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# Promoting Eco driving with Post Trip Visualized Storytelling

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## ABSTRACT

Visualized storytelling is often used to explain complicated environmental issues, raise ecological consciousness, and promote sustainable behavior. In this study, we develop and test a model demonstrating how post-trip visualized storytelling encourages eco-driving behaviors. We explore the effect of post-trip visualizations on eco-driving behaviors by examining the literature on human-computer interaction. We test our hypothesis in an experiment using eye tracking and driving simulation. Results indicate that animated illustrations and narrative sequence improved eco-driving practices. Overall, this study contributes to information systems literature by unraveling the effects of post-trip visualized storytelling on eco-driving behaviors.

### Keywords

Visualized storytelling, eco-driving behaviors, eye-tracking, driving simulation.

## INTRODUCTION

According to the Intergovernmental Panel on Climate Change, global warming has caused many extreme weather events that have displaced more than 13 million people (Pörtner et al. 2022). Scientists have long identified road transportation as a significant contributor to global warming (Voiland 2010). Environmentalists have advocated the importance of promoting sustainable driving practices. Sustainability interventions have traditionally transpired as policy programs and physical awareness campaigns, while digital interventions are becoming an increasingly popular method of promoting sustainable behaviors. Digital interventions for sustainable driving often involve post-trip information visualizations that enable individuals to understand the environmental impact of vehicular operations (Dahlinger et al. 2018). However, little is known about the effectiveness of post-trip visualized narratives in influencing subsequent driving behaviors.

Information Systems (IS) research has significantly progressed toward understanding visualized narratives. Prior studies have focused on understanding the effects of different static visualization, such as texts and charts on decision making (e.g., Choi et al. 2015). IS researchers have also examined dynamic visualizations (e.g., Lee et al. 2012). While IS research has advanced our understanding of various techniques of information visualizations, there needs to be more research uncovering the underlying mechanisms through which visualizations influence sustainable behaviors. This study aims to enrich the IS literature by examining the effects of visualizations on promoting sustainable behaviors. Specifically, drawing on Human-Computer Interactions (HCI) research, we elucidate how motion visual elements and presentation sequence changes subsequent driving behaviors.

## RELATED LITERATURE

### Vehicular Emission and Eco-Driving

Carbon emission has been recognized as the primary contributor to multiple environmental issues (Morelli 2011). Specific to reducing carbon emissions, sustainable transport has been championed as the vital mitigation of vehicular emissions. Various approaches to sustainable transport have been identified, such as utilizing alternative fuel sources and converting to electric cars. However, using alternative fuel sources can be hindered by engine designs and the construction of new fuel production facilities. Furthermore, battery production might incur a large carbon footprint, and electricity generation remains predominately reliant on the burning of fossil fuels. A relatively viable strategy is to persuade drivers to adopt eco-driving, a fuel-efficient driving technique that focuses on maintaining consistent driving speed and avoiding unnecessary harsh accelerations (Barkenbus 2010).

### Visualizations

Visualizations present data with multiple dimensions using visual elements, such as lines, shapes, and objects, on charts and diagrams (Card et al. 1999). Contemporary work on visualizations has adopted an exploratory, experience-centric approach to understanding how individuals engage with data on their past behaviors (e.g., Karyda et al. 2020). Recent HCI research has extensively examined post-trip visualizations in understanding driving behaviors. For instance, Fairclough and Dobbins (2020) utilized the heartbeat data of drivers and their driving data to construct a line graph that dynamically illustrated the synchronized changes in cardiovascular activities and driving conditions. Compared with drivers not receiving any post-trip visualizations, drivers receiving visualizations were better able to recall instances of frustration emotions during specific occurrences of traffic jams, which helped them understand the negative health consequences and motivated them to adopt anger management strategies.

### *Change Illustration*

The HCI literature has advanced several techniques on how data can be *shown* to help viewers understand complex issues (e.g., Tory and Moller 2004). One essential technique is illustrating value changes with animation, which has been broadly applied to presenting temporal changes in various contexts. Considering the importance of change illustration, this study considers static and animated illustrations. Static illustration presents value changes with stationary visual elements. Animated illustration presents the temporal dimension of changes with motions (Schnotz and Lowe 2008).

Past research examining visual attention explains that endogenous factors, such as contextual knowledge and past viewing experience, can strongly influence how viewers attend static presentations (e.g., Jiang and Chun 2001). With static illustration, endogenous factors predominately drive attention allocation; hence, viewers may focus on vastly different visual elements. By contrast, when viewing presentations with motions, viewers' visual attention often focuses on specific motion visual elements, indicating attentional synchrony (Smith and Henderson 2008), and less individual variability in attention allocation. Accordingly, with animated illustration, viewers' attention is expected to be subliminally regulated by the motions in visualizations.

### *Narrative Sequence*

The HCI literature has begun to explore how data can be *told* through narrative storytelling. Narrative storytelling shows increasing promises for telling data stories on the causes and consequences of environmental issues (Gordon et al. 2018). Understanding causal relationships often requires detailed comprehension of both the present and future environments, necessitating numerous the presentation of multiple visualizations. Yet simultaneous exposure to multiple visualizations can inhibit understanding since individuals can experience split-attention (Rosenholtz et al. 2007). As a result, one might need help to focus on a visual element for complete understanding. An antidote to split-attention is the storytelling technique, in which multiple visualizations are not presented simultaneously but conveyed in selected subsets to provide detailed explanations in an organized narrative (Echeverria et al. 2018). Considering the importance of storytelling in explaining causality, this study focuses on two sequences of visualization narrative, namely prospective narrative and retrospective narrative. Prospective narrative tells a data story following its chronological sequence in which events of the narrative are arranged in order of time. By contrast, a retrospective narrative tells a data story in reverse chronology.

Despite the increasing applications of narrative storytelling in visualizations, rarely has past research put forth a systematic account of the impact of narrative sequence on individuals' understanding of causal events. To this end, this study draws on construal level theory to offer a comprehensive explanation. The theory posits that events can be construed as either psychologically proximal or distant (Trope and Liberman 2010). Proximal events are often accessible for individuals to relate to because those represent "pushes and pulls of everyday life" (van Trijp 2013, p. 92) that offer rich information. By contrast, the further psychologically distant an event is from a person's present situation, the more effort is required to construe it mentally, and hence the more abstract and generalized the resulting mental representation will become. Consistent with construal level theory, with prospective narrative, a data story that commences with a depiction of the present situation is likely to encourage viewers to adopt a concrete mindset. With retrospective narrative, however, viewers are initially presented with illustrations of future consequences, likely stimulating viewers' abstract mindset.

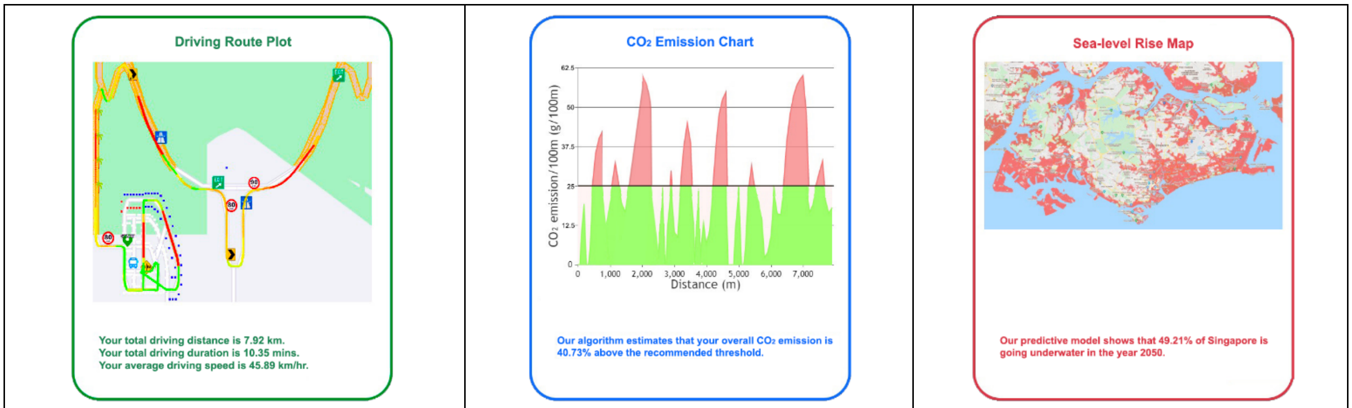
In addition, the psychological construal literature suggests that individuals' mindsets can fundamentally shape the way individuals interpret information presentation (Berson and Halevy 2014). Individuals with a proximal mindset prefer concrete information presentation since they are particularly alert to low-level details. Similarly, individuals with a distal mindset would find abstract information presentation particularly attractive and easy to understand due to construal fit, which occurs when individuals experience congruence between their mental perspective and new information. More importantly, when an incongruence occurs, individuals might struggle to comprehend the information fully, and at times, become highly skeptical about the presented information.

## RESEARCH MODEL AND HYPOTHESIS DEVELOPMENT

Following the sustainability literature, to provide comprehensive illustrations of the impact of individuals' present driving behaviors on the future environment, we constructed three visualizations to illustrate the environmental impact of driving behaviors (Figure 1), namely the driving route plot, carbon emission chart, and sea-level rise map. Based on the three visualizations, we investigate the effects of post-trip visualized narratives on promoting eco-driving behaviors.

### Eco-Driving Behaviors

Singh and Kathuria (2021) proposed three categories of observations for examining driving behaviors, namely trip-specific, car-specific, and driver-specific observations. Trip-specific observations, such as speed and distance, are essential to evaluating acceleration and deceleration and hence have been commonly utilized to estimate driving behaviors. Car-specific observations provide a mechanical perspective on driving behaviors (e.g., braking force). Driver-specific observations focus on capturing individuals' attention (e.g., eyes-off-road times and eyes-on-road times) using eye-tracking devices. While eyes-on-road represent drivers' attention on the forward road conditions during vehicle operations, eyes-off-road




| 1A: Driving route plot | 1B: Carbon emission chart | 1C: Sea-level rise map |
|---|---|---|

**Figure 1. Visualized Narrative**

characterize drivers' attention toward the vehicle interior, such as the dashboard, speedometers, and tachometer (Olsen et al. 2005). Given the importance of the three observation categories, this study focuses on driving smoothness, braking aggressiveness, and visual attention allocation.

### *Change Illustration and Eco-Driving Behaviors*

The motion visual elements of animated illustration are visually salient features that can lead to attentional synchrony, whereby individuals' attention is subliminally synchronized with the motions (Smith and Henderson 2008). Following this logic, when the environmental impact of individuals' past driving behaviors is illustrated through animated illustration, individuals can better focus on the animated visual elements that help them recall specific moments of their driving. Furthermore, a key challenge to understanding multiple visualizations is cognitive integration, which synthesizes information from various sources (Nurgaleeva 2015). Animated illustration provides anchors that help integrate information from various visualizations. Consequently, animated illustration can enhance individuals' understanding of driving behaviors and their associated environmental impact, leading them to exercise more regulated driving behaviors. Therefore, we propose the following hypothesis:

*H1: Compared with static illustration, animated illustration will increase eco-driving behaviors (i.e., driving smoothness, braking aggressiveness, and visual attention allocation).*

### *Interaction between Change Illustration and Narrative Sequence*

The construal level literature suggests that when individuals are prompted with a proximal event, they assume a concrete mindset and focus on low-level details in interpreting information presentation (Trope and Liberman 2010). However, when a distal event is prompted, individuals adopt an abstract mindset that induces them to focus on high-level details. More importantly, according to construal level theory, congruence between the adopted mindset and information presentation increases individuals' psychological engagement in understanding the information, which motivates them to expend effort on relevant activities (Humphreys et al. 2021).

Narrative sequence determines the chronological order in which the data story is presented. In the case of prospective narrative, the data story begins with a visualization depicting individuals' recent driving behaviors. Prompted by a proximal driving event, a concrete mindset is activated. This concrete mindset will likely elevate individuals' attention to specific details in understanding the visualization. With animated illustration, individuals are provided with motion visual anchors to help them understand the moment-to-moment changes in driving behaviors and environmental damages. More importantly, the high visual prominence of momentary changes among multiple visualizations matches individuals' concrete mindset, intensifying their focus on concrete details in understanding the environmental impact of their driving behaviors. Consequently, individuals will become motivated to take on eco-driving behaviors. On the contrary, in the case of retrospective narrative, the data story commences with a depiction of the future environment. As a result, individuals are likely to adopt an abstract mindset that would prompt them to focus on the general essence in understanding the visualized narrative. Animated illustration emphasizes the specific momentary changes among multiple visualizations and hence is not likely to match individuals' focus on general understanding. Therefore, animated illustration connotes an incongruence between the activated perspective and available information. Thus, we predict the following effects:

*H2: The effect of change illustration on eco-driving behaviors is stronger in the prospective narrative condition than in the retrospective narrative condition.*

## RESEARCH METHOD

### Experimental Design

To test the proposed hypotheses, a laboratory experiment with a 2 (change illustration, static illustration vs. animated illustration) × 2 (visualization narrative, prospective narrative vs. retrospective narrative) between-subjects factorial design. Change illustration in the experiment was manipulated by presenting the three charts with or without animation. In the static illustration condition, subjects were shown with static, completed charts that depicted the environmental consequences of their simulator driving. In the animated illustration condition, subjects were presented with progressively constructed charts. Visualization narrative was manipulated by varying the presentation sequence of the three visualizations. With prospective narrative, subjects were first presented with the driving route plot and carbon emission chart. Subsequently, the sea-level rise map was collectively shown with the carbon emission chart. With retrospective narrative, the three visualizations were presented in a reversed sequence.

### Sample and Experimental Procedures

Subjects in this experiment were adults with valid driving qualifications and driving experiences. One week before the experiment, they were asked to provide demographic information, driving experience, and driving frequency, and respond to questions measuring the control variables. 100 subjects were recruited to participate in the experiment. Experiment administrators facilitated the experiment[1]. Subjects were randomly assigned to one of the four experimental conditions (Table 1). They were asked to complete three rounds of driving simulations (i.e., a familiarization drive, the 1st scenario drive, and the 2nd scenario drive 2 ). The essential purpose of the familiarization drive was to get subjects accustomed to the controls and simulation environment.[3] After completing the 1st scenario drive, subjects were presented with the visualized narrative on the environmental impact of their driving behaviors on the computer screen in the 1st scenario drive. Afterward, subjects completed the final round of stimulation driving.

| | Prospective Narrative | Retrospective Narrative |
|---|---|---|
| Static Illustration | 25 | 25 |
| Animated Illustration | 25 | 25 |

**Table 1. Experimental Conditions**

We utilized eye-tracking to facilitate objective measures of subjects' visual attention during their driving simulation. The literature on driving behaviors has extensively examined drivers' attentions in two aspects: eyes-on-road and eyes-off-road. While eyes-on-road represents drivers' attention on the forward road conditions during vehicle operations, eyes-off-road characterizes drivers' attention diverted away from the road towards the vehicle interior, such as the dashboard, speedometers, and tachometer (e.g., Olsen et al. 2005). Accordingly, to capture individuals' visual attention during the driving simulation (Blascheck et al. 2017), we have created four distinct areas of interest (AOI), namely the windscreen region (i.e., AOI1), speedometer region (i.e., AOI2), tachometer region (i.e., AOI3), and other regions (i.e., AOI4).

### Data Analysis

#### Subject Demographics

Among the 100 subjects, 50 were female. The age of the subjects ranged from 22 to 45, with the average driving experience and average driving frequency being 8.32 years of license age and 35.11 times per month, respectively. No significant differences were found among subjects randomly assigned to each of the four experimental conditions.

#### Measurement

Driving smoothness was computed based on the subjects' driving patterns in the simulation. Following Chen et al. (2019), we adapted the Symbolic Aggregate Approximation (SAX) method to translate a subject's simulation driving data into a single score. A higher score indicates smoother driving behaviors. Braking aggressiveness was computed based on the subjects' foot pressure on the brake pedal in the simulation. Procedures to compute braking aggressiveness are mainly similar to that of computing driving smoothness. A higher score indicates greater braking aggressiveness. Following the eye-tracking literature (Bera et al. 2019) , we operationalize visual attention allocation to each AOIs in terms of fixation count and dwell time percentage to examine visualization allocation to various areas of interest[4].

#### Tests of Direct Effect Hypotheses

A multivariate analysis of variance (MANOVA) was conducted to detect the combined effects of change illustration emphasis and narrative sequence on eco-driving behaviors. Results revealed an overall significant impact. To test the impact of the independent variables on each outcome, separate analyses of variance (ANOVAs) were conducted.

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[1] Four experiment administrators, who were not aware of the hypotheses and unknown to each other, conducted the experiments. The administrators were trained to follow the pre-established experimental procedures and avoid unnecessary interactions with subjects. Each administrator conducted the experiment in one single experimental condition.

[2] Eye-tracking calibration was performed with the standard nine-point fixation test before each driving simulation. Each of the two scenario drives commenced with a similar narrative that asked subjects to imagine a daily commute scenario; each drive was performed on a designated route in which the traffic condition was controlled.

[3]The entire driving simulation environment was customized to reflect local traffic conditions (i.e., car license plates, signboards, and traffic rules).

[4] Dwell time percentage is about the proportion of time a subject fixated on an AOI within a period.

ANOVA results revealed that animated visualization leads to a higher level of driving smoothness (Table 2), a lower level of braking aggressiveness (Table 2), as well as more fixation count (Table 3), and a higher dwell time percentage (Table 4) on both the speedometer and tachometer than does static visualization. Therefore, H1 is supported. Since the interaction effects are significant, we further analyzed the simple main effect. Overall, results suggest that under the prospective narrative condition, compared with static visualizations, animated visualizations lead to a higher level of driving smoothness, a lower level of braking aggrievances, as well as more fixation count and a higher dwell time percentage on the speedometer and tachometer. By contrast, the interaction effects are less pronounced under the retrospective narrative condition. Therefore, H2 is supported.

## DISCUSSION

Our results supported our hypotheses. First, as we hypothesized earlier, we found that subjects in the animated illustration condition maintained higher driving smoothness, lower braking aggressiveness, and greater visual attention on the speedometer and tachometer. We also argued that the effects of change illustration interacted with a narrative sequence in influencing eco-driving behaviors. Our results showed that animated illustration increased eco-driving behaviors with prospective narrative compared with static illustration. The effects of animated illustration on eco-driving behaviors were less pronounced with retrospective animation.

### Limitations and Future Directions

Our contributions may be limited by using a driving simulation environment. This study utilized a simulation environment that has been broadly employed in prior driving behavior research. While extensive customizations have been performed to ensure natural driving behaviors, the simulation environment may not completely resemble the bodily experience in actual driving (e.g., physical vibrations and motions). However, we wish to highlight that field studies examining driving behaviors by employing the Symbolic Aggregate Approximation method reported driving smoothness scores that range from 0.2 to 0.7 (e.g., Chen et al. 2019), which are primarily similar to the scores captured in our laboratory setting. This evidence helps to indicate the comparability of our laboratory observations with prior field studies. Furthermore, this study focuses on understanding the driving behaviors of typical drivers. Vocational drivers may have vastly different driving experiences and possess additional skills in operating vehicles and responding to impromptu traffic conditions. We recommend that future studies consider field experiments with transport companies where visualizations of drivers' carbon footprint and associated environmental damages can be provided periodically.

### Theoretical Implications

This paper makes several important contributions to the literature. First, we contribute to the IS literature by unraveling the effects of visualized narratives on behaviors. While people might thoroughly understand future environmental issues, they may need help to maintain sustainable behaviors. Such finding has enthused scholars to examine the design and evaluation of visualizations for enhancing individuals' understanding of the environmental impact of their behaviors (Schneider et al. 2018). This study thus makes an important contribution to the IS literature by demonstrating how post-trip visualized narratives can be utilized to promote eco-friendly behaviors.

Additionally, while the visualization literature suggests that storytelling can help individuals understand complex issues, our findings show that storytelling can lead to unexpected outcomes. Specifically, this study enriches the HCI literature by applying the construal level theory to visual narratives. Overall, our findings suggest that the congruence between individuals' adopted mindset and information presentation in visualized narratives is important. This study thus shows that visualization research should consider both the sequential aspect of visualized narratives and the dynamic aspect of visualizations. Lastly, this study identifies and demonstrates eco-driving behaviors in multiple manifestations. It is noteworthy that past research has mainly focused on quantifying vehicular speed increase as the only operationalization of eco-driving behaviors. To this end, we provide fresh insights by demonstrating three attributes of driving behaviors, namely driving smoothness, braking aggressiveness, and attention allocation.

### Practical Implications

This work makes significant contributions to practice. Our study reveals a powerful way to promote eco-driving behaviors through visualized narratives illustrating individuals' present behaviors on future environmental consequences. Specifically, we found that animated illustration helps individuals focus on the motion visual elements, recall specific moments of their previous behaviors, and enhance their associations between those behaviors and changes in the future environment. Hence, we recommend that intervention specialists might consider incorporating multiple visualizations in designing digital behavior change programs with animated visual elements to enhance individuals' comprehension of future consequences of their present behaviors. The effect of animated illustration on behavior can likely be extended beyond the sustainability contexts, into settings with negligible future personal implications, such as charitable behaviors and voluntarism.

We also reveal the interaction effects between change illustration and narrative sequence on eco-driving behaviors. Prospective narrative amplifies the impact of animated illustration, whereas the difference between animated and static illustrations is less pronounced with retrospective narrative. Our finding underlines the importance of establishing a personal, relatable context in animated narratives. A common misconception is that animated illustration will always improve understanding.

| | Driving Smoothness | | | | | Braking Aggressiveness | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Source | Type III SS | df | Mean Square | F | Sig. | Type III SS | df | Mean Square | F | Sig. |
| INTCP | 38.80 | 1 | 38.80 | 6114.71 | 0.00 | 21.83 | 1 | 21.83 | 1104.19 | 0.00 |
| CI | 0.51 | 1 | 0.51 | 81.04 | 0.00 | 0.34 | 1 | 0.34 | 17.07 | 0.00 |
| NS | 0.02 | 1 | 0.02 | 3.43 | 0.05 | 0.23 | 1 | 0.23 | 11.41 | 0.00 |
| CI×NS | 0.95 | 1 | 0.95 | 150.33 | 0.00 | 0.40 | 1 | 0.40 | 20.20 | 0.00 |
| Total | 40.90 | 100 | | | | 24.69 | 100 | | | |
| NS = prospective narrative | | | | | | | | | | |
| CI | 1.43 | 1 | 1.43 | 188.35 | 0.00 | 0.74 | 1 | 0.74 | 28.49 | 0.00 |
| Total | 1.80 | 49 | | | | 1.97 | 49 | | | |
| NS = retrospective narrative | | | | | | | | | | |
| CI | 0.03 | 1 | 0.03 | 3.64 | 0.05 | 0.00 | 1 | 0.00 | 0.09 | 0.76 |
| Total | 0.28 | 49 | | | | 0.66 | 49 | | | |

**Table 2. ANOVA Results and Analysis of Simple Mean Effects**

| Fixation Count on AOI2 [Fixation Count on AOI3] | | | | | |
|---|---|---|---|---|---|
| Source | Type III SS | df | Mean Square | F | Sig. |
| INTCP | 893592.09 [231938.56] | 1 | 893592.09 [231938.56] | 275.72 [106.11] | 0.00 |
| CI | 117717.61 [49907.56] | 1 | 117717.61 [49907.56] | 36.32 [22.83] | 0.00 |
| NS | 35156.25 [32616.36] | 1 | 35156.25 [32616.36] | 10.85 [14.92] | 0.00 |
| CI×NS | 181561.21 [92659.36] | 1 | 181561.21 [92659.36] | 56.02 [42.39] | 0.00 |
| Total | 1539153.00 [616964.00] | 100 | | | |
| NS = prospective narrative | | | | | |
| CI | 295834.32 [139286.42] | 1 | 295834.32 [139286.42] | 76.75 [36.70] | 0.00 |
| Total | 480856.08 [321466.58] | 49 | | | |
| NS = retrospective narrative | | | | | |
| CI | 3444.50 [3280.50] | 1 | 3444.50 [3280.50] | 1.31 [3.69] | 0.26 [0.05] |
| Total | 129548.58 [30942.50] | 49 | | | |

**Table 3. ANOVA Results and Analysis of Simple Mean Effects**

| Dwell Time % on AOI2 [Dwell Time % on AOI3] | | | | | |
|---|---|---|---|---|---|
| Source | Type III SS | df | Mean Square | F | Sig. |
| INTCP | 1718.35 [727.46] | 1 | 1718.35 [727.46] | 101.25 [50.40] | 0.00 |
| CI | 354.74 [231.96] | 1 | 354.74 [231.96] | 20.90 [16.07] | 0.00 |
| NS | 114.90 [207.17] | 1 | 114.90 [207.17] | 6.77 [14.35] | 0.01 |
| CI×NS | 333.90 [433.46] | 1 | 333.90 [433.46] | 19.67 [30.03] | 0.00 |
| Total | 4151.20 [2985.64] | 100 | | | |
| NS = prospective narrative | | | | | |
| CI | 688.48 [649.79] | 1 | 688.48 [649.79] | 23.05 [23.31] | 0.00 |
| Total | 2122.45 [1987.79] | 49 | | | |
| NS = retrospective narrative | | | | | |
| CI | 0.16 [15.62] | 1 | 0.16 [5.62] | 0.04 [3.76] | 0.85 [0.05] |
| Total | 195.50 [63.22] | 49 | | | |

**Table 4. ANOVA Results and Analysis of Simple Mean Effects**

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