Promoting Eco-driving through Persuasive Visualization

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ABSTRACT

The goal of sustainability is to preserve resources for future generations. Climate change is a major environmental problem that violates the goal of sustainability. A key strategy to combat climate change is to reduce carbon emission that is largely generated by road transport. Traditional interventions on promoting eco-driving behaviors often fail to convince people to alter their driving behaviors. The growing use of persuasive visualization allows individuals to become aware of the relationship between their driving behaviors and the associated environmental impact. Drawing on the expectancy theory of motivation, this study plans to explore ways to design effective visualization to promote eco-driving behaviors. Additionally, this study proposes a unique lab experiment that enables the manipulation of visualizations and presents an opportunity to observe individuals' driving behavioral changes.

Keywords

Sustainability, expectancy theory of motivation, visualization.

INTRODUCTION

The challenge of climate change poses an enormous and widespread risk to the natural environment. The main cause of climate change is carbon emission that is generated through various human activities, including agriculture, consumption, and transportation. Carbon emission generated by vehicles forms a major component of global energy-related carbon emissions (Zhang, Fujimori, Dai, & Hanaoka, 2018). Among the policy options to reduce vehicle emissions is eco-driving. Fuel consumption reduction through increasing driver awareness towards driving economy is a cost-efficient way to reduce energy use and emissions (IEA, 2005)

Although past studies have reported various ways to motivate eco-driving, scholars have consistently noted that drivers often slip back to less environmental-friendly driving habits resulting in lower fuel reduction (Barla, Gilbert-Gonthier, Castro, & Miranda-Moreno, 2017). In general, studies have revealed that the greatest challenge faced by eco-driving initiatives is to elevate individual awareness about the environmental impact of vehicles' carbon emissions and more importantly, their assumption of responsibility on the future environmental impact. First, the full impact of vehicular carbon emissions often takes time to surface, making it difficult to convince individuals to drive in an eco-efficient manner. Second, environmental problems are global issues that can only be effectively managed with collective action (Sörqvist & Langeborg, 2019). Individuals often dismiss the importance of their individual responsibilities in reducing carbon emissions and ignore the fact that individual initiatives to reducing carbon emissions is fundamental to accumulative effects. Collectively, without a clear understanding of the relationship between individuals' behaviors and the future environmental consequences, individuals are unlikely to become highly motivated to change their driving behaviors.

To understand individuals' motivation for behavioral changes, we draw on expectancy theory as the key theoretical framework to guide our investigation of promoting eco-driving behaviors. The theory posits that individuals are motivated to alter their behaviors when they are aware of proximal outcomes as well as distal outcomes that are caused by their behaviors (e.g., the short-term impact and long-term consequences of consumption behaviors). In the context of eco-driving, we focus on vehicular carbon emission as the proximal outcome of driving and center on the environmental consequence of vehicular carbon emission as distal outcome of driving. Correspondingly, the first objective of this study is to uncover ways to facilitate the visualization of immediate and distal outcomes of individuals' driving activities, which subsequently persuade individuals adopt eco-efficient driving techniques.

The visualization literature has broadly examined designs that elevate individuals' awareness of and attention to environmental consequences to encourage sustainable behaviors. For instance, Shiraishi, Washio, Takayama, Lehdonvirta, Kimura, and Nakajima (2009) presented a user study with six families over four weeks, who were confronted with an in-home display called "EcoIsland" that visualized users' current eco-friendly behavior to persuade them to change their lifestyle patterns and thereby reduced their CO_2 emissions. The visualization literature has broadly examined two key ways of information presentation, namely static information presentation and dynamic information presentation. While some studies show that animated visualization (e.g., progressive, revelation, and motion) can help orient individuals' attention across transitions to facilitate understanding, other studies show that animated visualization may present unnecessary visual clutters and lead to information overload (De Koning, Tabbers, Rikers, & Paas, 2010; Lin, Dwyer, & Development, 2010). Overall, our understanding towards the effectives of animation in persuasive visualization remains largely inclusive. Correspondingly, our second objective is to identify effective visualization designs to promote eco-driving.

THEORIZATION

Sustainability

Sustainability is largely considered in the tension between present development and future availability of resources. Oftentimes, sustainable development is achieved by simultaneously meetings needs of the present generation and preserving the needs of the future generations. Consequently, climate change presents unprecedented environmental problems that fundamentally challenge sustainability at large. (Fenichel, Levin, McCay, Martin, Abbott, & Pinsky, 2016).

Vehicular carbon emission is that main contributor of global carbon emission. Multiple options are available for drivers to maintain, if not reduce, carbon emission generated by their driving activities. For example, car owners might purchase vehicles with improved fuel-efficiency. Unfortunately, most active vehicles remain largely fuel-inefficient, and at times, poorly maintained and hence further exacerbating the emission problem (Keith, Houston, & Naumov, 2019). On another note, vehicular emission can be substantially reduced with public transport usage. Despite its promises, public transport is only feasible in areas with relatively large populations. Drivers might also be reluctant give up the convenience of driving for the discomfort and crowdedness in mass transportation. Considering the prolonged duration to increase overall fuel efficiency in vehicles and resistance to commute on public transportation, a persuasive strategy focusing on promoting eco-driving, which is a set of driving styles that characterize fuel-efficient driving such as the avoidance of braking and maintenance of constant driving speed (Barkenbus, 2010), is deemed most feasible and relevant to reducing global carbon emission.

Visualization

Visualization is the use of computer-supported graphical representations of abstract data to acquire insights (Card, 1999). Insights are often derived through adopting fresh perspectives that allow individuals to draw attention on previously unnoticed issues. While visualization is typically designed to facilitate insight acquisition, visual clutters can make visualization unhelpful, and detrimental at times, to deriving insights. Visual clutter is the state in which excessive and/or disorganized visual representations hinder viewers' comprehension of the display information (Rosenholtz, Li, & Nakano, 2007). For example, in biology educations, animations can be used to depict the collective functions of multiple organs in a body system, which can be perceptually and cognitively overwhelming. This notion of information overload can be explained by the split-attention effects, in which attention to one presentation component may result in neglect of information in a different and accompanying presentation component (Lowe, 2003)

Visualization and Expectancy Theory

The visualization literature has broadly recommended storytelling as a design consideration in facilitating effective comprehension and inference. Storytelling typically relies on defining a meaningful order for, or establishing connections between, visual representations (Segel & Heer, 2010). The storytelling approach suggests that visualization begins with an introduction to the situation, following by a series of events that at times involves tension or conflict. The entire story concludes with a final resolution in which a call for action is often implied, if not explicitly prompted. According to Fisher (2021), effective storytelling makes viewers not only the receiver but also put them in the roles of an actor, moving from a basic understanding of the information in a story to connect the information to viewers' personal experience to generate subjective interpretations. Similarly, to reduce visual clutter in visualization, a predefined and organized sequence of visual representations effectively keeps viewers oriented across a series of transitions, which enables them to develop a clear understanding of the story. In addition, storytelling in visualization typically provides viewers with a prescribed ordering of visual representations, through which viewers can derive interpretations by inferring the connections between visual representations themselves. In other words, viewers can fill in the gaps in the story with their preexisting experiences, and therefore, they are engaged in the storytelling (Figueiras, 2014)

The expectancy theory of motivation provides a theoretical explanation on the persuasive effects of storytelling (Vroom, 1964). The theory explains that motivation is a function of the expectation of success, which can be estimated in both proximal consequences and distal consequences. Whereas proximal consequences depict the short-term outcomes after adopting certain behavioral changes (i.e., the immediate air quality improvement of reduced emission), distal consequences illustrate long-term implications (i.e., the enduring climate change of reduced emission). For instance, in a study examining electricity smart metering, Tiefenbeck, Goette, Degen, Tasic, Fleisch, Lalive, and Staake (2018) found that when individuals were provided with feedback on the immediate effect of taking a hot shower on resource depletion and the distal effect of resource depletion on shrinking ice floe, they would attribute the negative environmental impacts to hot shower and hence become especially motivated to lower shower temperature and reduce shower duration.

Types of Visualization

Excessive and/or disorganized visual representations are widely recognized to hinder viewers' comprehension of visualization. Scholars have generally recommended the coherence principle, which suggests that effective visualization is achieved by aligning external representation of visualization with internal representation in viewers' cognitive processing (Alhadad, 2018). Applying the coherence principle, visualization research has advanced the importance of visualization dynamicity in enhancing persuasiveness of visual representation. In particular, the literature suggests that visualization persuasiveness can be influenced by presenting static or animated visual representations. Static visualization is commonly implemented through still images. Animated visualization is often implemented with dynamic images that transform structures or other properties with the focus to illustrate changes over time (Schnotz & Lowe, 2008).

Visualization often is implemented with accordance to the principle of storytelling by presenting visual representations in certain predefined sequence, such as chronological order and reversed chronological order. Whereas chronological order depicts a natural order of temporal events (i.e., an earlier event is presented prior to the presentation of a latter event), reversed chronological order offers the eventual outcome prior to a progressive presentation of events increasingly proximal to the presence (Hullman, Drucker, Riche, Lee, Fisher, & Adar, 2013). It is worthy to note that the impact of temporal orders in visualization on viewer understanding remains largely unknown. Viewers typically attempt to rationalize visualization by anticipating trajectories of visual representations or deriving the relationships (i.e., cause and effect relationships) among visual representations. According to the psychology literature, reasoning is a process of drawing conclusions or constructing explanations based on available information. Scholars have generally focused on two types of reasoning, namely induction reasoning and deduction reasoning. Inductive reasoning subsumes a thinking process in which individuals derive conclusions through their exploratory observations. Since the reasoning process does not commence with a preestablished premise, inductive reasoning often does not arrive at a specific conclusion but does lead to multiple, and at times conflicting, conclusions (Ketokivi & Mantere, 2010). By contrast, deductive reasoning subsumes a thinking process in which individuals draw on a preestablished premise to conduct confirmatory observation with the objective of either supporting or rejecting the premise.

HYPOTHESES

Visualization facilitates mental recall of driving experience. The coherence principle suggests that effective visualization should align the external representation of the visualization with the internal representation in viewers' cognitive processing. In the context of eco-driving, the internal representation in viewers' cognitive processing is essentially the re-enactment of the moment-to-moment commuting experience in mind, which fundamentally consists of series of motions over time. In this case, animated visualization that shows the motions of the vehicle creates a better cognitive fit between its presentation format and drivers' mental recall process, which facilitates the process of memory retrieval. By contrast, with static visualization that only provides the end state of drivers' commuting experiences, drivers might have to draw extra cognitive effort themselves to recall moment by moment experiences of the entire journey. Collectively, in the context of eco-driving, we expect that animated visualization, compared with static visualization, would be more effective in facilitating drivers' recall of past commuting experiences, which subsequently improve their driving behaviors.

H1: Compared with static visualization, dynamic visualization will increase eco-driving.

We expect visualization presented in reversed chronological order will increase eco-driving compared with visualization presented in chronological order. Whereas visualization with chronological order triggers inductive reasoning, visualization with reversed chronological order will lead to deductive reasoning. In the context of eco-driving, visualization with chronological order would first show drivers observations of their driving behaviors. With multiple observations, drivers are likely to evaluate their driving performance in differently and hence, they are likely to conclude that they performed well. By contrast, visualization with reversed chronological order first informs drivers of the assumption that the vehicle's carbon emission damages the environment. With this assumption in mind, drivers are oriented to find relevant evidence of the impact of their driving behaviors, in which they are likely to become more aware of specific driving segments that cause harm to the environment. By being aware of the negative consequences of driving and ascribing these environmental damages to one's own responsibility, drivers are likely to become motivated to engage in eco-driving behaviors. Hence, we propose the hypothesis that:

H2: Compared with visualization in chronological order, visualization in reversed chronological order will increase eco-driving.

We expect that the effect of visualization dynamicity on eco-driving behaviors is moderated by temporal sequence. Through animated visualization, drivers are inclined to and better able to find evidence associated with the impact of their driving behaviors. By contrast, through static visualization, although with that assumption in mind, drivers are unlikely to recall their past driving behaviors and hence, drivers are unlikely to engage in eco-driving behaviors. By contrast, through animated visualization, without a pre-established assumption, drivers can find observations of driving behaviors that do not harm the environment and hence, they are likely to deny their responsibilities of causing the environmental damages and become reluctant to perform eco-driving. With static visualization, drivers are not convinced of the negative impacts of their driving behaviors on the environment and at the same time, they could not recall past driving behaviors. Consequently, drivers are even unlikely to engage in eco-driving behaviors. Collectively, we propose the hypothesis that:

Hypothesis 3: The effect of visualization dynamicity on eco-driving is moderated by narrative sequence.

PROPOSED METHODOLOGY

A laboratory experiment with a 2 (visualization dynamicity, static visualization versus animated visualization) × 2 (narrative sequence, chronological order versus reversed chronological order) factorial design will be conducted to test the proposed hypotheses. The visualization presented to participants consists of three visual representations, namely (i) route plot, (ii) CO_2 emission chart, and (iii) land underwater map. The (i) route plot provides a speed trace of participants' driving on the simulator. The (ii) CO_2 emission chart illustrates an estimation of the amount of carbon dioxide that participants have generated in the driving simulation. The (iii) land underwater map provides a graphical depiction of the impact of sea-level rise in Singapore in 2050. The projection is computed based on a general CO_2 emission consistent with participants' emissions in the driving simulation. Since the experiment will be conducted in Singapore, we plan to utilize the map of Singapore to show land underwater to make it relevant for all participants.

Visualization dynamicity in the experiment will be manipulated by presenting the three visual representations (i.e., (i) to (iii)) using static visualization or animated visualization. In the static visualization condition, participants will be presented with the static images of the completed charts. In the animated visualization condition, the three charts will be presented with dynamic plotting, starting from blank charts and progressively plotted until completion. More importantly, animation in the (i) route plot will be synchronized with the animation in the (ii) CO_2 emission chart as well as that in the (iii) land underwater map. Temporal sequence will be manipulated by changing the presentation order of the three visual representations. In the condition of chronological order, we will first present participants with the (i) route plot and the (ii) CO_2 emission chart, followed by the (ii) CO_2 emission chart and the (iii) land underwater map. In reversed chronological order, the same three visual representations will be presented but in the reversed order.

We will recruit university students with driving licenses (N=200) to take part in a driving simulation experiment. The driving simulation experiment will be conducted in a computer lab and participants will come to the lab individually. The laboratory experiment will involve asking participants to drive using simulator in a controlled environment. The advantage of using a driving simulator is that we can control the route and other environmental factors in driving among all participants, and hence we can exclude all factors that could obscure the effect we wish to study. Raw data will be captured by the driving simulator, which will be used for measuring driving performance. The driving simulator will be configured with a Singapore road scenario. Upon arrival at the laboratory, participants will be informed that the objective of the experiment is to evaluate a driving simulator. They will be asked to use the simulator to complete three driving tasks on the same route with different traffic conditions. The first driving task will be used as a familiarization round to have subjects accustomed to the simulator hardware and software environment. The second driving task will be used to capture subjects' driving efficiency. The captured data will be used to generate driving efficiency analytics (i.e., visualization) where experimental conditions are administrated. Afterward, subjects will perform the final driving task.

Participants' driving will be recorded and analyzed to understand changes in their driving behaviors. A key challenge in the lab experiment is to generate driving scores that are relevant to actual driving behaviors. Different drivers have different driving behaviors due to their personal characteristics and driving skills. Some drivers prefer to drive aggressively, while others are more cautious. Thus, it is necessary to find a way to describe an individual driver's driving behavior characteristics. By following Chen, Zhao, Zhang, Rong, and Liu (2019), we plan to employ the Symbolic Aggregate Approximation (SAX) method to extract typical driving patterns. As time-series data, a reasonable simplification is needed for the extracted features to reduce the complexity. The entire process of SAX can be summarized into 5 steps: (1) data normalization, (2) data grading and coding, (3) pattern detection, (4) typical pattern extraction, and (5) quantification.

In addition, emerging research has started to use information about eye movements and fixations to measure stimuli-induced visual attention. For example, Pakdamanian, Feng, and Kim (2018) have used imotion to assess individuals' visual attention to driving. They found that whole-body haptic feedback can re-orient individuals' visual attention to driving, which forces individuals to take active control of their vehicles and increases safe-driving behaviors. Accordingly, we plan to utilize imotion to track participants' eye position and movement to access their visual attention to driving. Individuals pay more visual attention to driving can imply that they spend more effort in driving. The data on participants' visual attention will be recorded and analyzed to understand changes in terms of individuals' effort spent in driving.

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