioral plans: An experimental analysis of travel feedback programs." *Transportation Research Part D: Transport and Environment* 10.5, 385-393.

Fujii, S. and Taniguchi, A. (2006). "Determinants of the effectiveness of travel feedback programs---a review of communicative mobility management measures for changing travel behaviour in Japan." *Transport policy* 13.5, 339-348.

Furuhata, M., Dessouky, M., Ordóñez, F., Brunet, M. E., Wang, X., & Koenig, S. (2013). Ridesharing: The state-of-the-art and future directions. *Transportation Research Part B: Methodological*, *57*, 28-46.

Gaker, D., Vautin, D., Vij, A., & Walker, J. L. (2011). The power and value of green in promoting sustainable transport behavior. *Environmental Research Letters*, *6*(3), 034010.

Gärling, T. and Fujii, S. (2002). Structural equation modeling of determinants of planning. *Scandinavian Journal of Psychology* 43.1, 1-8.

Gollwitzer, P. M. (1999). Implementation intentions: strong effects of simple plans." *American psychologist* 54.7, 493.

Graham-Rowe, E., Skippon, S., Gardner, B., & Abraham, C. (2011). Can we reduce car use and, if so, how? A review of available evidence. *Transportation Research Part A: Policy and Practice*, *45*(5), 401-418.

Guo, Z., Derian, A., & Zhao, J. (2015). Smart devices and travel time use by bus passengers in Vancouver, Canada. *International Journal of Sustainable Transportation*, 9(5), 335-347.

 ACCEPTED MANUSCRIPT

Hong, J., & Thakuriah, P. (2016). Relationship between motorized travel and time spent online for nonwork purposes: An examination of location impact. *International Journal of Sustainable Transportation*, 10(7), 617-626.

Jariyasunant, J., Abou-Zeid, M., Carrel, A., Ekambaram, V., Gaker, D., Sengupta, R., & Walker, J. L. (2015). Quantified traveler: Travel feedback meets the cloud to change behavior. *Journal of Intelligent Transportation Systems*, *19*(2), 109-124.

Julsrud, T.E. & Denstadli, J.M. (2017). Smartphones, travel time-use and attitudes to public transport services. Insights from an explorative study of urban dwellers in two Norwegian cities. *International Journal of Sustainable Transportation*. DOI: 10.1080/15568318.2017.1292373.

Jylhä, A., Nurmi, P., Sirén, M., Hemminki, S., & Jacucci, G. (2013). Matkahupi: a persuasive mobile application for sustainable mobility. In *Proceedings of the 2013 ACM conference on Pervasive and ubiquitous computing adjunct publication*, ACM, 227-230.

Klein, M., Mogles, N., & Van Wissen, A. (2011). Why won't you do what's good for you? Using intelligent support for behavior change. In *Human Behavior Understanding*, Springer Berlin Heidelberg, 104-115.

Klein, M., Mogles, N., & van Wissen, A. (2014). Intelligent mobile support for therapy adherence and behavior change. *Journal of biomedical informatics*, *51*, 137-151.

Kormos, C., Gifford, R. & Brown, E. (2014). The Influence of descriptive social norm information on sustainable transportation behavior: A field experiment. *Environment and Behavior*, 0013916513520416.

Lane, N. D., Mohammod, M., Lin, M., Yang, X., Lu, H., Ali, S., Doryab, A., Berke, E., Choudhury, T & Campbell, A. (2011). Bewell: A smartphone application to monitor, model and promote wellbeing. In *5th international ICST conference on pervasive computing technologies for healthcare*, May, 23-26.

Langrial, S., Lehto, T. & Oinas-Kukkonen, H., Harjumaa,M. & Karppinen, P. (2012). Native Mobile Applications For Personal Well-Being: A Persuasive Systems Design Evaluation. In *PACIS*, 93.

Lathia, N., Pejovic, V., Rachuri, K. K., Mascolo, C., Musolesi, M., & Rentfrow, P. J. (2013). Smartphones for large-scale behavior change interventions. *IEEE Pervasive Computing*, (3), 66-73.

Lehto, T. & Oinas-Kukkonen, H. (2010). Persuasive features in six weight loss websites: A qualitative evaluation." *Persuasive technology*. Springer Berlin Heidelberg, 2010. 162-173.

Lehto, T. & Oinas-Kukkonen, H. (2011). Persuasive features in web-based alcohol and smoking interventions: a systematic review of the literature. *Journal of Medical Internet research* 13.3, e46.

Magliocchetti, D., Gielow, M., De Vigili, F., Conti, G., & De Amicis, R. (2011). A personal mobility assistant based on ambient intelligence to promote sustainable travel choices. *Procedia Computer Science*, *5*, 892-899.

Meloni, I., Sanjust, B., Delogu, G., & Sottile, E. (2014). Development of a Technological Platform for Implementing VTBC Programs. *Transportation Research Procedia*, *3*, 129-138.

Meloni, Italo, and Benedetta Sanjust di Teulada (2015). I-Pet Individual Persuasive Eco-travel Technology: A tool for VTBC program implementation. *Transportation Research Procedia* 11, 422-433.

 ACCEPTED MANUSCRIPT

Mintz, J., Branch, C., March, C., & Lerman, S. (2012). Key factors mediating the use of a mobile technology tool designed to develop social and life skills in children with Autistic Spectrum Disorders. *Computers & Education*, *58*(1), 53-62.

Mintz, J., & Aagaard, M. (2012). The application of persuasive technology to educational settings. *Educational Technology Research and Development*, *60*(3), 483-499.

Möser, G., & Bamberg, S. (2008). The effectiveness of soft transport policy measures: A critical assessment and meta-analysis of empirical evidence. *Journal of Environmental Psychology*, *28*(1), 10-26.

Mun, M., Reddy, S., Shilton, K., Yau, N., Burke, J., Estrin, D., Hansen, M., Howard, E., West, R. & Boda, P. (2009). PEIR, the personal environmental impact report, as a platform for participatory sensing systems research. In *Proceedings of the 7th international conference on Mobile systems, applications, and services*, ACM., June, 55-68.

Oinas-Kukkonen, H. (2010). Behavior change support systems: A research model and agenda. In *Persuasive Technology*, Springer Berlin Heidelberg, 4-14.

Oinas-Kukkonen, H. (2013). A foundation for the study of behavior change support systems. *Personal and ubiquitous computing*, *17*(6), 1223-1235.

Oinas-Kukkonen, H., & Harjumaa, M. (2009). Persuasive systems design: Key issues, process model, and system features. *Communications of the Association for Information Systems*, *24*(1), 28.

Patterson, Z., & Fitzsimmons, K. (2016). DataMobile: Smartphone Travel Survey Experiment. *Transportation Research Record: Journal of the Transportation Research Board*, (2594), 35-43.

Ploderer, B., Reitberger, W., Oinas-Kukkonen, H., & van Gemert-Pijnen, J. (2014). Social interaction and reflection for behaviour change. *Personal and ubiquitous computing*, *18*(7), 1667-1676.

Richter, J., Friman, M., & Gärling, T. (2011). Soft transport policy measures: Gaps in knowledge. *International journal of sustainable transportation*, *5*(4), 199-215.

Riley, W. T., Rivera, D. E., Atienza, A. A., Nilsen, W., Allison, S. M., & Mermelstein, R. (2011). Health behavior models in the age of mobile interventions: are our theories up to the task?. *Translational behavioral medicine*, *1*(1), 53-71.

Rojas IV, M. B., Sadeghvaziri, E., & Jin, X. (2016). Comprehensive Review of Travel Behavior and Mobility Pattern Studies That Used Mobile Phone Data. *Transportation Research Record: Journal of the Transportation Research Board*, (2563), 71-79.

Sadeghvaziri, E., Rojas IV, M. B., & Jin, X. (2016). Exploring the Potential of Mobile Phone Data in Travel Pattern Analysis. *Transportation Research Record: Journal of the Transportation Research Board*, (2594), 27-34.

Schrammel, J., Busch, M., & Tscheligi, M. (2013). Peacox-Persuasive Advisor for CO2-Reducing Cross-Modal Trip Planning. In *PERSUASIVE (Adjunct Proceedings)*.

Siddiqi, Z. & Buliung, R. (2013). Dynamic ridesharing and information and communications technology: past, present and future prospects. *Transportation Planning and Technology* 36.6, 479-498.

Tang, L., & Thakuriah, P. V. (2012). Ridership effects of real-time bus information system: A case study in the City of Chicago. *Transportation Research Part C: Emerging Technologies*, *22*, 146-161.

ACCEPTED MANUSCRIPT

Vij, A., Carrel, A., & Walker, J. L. (2013). Incorporating the influence of latent modal preferences on travel mode choice behavior. *Transportation Research Part A: Policy and Practice*, *54*, 164-178.

Wang, J., Wang, Y., Wei, C., Yao, N., Yuan, A., Shan, Y., & Yuan, C. (2014). Smartphone interventions for long-term health management of chronic diseases: an integrative review. *Telemedicine and e-Health*, *20*(6), 570-583.

Webb, T., Joseph, J., Yardley, L., & Michie, S. (2010). Using the internet to promote health behavior change: a systematic review and meta-analysis of the impact of theoretical basis, use of behavior change techniques, and mode of delivery on efficacy. *Journal of medical Internet research*, *12*(1), e4.

Weiss, M., Staake, T., Mattern, F., & Fleisch, E. (2012). PowerPedia: changing energy usage with the help of a community-based smartphone application. *Personal and Ubiquitous Computing*, *16*(6), 655-664.

Yang, C. H., Maher, J. P., & Conroy, D. E. (2015). Implementation of behavior change techniques in mobile applications for physical activity. *American journal of preventive medicine*, *48*(4), 452-455.

Zhang, D., Schmöcker, J. D., Fujii, S., & Yang, X. (2015). Social norms and public transport usage: empirical study from Shanghai. *Transportation*, 1-20.

 ACCEPTED MANUSCRIPT

Table 1. Coding Protocol used for PSD Evaluation of 9 BCSSs (developed from Kukkonen and Harjumaa, 2009; Kelders et al, 2012; Lehto and Kukkonen, 2011; Langrial et al, 2012)

Persuasion Strategy	**Description**	**Coded as element included when the BCSS:**	**Example Implementation**
Reduction	A system that reduces complex behavior into simple tasks helps users perform the target behavior, and it may increase the benefit/cost ratio of a behavior.	Specifically divides the target behavior into small, simple steps	A support system for weight management includes a diary for recording daily calorie intake, thereby dividing the target behavior (reducing calorie intake) into small, simple steps of which one is recording calorie intake
Tunneling	Using the system to guide users through a process or experience provides opportunities to persuade along the way. System	Delivers content in a step-by-step format with a predefined order	A support system for the prevention of depression that delivers the content in sequential lessons that can only be accessed when the previous lesson is

			completed
Tailoring	Information provided by the system will be more persuasive if it is tailored to the potential needs, interests, personality, usage context, or other factors relevant to a user group.	Provides content that is adapted to factors relevant to a user group, or when feedback is provided based on information filled out by a participant	A support system for personal training provides different information content for different user groups, e.g. beginners and professional
Personalization	A system that offers personalized content or services has a greater capability for persuasion	Provides content that is adapted to one user (ie, the name of the user is mentioned and/or the user can adapt a part of the intervention)	A support system personalizes service and content based on user-inputs and other known variables e.g. name, gender, age, location, language
Self-monitoring	A system that keeps track of one's own performance or status supports the user in achieving goals.	Provides the ability to track and view the user's behavior, performance or status	A support system for smoking cessation allows participants to review their smoking by sending immediate feedback forms

			and copies of the personalized assessments to their email accounts.
Simulation	Systems that provide simulations can persuade by enabling users to observe immediately the link between cause and effect.	Provides the ability to observe the cause-and-effect relationship of relevant behavior	A support system for smoking cessation includes an interactive smoker's risk tool that simulates changes in the risk of death due to smoking based on the smoker's history and time of quitting.
Rehearsal	A system providing means with which to rehearse a behavior can enable people to change their attitudes or behavior in the real world.	Provides the ability and stimulation to rehearse a behavior or to rehearse the content of the intervention	A support system that includes a flying simulator that helps flight pilots practice for severe weather conditions
Praise	By offering praise, a system can make users	Offers praise to the participant on any	A support system that aims to promote healthy

	more open to persuasion.	occasion	nutritional habits compliments participants when they have eaten 2 pieces of fruit for 5 days
Rewards	Systems that reward target behaviors may have great persuasive powers.	Offers some kind of reward when the participant performs a target behavior relating to the use or goal of the intervention	A support system for the treatment of social phobia gives points to participants when they engage in exposure exercises
Reminders	If a system reminds users of their target behavior, the users will more likely achieve their goals.	Provides reminders about the use of the intervention or the performance of target behavior	A support system to support self-management among patients with rheumatic arthritis sends an automatic email message to remind the participant that the new lesson may begin
Suggestion	Systems offering fitting suggestions will have greater persuasive	Provides a suggestion to help the participants reach the target behavior	A support system for weight management provides low-calorie

	powers.		recipes
Similarity	People are more readily persuaded through systems that remind them of themselves in some meaningful way.	Is designed to look familiar and designed especially for the participant	A support system for the treatment of panic disorder in teenage girls explains the exercises through a teenage girl with panic problems
Liking	A system that is visually attractive for its users is likely to be more persuasive.	Is visually designed to be attractive to the participants	A support system that aims at encouraging children to take care of their pets properly has pictures of cute animals
Social Role	If a system adopts a social role, users will more likely use it for persuasive purposes	Acts as if it has a social role (eg, a coach, instructor, or buddy)	A support system to support self-management among patients with migraine incorporated an avatar to guide the participant through the intervention
Social learning	A person will be more motivated to perform a	Provides the opportunity and stimulates	A support system for weight management

	target behavior if (s)he can use a system to observe others performing the behavior.	participants to see others using the intervention or performing the target behavior	provides the option, and stresses the importance, of posting physical activity self-monitoring data on the discussion board and commenting on the performance of others
Social comparison	System users will have a greater motivation to perform the target behavior if they can compare their performance with the performance of others.	Provides the opportunity for participants to compare their behavior to the target behavior of other participants and stimulates them to do this	A support system for drug abuse prevention for teenagers automatically compares the response of the participant to other users of the intervention
Normative influence	A system can leverage normative influence or peer pressure to increase the likelihood that a person will adopt a target behavior	Provides normative information on the target behavior or the usage of the intervention	A support system to promote self-management among patients with COPD provides feedback on the level of physical activity of the participant by comparing it to the

			physical activity of well-managed COPD patients
Social facilitation	System users are more likely to perform target behavior if they discern via the system that others are performing the behavior along with them.	Provides the opportunity to see whether there are other participants using the intervention	A support system that provides opportunity to contact others using the same intervention (e.g. discussion group, peer-to-peer forums, chat rooms)
Cooperation	A system can motivate users to adopt a target attitude or behavior by leveraging human beings' natural drive to co-operate.	Stimulates participants to cooperate to achieve a target behavior	A support system for the promotion of physical activity stimulates participants to form groups and to achieve the group goal of a certain number of steps each week
Competition	A system can motivate users to adopt a target attitude or behavior by leveraging human	Stimulates participants to compete with each other to achieve a target behavior	A support system for diabetes management among children includes a leaderboard in which the

ACCEPTED MANUSCRIPT

	beings' natural drive to compete.		children who enter blood glucose levels at the right times receive the highest place
Recognition	By offering public recognition for an individual or group, a system can increase the likelihood that a person/group will adopt a target behavior.	Prominently shows (former) participants who adopted the target behavior	A support system for treatment of anxiety includes a testimonial page where successful users of the intervention tell their story

ACCEPTED MANUSCRIPT

Table 2. Framework for Characterizing the Effectiveness Evaluation Study (adapted from Graham-Rowe et al, 2011)

Intervention Strategy	**Methodological Quality**	**Outcome Measure**
Psychological Structural	High: Experimental, quasi-experimental, and cohort-analytic (with control) Low: Case controlled/cross sectional and cohort uncontrolled	Distance Mode change Trips/frequency Time/duration

Table 3. Overview of BCSSs reviewed/evaluated in this paper

Name of BCSS, implementation country and main reference	Description of main functionality and objective
IPET, Italy, (Meloni et al, 2014)	IPET is an Individual Persuasive Eco-Travel Technology. IPET is not, strictly speaking, a BCSS but a technological platform for large-scale implementation of voluntary travel behavior change program. The BCSS (or the mobile application) is called Activity Locator. The system collects relevant trip information, converts the data into an activity-travel diary and provides, through mail or a website, a personalized travel plan in place of car.
MatkaHupi, Finland, (Jylhä et al, 2013)	MatkaHupi automatically tracks the carbon emissions of the transportation modes and uses this information to recommend the traveler a set of challenges, such as “Reduce this week’s CO2 by 10%” or “Walk 3km.”
QT, United States, (Jariyasunant et al, 2015)	QT (Quantified Traveler) is a computational travel feedback system that aims to change mode or trip choice, without need for traditional travel counselors. The system automatically collects trip data, converts them into a travel diary and gives quantitative feedback (time and money spent, calories burned and CO_2 emitted) to the traveler.
Peacox, Austria,	PEACOX, or Persuasive Advisor for CO2-reducing cross-model trip

(Schrammel et al, 2013)	planning, is a multi-modal navigation smartphone application that aims to help users travel with lower carbon impact. Suggestions can be "We estimated that you could walk 29% of your car -- and 41% of your PT trips to save more CO2" or "Improve your Rank by reducing your CO2 Consumption. We recommend walking instead of using your car/PT for short trips."
Tripzoom, Netherlands, (Broll et al, 2012)	Tripzoom is a mobile application that constructs individual mobility profiles and patterns from mobile sensing. Based on this data, it then encourages the users to change their behavior by offering appropriate incentives and providing feedback from the community.
SuperHub, Italy, (Carreras et al, 2012)	SUPERHUB (SUstainable and PERsuasive Human Users moBility in future cities) is a mobile application and open source platform that aims to raise in citizens a personal awareness of the carbon impact of their daily mobility, thus fostering a more environmentally-friendly behavior. As an open-source platform, it collects, mines and aggregates data from a variety of mobility sources/providers, then builds eco-friendly and suitable multi-modal journey plans for citizens.
i-Tour, Italy, (Magliocchetti et al, 2011)	i-Tour, or intelligent Transport system for Optimised Urban Trips, is a personal mobility assistant that aims to promote sustainable travel choices. To encourage use of public transport, the system supports routing across a multimodal transport network.
PEIR, United States,	PEIR, the Personal Environmental Impact Report, is an application that

 ACCEPTED MANUSCRIPT

(Mun et al, 2009)	automatically calculates and provides estimates of one's environmental impact (carbon and sensitive site impact) and exposure (smog and fast food exposure).
Ubigreen, United States, (Froehlich et al, 2009)	UbiGreen Transportation Display uses iconic feedback (tree or polar bear) and ambient changes in the graphics of the user's mobile phones to provide awareness about green mobility behavior. Rewards can be earned by taking sustainable transportation.

Table 4. Presence of Primary Task, Dialogue and Social Support Features in 9 BCSSs

Category	Persuasive Feature	PEA-COX	Super-Hub	IPET	Trip-Zoom	iTour	Matka-Hupi	Ubi-green	PEIR	QT
Primary Task Support	Personalization (n = 9)	•	•	•	•	•	•	•	•	•
	Self-monitoring (n = 8)	•	•	•	•		•	•	•	•
	Reduction (n = 6)	•	•	•	•	•	•			
	Tailoring (n = 5)	•	•	•	•	•				
	Simulation (n = 5)	•	•	•		•	•			
	Rehearsal (n = 5)	•	•	•		•	•			
	Tunneling (n = 4)	•	•	•		•				
Dialogue Support	Similarity (n = 9)	•	•	•	•	•	•	•	•	•
	Liking (n = 8)	•	•	•	•	•	•	•	•	
	Praise (n = 7)	•	•	•	•		•	•	•	
	Suggestion	•	•	•	•	•	•	•		

	(n = 7)									
	Rewards (n = 6)	•	•	•	•		•	•		
	Reminders (n = 5)	•	•	•	•				•	
	Social Role (n = 0)									
Social Support	Social learning (n = 6)	•	•	•	•				•	•
	Social comparison (n = 6)	•	•	•	•				•	•
	Norm. Influence (n = 5)	•	•		•				•	•
	Competition (n = 5)	•	•	•	•				•	
	Recognition (n = 5)	•	•	•	•				•	
	Social facilitation (n = 1)					•				
	Cooperation (n = 1)	•								

ACCEPTED MANUSCRIPT

Table 5. Details on Evaluation of Effectiveness of BCSSs

BCSS (LOCATION)	QUALITY OF STUDY DESIGN	INTERVENTION	MEASURE TYPE	OUTCOMES
QT (California)	Low (cohort-uncontrolled)	N = 135 subjects; Duration of 3 weeks	Distance Pro-environmental attitudes	Significant: driving distance (-), awareness (+), attitudes (+), intention (+) Not significant: distance of walk/bike/transit
Peacox (ITS Vienna)	Low (cohort-uncontrolled)	N = 24 subjects; Duration of 8 weeks	Modal change Pro-environmental attitudes	Significant: attitude towards transport modes (+) Not significant: environmental concern, modal change
SuperHub** (Barcelona, Helsinki, Milan)	Low (cohort-uncontrolled)	N = 471 subjects; Duration of 8 weeks	Trips Carbon emissions Pro-environmental attitudes and motivation	Not significant: environmental attitudes, behavior

** Only the result of the second trial is reported since the document for the final trial is not yet published.