Investigating the Embodied Effect in Drivers' Safe Headway Learning

by

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ABSTRACT

Safe headway learning plays a core role in driving education. Traditional safe headway education just use the oral and literal methods to educate drivers the concept of safe headway time, while with the limitation of combining drivers subject and situational domains for drivers to learn. This study investigated that whether using ego-moving metaphor to embody driver's self-awareness can help to solve this problem. This study used multiple treatments (ego-moving and time-moving instruction of safe time headway) and controls with pretest experimental design to investigate the embody self-awareness effect in a car-following task. Drivers (N=40) were asked to follow a lead car at a 2-seconds safe time headway. Results found that using embodied-based instructions in safe headway learning can help to improve driver's headway time accuracy and performance stability in the car-following task, which supports the hypothesis that using embodied-based instructions help to facilitate safe headway learning. However, there are still some issues needed to be solved using embodied-based instructions for the drivers' safe headway education. This study serves as a new method for the safe headway education while providing empirical evidence for the embodied theories and their applications.

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Thanks for my committee members (Scotty D. Craig, Robert Gray and Hyunjin Song), without them, this thesis would have never been possible without the help of them ☺

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CHAPTER 1

INTRODUCTION

Safe headway learning plays a core role in driver education. Mastering the concept of safe headway means drivers can control their own safety during driving when following vehicles. Such a learning process and its transfer to changing environment can serve as a basic skill for traffic safety. Safe headway learning means the driver has the ability to transfer the standard and abstract concept of safe headway from the brain to finish motion control to apply the concept in the changing environment in car following task. This requires the driver to have a deep understanding of the process that allows for the creation of their personal meaning for the concept which can then transfer into different environments (Mayer, Fennell, Farmer, & Campbell, 2004). Safety headway concept transferred to applied settings requires drivers to observe the outer environment to gain situational awareness (Walker, Stanton, Kazi, Salmon, & Jenkins, 2009), detect the potential of being at risk to control their vehicle in a safe margin between vehicles (Lewis-Evans et al., 2010; Summala, 1988) in simple car-following model. To create personal meaning of safe headway, drivers need to focus on both subject and situational domains. Subject domain includes driver's body states such as marijuana smoking effects (A. Smiley, Moskowitz, & Ziedman, 1985; A. M. Smiley, Moskowitz, & Zeidman, 1981) and exhaustion (Fuller, 1981), driver's perception-motor skills (van Winsum, 1998), driver's decision making (Lewis-Evans et al., 2010) and driver's ability to maintain an accurate safe time headway (Risto & Martens, 2013). Situational domains include environment changes such as traffic flow, changes in roadway geometry, traffic signal timing and headway (Ranney, 1999). Traditional education in driving safety maintains that driver should focus on the environment domains to gain situational awareness to keep driving safety through standard post-hoc analyze results while ignoring driver's personal situation such as driver's body states. This may hinder drivers combine both their subject domains and situational domains to create their personal meanings to form their own safe headway concept to withstand environmental changes. As a result, finding a way to integrate both subject and situational domains to help better transfer safe headway driving experience to drivers, and compare its effect with traditional education method serves a main problem in safe headway learning.

Embodied theory proposed that human bodies have the ability to integrate resources to solve the task triggered by environment. These resources include previous knowledge of the task in the brain, internal body states and the environment which finally coupled together via perceptual system (A. D. Wilson & Golonka, 2013). This ability allows humans to use limited resource to reach the optimal performance and therefore reach the action economy (Proffitt, 2006). Embodied theory has been proof in psychology area (Proffitt, 2006), robotics area (A. D. Wilson & Golonka, 2013) and motion control area (Todorov, 2004). Additionally, according to Zahavi (2002) and Mayer (2004), except for traditional embodied theories that just using body as a tool to improve task solving skills, using pronoun to induce people’s self-awareness in learning can help better transfer knowledge from abstract domains to applied settings to foster meaningful learning. Because safe headway learning problem can be viewed as a task triggered by the dynamic traffic environment (Fuller, 2005), and safe headway concept is learned from abstract domains from oral and literal expressions through words and languages, here the research question is: can embodied-based training that induce people’s self-awareness be implemented to improve participant’s safe headway concept learning performance in car-following model?

CHAPTER 2

LITERATURE REVIEW

Car following model, safe margin and traffic safety

Traffic is a complex system that car following model serves as a simple model to research the traffic problem (Homburger, Keefer, & Mcgrath, 1982). Factors that influence safety in car-following model can be deduced in complex traffic stream (May, 1990).

In the car-following model, keeping safe means drivers should keep their vehicle in a safe margin (Fuller, 2005). Safe margin means that the driver should not follow a lead vehicle too close to avoid risk (Fuller, 1984). Traditional education in safe driving behavior training uses time headway to measure the distance between a lead vehicle and a driver's vehicle. Time headway represents the time interval between the lead vehicle and the driver's vehicle (van Winsum, 1998). The meaning of time headway is to tell the mean value of safe margin to the drivers that raise their awareness about what does safe margin mean to reduce their probability to cause a crash.

There are three kinds of risk in the car-following model: the objective risk, subjective risk estimate and the feeling of risk (Fuller, 2005). Objective risk means the objective probability of being involved in a collision. This usually comes from a post hoc analysis from accident data, which refers to one kind of sources of the mean value of safe time headway. Subjective estimates of risk mean driver's own estimates of the (objective) probability of being involving in an accident. These estimates of risk represent the output of a cognitive process based on the previous knowledge in the brain while the feeling of risk represents an emotional outcome triggered by the environment. Subjective estimates of risk and feeling of risk may be closely associated when the subjective estimates of risk have exceeded some critical value. Such a value may serve as a critical threshold that represents the safe margin. Once the time headway has passed a critical threshold, driver's feeling of risk, task difficulty, and feeling of comfort will increase harshly (See Figure 1.). Such a threshold was found to be in 1.5 second time headway. In addition, participant's confidence in driving abilities was found to be negatively related to their perceived feeling of risk (Matthews & Moran, 1986). As a result, harsh changes in driver's feeling of risk, task difficulty, feeling of comfort and confidence in driving abilities can help drivers to improve driver's awareness of safe margin of distance. And such a safe margin is in around 1.5 seconds.

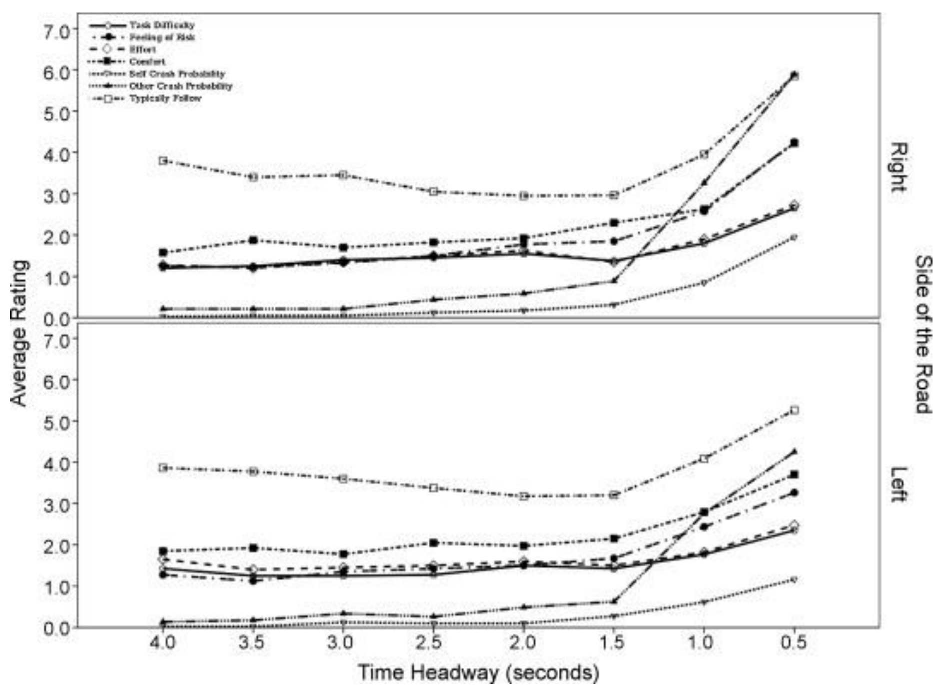

Figure 1. Drivers will feel a significant increase in risk and discomfort when following vehicles in 1.5 seconds time headway(Lewis-Evans, De Waard, & Brookhuis, 2010).

Except for safe margin awareness, there are also other variables that drivers use to control the safe margin: accuracy and reaction time. Accuracy means the driver has to keep the time headway in a safe margin which they were taught in driving training in car-following. If the time headway they are following is shorter than the safe margin they were told, the probability of being at risk may increase. There are two kinds of assessment to measure accuracy. First is the absolute estimation error (Taieb-Maimon & Shinar, 2001), which describes the headway choice accuracy of the driver. Second is the relative estimation error (Taieb-Maimon, 2007), which describes the direction of deviation of a chosen headway from an instructed headway. Both assessments serve a useful tool in measuring headway accuracy. Second is reaction time. Reaction time means driver should control their braking response to avoid being too close to the lead vehicle. Such a response is highly related to driver's perceptual-motor skills. If a driver has high perceptual-motor skills, they will choose smaller time headway because high perceptual-motor skills can reduce reaction time to brake response to avoid collision (van Winsum, 1998). These variables can help to estimate safe margin control behavior performance to determine whether the driver has followed a headway that is safe to him/her while driving.

Driver education in safe driving behavior

However, although many drivers know what the distance a safe time headway is representing for, they may still have trouble in implementing the safe time headway in car following. First is that, when driver first receive their driving education, the time headway told by the instructor or in the brochure of the driving institute is a new experience to new drivers, which means that it is a new situation a new driver never facing with. Because what the new drivers know about the safe distance in the brochure is displayed in two-dimension view, even though the new drivers have read how far the safe distance between two vehicles and get about how long of the distance from the brochure (see Figure 2.), they may still find it hard to apply it in the actual driving environment because the actual driving environment is displayed in three-dimension view. In addition, even though the new drivers have

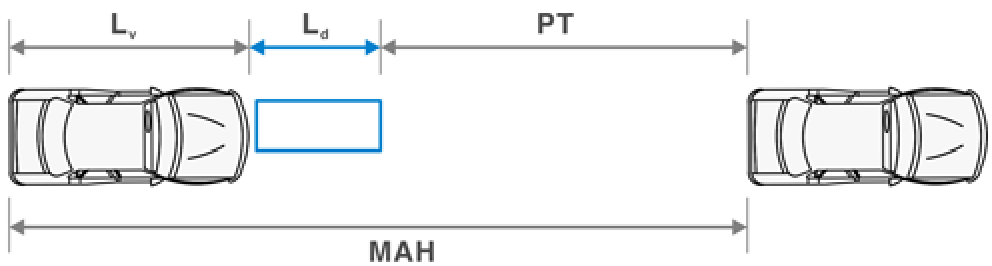

Figure 2. Length of the headway displayed in the two-dimension view. (http://ops.fhwa.dot.gov/publications/fhwahop08024/chapter5.htm, 2015.12.01).

understood about what the distance is being represented by time headway, the accuracy of the driver's perceptual distance will still be affected by their vehicle's speed (Risto & Martens, 2013), which means the distance under a certain speed each headways representing will not always be safe under another speed. What's more, because the ability to keep a constant distance while driving will also be affected by driver's perceptual-motor skills (van Winsum, 1998), even using the same headway in the same speed, it is still not safe enough for the different drivers. As a result, to form and get better understanding of safe time headway, drivers should learn, feel and form their own safe headway based on the "safe time headway" told by driving institute and the real physical driving environment to finish their learning transfer.

Embodiment and safe driving behavior

Embodiment means human engage their major modalities (i.e., the sense systems that include visual, auditory, and kinesthetic) in a physical movement to perform some behavior or to learn (Johnson-Glenberg, Koziupa, Birchfield, & Li, 2011). Such a phenomenon is found to have an effect on human language learning (Glenberg & Kaschak, 2002), which means human bodies have the potential to learn and can serve as an additional resource for learning (Klemmer, Hartmann, & Takayama, 2006). Researchers in the learning science, psychology and human-computer-interaction area have found that human bodies can facilitate learning for abstract concepts such as math (Howison, Trninic, Reinholz, & Abrahamson, 2011), politics (Dijkstra, Eerland, Zijlmans, & Post, 2014), time (Casasanto & Boroditsky, 2008) and even system control (Antle, Corness, & Droumeva, 2009). As a result, using bodies as an additional resource for learning can be beneficial for the abstract concept learning, especially the concepts people have never experienced.

Because the headway instructions that were conveyed through literal (through the brochures) or oral (through the driving instructor who teaches you) methods that are hard to just imagine if the learner has never experienced directly, they can be viewed as one of the abstract concepts, which were called symbols. Therefore, here an idea to solve the problem is, how to find a way for drivers to get better understand and learn about the concepts they have never exposed to and even understand better when they are exposing to the driving environment to reduce the chance to involve in a dangerous situation? Here the driver’s body can be a help.

In 1990, Harnad proposed the symbol grounding problem. This problem views human abstract concepts as a projection from the connections between human sensations. As the theory developed, Barsalou (2008) raised the grounded cognition from the interaction with the world in perception, sensation and motion. As a result, human bodies can serve as an additional resource to assist concept forming because the body can serve as a role to perform and receive the perception, sensation and motion to form the concept of “safe” headway for drivers. And the method of viewing the body as the role to perform and receive the perception, sensation and motion to assist forming is named embodied learning. Therefore, embodied learning can be a new way to help drivers to construct their own concept of “safe” time headway and increase safe driving performance.

However, although using embodiment can help to assist forming the concept of “safe” time headway based on the description of the symbol grounding problem and the grounded cognition theory, the mechanism of why embodiment can help to assist driver’s concept of “safe” time headway in their driving reality is still unclear. The theories described above were too abstract and far away from reality that may need to be given a more detail explanation in the driving environment. As it can see, one of the cores to view a headway as “safe” is that the drivers’ feeling of risk is increasing sharply after they reach the safe margin (see Figure 1.). Second, what drivers thinking about the safe distance they perceived is accurate enough of what the physical distance they are thinking. Third, for the drivers, the safe time headway they choose must fit their perceptual-motor skills (van Winsum, 1998) that match their reaction time, and make them feel confidence to keep a distance that will not induce their feeling of risk. As a result, if embodiment can help to improve these aspects then embodiment can help to improve performance of driver’s safe driving behavior.

It is possible that embodiment can help to improve driver's feeling of risk, perceptual accuracy, reaction time and make them feel more confidence to keep a distance. According to the Somatic Marker theory (A. Damasio, 2008; A. R. Damasio, 2004), some kinds of body states, emotions are resulted from mostly learnt environmental triggers. As a result, body states can bias action towards some certain outcomes, even if the individual does not have much awareness of them. In addition, Zero-Risk theory (Näätänen & Summala, 1974), the Driving Intensity model (Peltzman, 1975) and the Risk Avoidance theory (Fuller, 1984), also viewed that the awareness of being at risk in an accident will be a central factor in driver's decision making. The driver's body state can affect the action of outcomes involving risk in an accident even it is below the awareness of the driver. Additionally, the awareness of being at risk can affect the driver's decision while driving. So the body can serve as an additional factor to help drivers to avoid risk, solve the driving task and therefore reduce the chance of being in a collision.

Lewis-Evans, De Waard, and Brookhuis's experiment (see Figure 1.) has proved this effect, which means body states can help to define driver's safe margin. Once the driver past the short headway (at around 1.5 seconds), driver's feeling of risk, feeling of comfort and task difficulty will increase harshly, which means body feelings will become more effective in detecting risk in shorter headways. As a result, putting body feelings as one of the resources in driving to avoid risk and make driving more safety can help driver detect risk more easily to improve the safe margin control driving performance for the drivers, as well as helping them detect their own safe headway, especially in short headways.

Figure 3. Participant using her hand on the haptic device to perceive the slant of the hill (Proffitt, 2006).

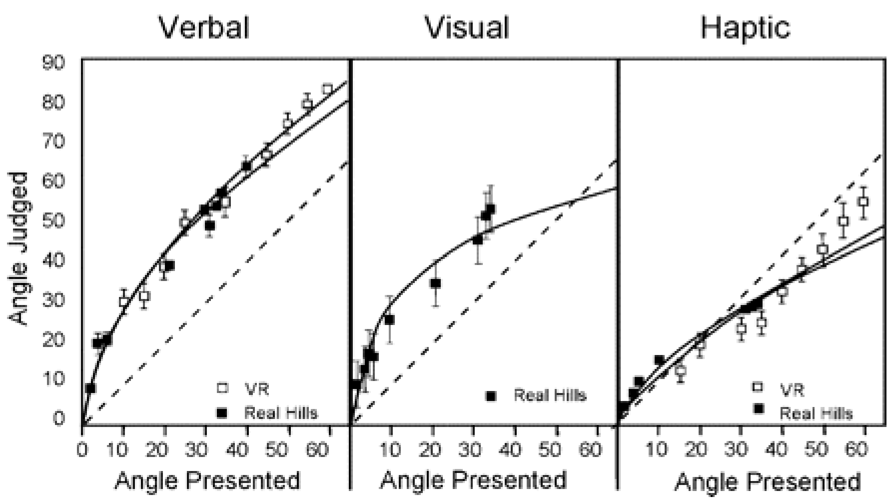

Figure 4. Using haptic device will help to increase the accuracy of hill slant perception (Proffitt, 2006).

Another aspect of viewing the headway as "safe" is the accuracy of driver's perceptual distance in vehicle following. If the accuracy is accurate enough for the drivers to perceive the actual physical environment, then it can help to reduce the mistake to perceive the safe distance and therefore reduce the chance to be at risk. As a result, the accuracy of the driver's perceptual distance can be one of the factors that helps to contribute to the construction of safe headway. As for embodiment in vehicle following in the accuracy perspective, there is an experiment that, if a person put their hands on a haptic device to perceive the slant of a hill (See Figure 3.) to increase the awareness of body existence, then the accuracy of the person to perceive the slant of the hill will increase (See Figure 4.). Another experiment in virtual reality area also discovered that using self-avatar to embodied participants's body awareness in the virtual environment can help to increase the accurate judgments of absolute egocentric distance (Mohler, Creem-Regehr, Thompson, & Bülthoff, 2010). As a result, if body awareness was involved in the perception of the physical environment, the accuracy of perceiving the physical environment will increase. Therefore, involving body awareness to make people aware their body state and body position in perceiving the distance in vehicle following can help to improve drivers' performance in headway accuracy.

Embodiment also affects reaction time and confidence in driving abilities to affect safe driving behavior. Because internal state-related factors like smoking marijuana (A. Smiley et al., 1985; A. M. Smiley et al., 1981), prolonged driving (Fuller, 1981) will lead to longer headway choice to make drivers themselves have more reaction time to prepare for avoiding a collision, embodiment can help drivers to focus on their inner state that help them to reduce their function of costs to perform the braking action (Proffitt, 2006). Such a reduction of function costs can result in less reaction time. For the driving abilities, body dimension which includes feeling united with the vehicle and knowing the exact position of the vehicle was found to be positively related with drivers' confidence in driving ability (Tronsmoen, 2008). Therefore, embodiment can be viewed as positively related with drivers' confidence of driving ability. As the body's involvement increases, driver's confidence in their driving ability is the higher.

Situational awareness, agent-environment system and embodied metaphor

During the process of detection and control for safe margins, drivers have to observe the outer environment to keep track of what is happening and adapt their behavior, which such a mental process is called situational awareness. Situational awareness is the human perception of a dynamic agent-environment system that people use to comprehend information elements in the environment, keep track of what's going on, then make predictions of the future to control the safety based on their current situation (Bedny & Meister, 1999). In such a process, the driver must comprehend and integrate the meaning of information elements from the changing environment, then update their mental model to integrate their self-awareness into the environment to finish the environment control, which becomes an agent-environment system (Stanton, Chambers, & Piggott, 2001). In this situation, the driver must be conscious the outer environment not just simply foreign objects and his/her own experience of the outer environment to reveal the meaning of the outer environment for driver's subjectivity (Zahavi, 2002). Because based on embodied theories (Proffitt, 2006; A. D. Wilson & Golonka, 2013), body can serve as an original tool to experience the world (both mental model and body states), using embodiment methods to induce driver's self-awareness, embodied themselves into the environment can help the driver to update their mental model from their body experience, and finish updating situational awareness to form their own meaning of safe margin control.

This kind of learning effect has been proved in the multimedia learning area, which was called Personalization Effect (Mayer et al., 2004). When using the pronoun to refer student's self-awareness in the instructions (e.g. "During inhaling, [your] diaphragm moves down creating more space for [your] lungs."), students scored higher in the transfer test in learning human respiratory systems, which is resulted from students' deep cognitive process during learning and therefore foster meaningful learning. As a result, using pronouns to induce driver's self-awareness can help to enhance the situational awareness to transfer experience from learning instructions to the changing environment while driving, which resulted in better safe margin control behavior performance.

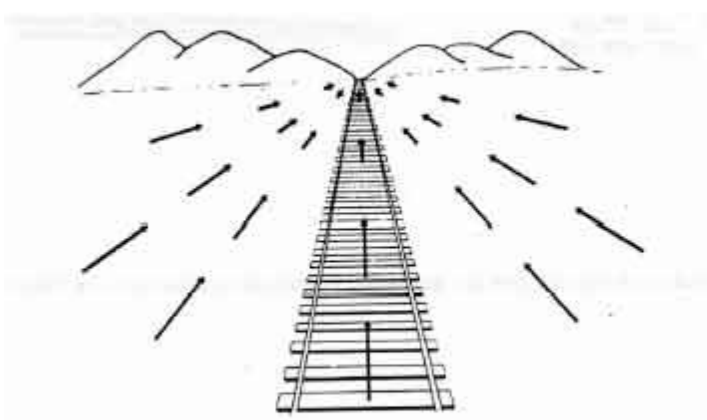

Figure 5. The optic flow
(http://www.simplypsychology.org/perception-theories.html)

To transfer the Personalization Effect into driving area, there is an additional factor to be concerned. As it can see, when driving, drivers are immersing in a three-dimension environment called the optic flow (see Figure 5.). Optic flow can be viewed in two directions that come through the drivers. One is that, drivers can view themselves as an agent, controlling their vehicle moving towards objects or vehicles ahead on the road, which is called the ego-moving metaphor schema (Boroditsky, 2000). The other is that, drivers can view themselves just sitting in their vehicle, being static, then waiting other objects from outer environment on the road to flow through themselves while driving. This is called the time-moving metaphor schema (See Figure 6.). This serves as the traditional instruction to educate drivers to use outer environment elements to perceive

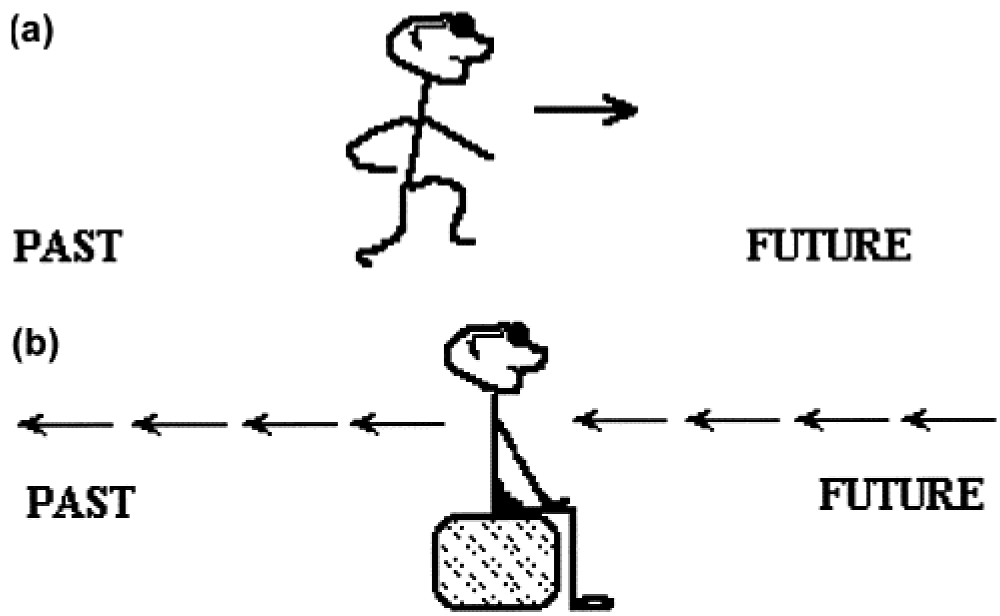

Figure 6. Ego-moving schema (a) and time-moving schema (b) (Boroditsky, 2000).

the safe time headway. Compared to the time-moving metaphor scheme, ego-moving metaphor schema emphasizes embodied driver's self-awareness as an agent in the environment to move towards the objects, which increase the awareness of the body's existence. In Boroditsky's experiment, a statement used the pronoun 'me' with a picture pointing the optic flow direction from the observer to the outer environment was used to prime the ego-moving schema in a two-dimension view (See Figure 7.). This design corresponds to Mayer's Personalization Effect. As a result, using ego-moving metaphor schema in driving can help drivers form their own concept of safe headway, improve their safe driving behavior and reduce the risk in causing in a collision. And to use such kind of metaphor from Boroditsky's experiment with a combination of Personalization Effect, what is needed to do is to transfer the two-dimension ego-moving metaphor into three-dimension.

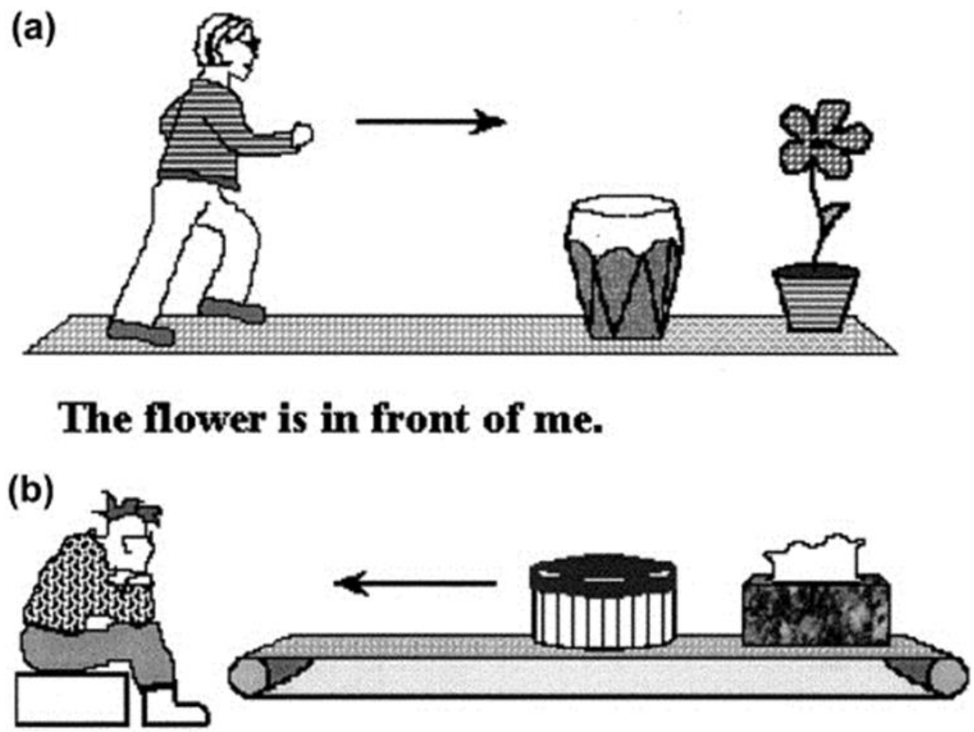

Figure 7. Ego-moving schema (a) and time-moving schema (b) in spatial form (Boroditsky, 2000).

Current hypotheses and proposed study

Embodied self-awareness can be helpful to improve participant's safe headway concept learning in applied settings in car-following model. According to embodied theories, human perception triggered by the environment is the human body's reflection of the environment based on the body's inner state to help the human solve tasks within the environment (A. D. Wilson & Golonka, 2013). Such a mechanism allows humans to limit resources from both environment and their body to reach the optimal performance and interact with the environment (Proffitt, 2006). This means that human action is resulted from human perception that serves as a cue for human to solve tasks to ensure human living based on both environment and body resources. As a result, participant's driving behavior to avoid risks can be a result of body states and feelings (Lewis-Evans et al., 2010). This effect will begin to increase once the time headway reaches a critical threshold at around 2 seconds, which can be defined as the safe margin. In addition, according to the Situational Awareness (Stanton et al., 2001) and Personalization Effect (Mayer et al., 2004), using pronouns to induce self-awareness to embody the driver in the environment can help to transfer previous experience into the current environment. But whether inducing driver's self-awareness to focus on themselves while reducing their attention in outer environment will reduce their situational awareness is still unclear. This must be evaluated through a falsifiable study. As a result, the goal of this study is to estimate whether inducing body self-awareness during driving can improve situational awareness and other safe driving behaviors in both learning and applied settings. The following hypotheses and predictions are proposed to provide evidence for this possibility.

H: Because embodied self-awareness can help drivers to integrate both environment and body resources to solve problems triggered by the environment to avoid risk, inducing embodied self-awareness when driving can help to improve safe driving behavior.

According to the hypothesis, the prediction here will be:

1_a: If embodied metaphor impacted situational awareness as proposed, then a larger number of elements will be reported in the embodied metaphor condition is activated than when time metaphor condition.

1_b: If embodied metaphor separately impacted feeling of risk, task difficulty, feeling of comfort and confidence of driving ability as proposed, then a higher ratings of feeling of risk, task difficulty, feeling of comfort and confidence of driving ability will be reported in the embodied metaphor condition is activated than when time metaphor condition.

$1_{c:}$ If embodied metaphor separately impacted absolute estimation error, related estimation error and reaction time as proposed, then a lower data of absolute estimation error, related estimation error and reaction time will be reported in the embodied metaphor condition is activated than when time metaphor condition.

CHAPTER 3

METHODS

Participants

A totally of 43 participants were recruited, among which 3 were left due to the report of suffering Motion Sickness or feeling discomfort in the study. Thus, a totally of 40 participants were counted in the study. Among the participants, 30 were males, 9 were females, 1 people choose "I do not wish to say". The participants' ages ranged from 18 to 31 years (M = 21.30, SD = 3.90). All participants have driving experience. The participants' driving experience ranged from 0[1] to 12 years (M = 3.51, SD = 3.181).

Design

The experiment was employed as a multiple treatments and controls with pretest design. There are two treatments. One was ego-moving metaphor treatment. This treatment used personal pronouns in the instruction to prime participants to drive the simulate vehicle approaching towards the lead vehicle as engaging body awareness into the vehicle driving process. Another was time-moving metaphor treatment. This treatment used object-based (not include any personal pronouns) instruction to prime participants drive the simulate vehicle facing the lead vehicle to slow down towards them as not engaging body awareness into the vehicle driving process. In the control condition, participants received non-priming materials that took the same time as the ego-moving and time-moving treatment. Participants did the pretest first, then received priming based on different conditions, then took the posttest again. During both the pretest and posttest, participants were asked to take

[1] 0 years means participants just received the driver's license within one year.

a car-following task. This car-following task asked participants to follow the lead vehicle in a 2-seconds headway, then brake the panel when the lead vehicle began to slow down. The dependent variables were situational awareness, feeling of risk, task difficulty, feeling of comfort, confidence of driving ability, reaction time, constant error and variable error.

Materials

Priming Materials. Because the ego-moving metaphor and time-moving metaphor materials Boroditsky used in the experiment (See Figure 7.) were displayed in two-dimension, to make the priming materials more fix in the three-dimension driving environment, a PowerPoint with the pictures demonstrating the car-following scenario was displayed in the priming section.

Ego-moving metaphor. Because ego-moving metaphor views people as the agent to approach the objects, ego-moving metaphor was designed to prime participants' body self-awareness when driving the simulate vehicle to approach to the lead vehicle. This treatment used personal pronouns instruction with three arrows in the image of environment pointing towards the lead vehicle from participants, with the lead vehicle image in the PowerPoint becoming larger as the presentation progresses to induce the priming effect. For example, when a lead car appeared on the screen, the instruction "When a car is slowing, it will become closer to me. I need to determine the headway time between myself and the car" was displayed, accompanied by the arrows pointing the lead vehicle from participants. The full script is in Appendix A.

Time-moving metaphor. Because time-moving metaphor views people being static, waiting objects moving towards them, time-moving metaphor was designed to prime using object-based view. The participants sitting in the simulate vehicle, then wait the lead vehicle slowing down to approach them. This treatment used object-based (not include any personal pronouns) instruction, the larger and larger lead vehicle image in the PowerPoint, and three arrows in the image of environment pointing towards participants from the lead vehicle to induce the priming effect. For example, when a lead car appeared on the screen, the instruction "When a car is slowing, environmental elements can be used to determine the headway time." was displayed, accompanied by the arrows pointing the participants from the lead vehicle. The full script is in Appendix A.

Control. Because control condition needed to be neutral that neither the participants are driving the simulate vehicle to approach to the lead vehicle nor the lead vehicle are slowing down to approach to the simulate vehicle, the instruction in the control condition just neutrally describe that the distance between two vehicles are decreasing, with no arrows in the image of the environment and the same lead vehicle image. These did not induce any kinds of vehicle movement, which help to maintain the control effect. For example, when a lead car appeared on the screen, the instruction "When a car is slowing, the distance between two cars is decreasing. The headway time needs to be determined." was displayed, accompanied by no arrows in the image. The full script is in Appendix A.

All materials were primed on an iPad Mini 2 placed on a holder in front of the participant in the simulator cab in the priming section. When priming, the participants were asked to keep the posture as driving cars, and read aloud the instruction on the PowerPoint. The experimenter would help to control the slides so that the participants would read the instruction smoothly. The participants needed to press the brake panel to induce the embodied effect for the post-test when the instruction asked them to do so.

Car-following task. Before the beginning of the formal car-following task, there was a practice section for the participants to practice following the lead car in a 2-seconds headway. There would be green number on the left-up corner of the screen presenting the current time headway between the lead vehicle and the participant's vehicle. Participants were asked to follow the lead vehicle at a 2-seconds time headway as accurate as possible using the green number as assistance, and to brake to avoid a collision when the lead vehicle slows down, then recover to follow the lead vehicle in a 2-seconds time headway when another lead car appear again. When the practice section ended, participants were asked to do the formal car-following task. The procedure and the requirement of the formal car-following task was almost the same as the practice one but have a longer running time.

At the beginning of the following task, a vehicle would appear on the right lane ahead of the participant's vehicle. When the participant accelerated their car, the lead car would begin to accelerate to a random speed. When passed some certain points on the driving map, the lead vehicle would suddenly slow down to 2mph, then accelerate to a random speed again. During the procedure, participants needed to follow the lead vehicle in a 2-seconds headway and to brake to avoid a collision when the lead vehicle slowed down. Each participant performed a totally of 8 trials in the car-following task. During the task, the headway-time between the two vehicles, and reaction time for the braking were measured by the system.

Apparatus. The DS-600c Advanced Research Simulator by DriveSafety™ was used for the experiment. This simulator is comprised of a 300 deg wraparound display, a full-width automobile cab (a Ford Focus) and a motion platform. Tactile and proprioceptive feedback cues were provided via dynamic torque feedback from the steering wheel and vibration transducers mounted under the driver’s seat. The motion platform provided coordinated inertial cues for the onset of longitudinal acceleration and deceleration. The data recording rate is 60 Hz.

There were two-lane in the three-dimension virtual environment. At the beginning of the driving test phrase, the participant’s vehicle was set in the right lane. Participants will be asked to practice the driving simulator to get familiar to control it, then the participants were asked to take the headway following task.

Reaction time. Reaction time was measured as the interval between the moment the lead vehicle starts to brake and the release of the accelerator pedal by the driver (van Winsum, 1998). This data was given by the DriveSafety™ system. The shorter the reaction time, the better driving performance the participants have.

Constant Error. Because the measured headway time from the study were all larger than 2-seconds, which means that there were means distinguishing the direction of the headway time accuracy. The headway time accuracy here was defined as the constant error between the driver’s perceptual distance and the actual physical distance. These data were calculated from the headway time from the DriveSafety™ system, which used the drivers’ perception headway time to minus the 2-seconds headway time. The lower the constant error, the higher time accuracy the participants have, the better driving performance the participants have.

Variable Error. Variable error was defined by the deviation scores from the DriveSafety™ system that describes the participants’ performance to keep their headway time stable. This data was given by the DriveSafety™ system. This was an added variable beyond the literature review because it was given by the set system. The lower the score, the lower the participant's performance deviation, the better driving performance the participants have.

Change Scores of Reaction Time, Constant Error and Variable Error. These scores are defined by how much scores were changed before and after the treatment in the pre-test and post-test. These scores were calculated using pre-test scores to minus post-test scores that come from the above variables. The higher the change score, the higher performance change the participants have.

Situational awareness. Situational awareness was measured using a query method (Endsley, 1988a, 1988b) in which the participants were asked to answer relevant questions about the driving scene. In this experiment, a total of seven SA questions were asked that pertained to the car-following task (e.g., "How many times have the lead car slowed down?" "Can you pass the left lane legally?"). This method was used because it can help better translate SA instrument into a more measurable one. The SA variable was measured by the total correct answers the participant has responded. When the participant has answered one correct answer, then the total SA scores were calculated as "one". In addition, the numbers of environmental elements participants recalled from Question Five (SA5) "What was the scenery of the foreground?" and the deviation scores away from the correct answers from Question Seven (SA7) "How many cars passed you going in the opposite direction?" were calculated separately for detail analysis. The higher score in the total situational awareness survey and SA5, the lower score in SA7, the better driving performance the participants have.

The whole part of the situational awareness question can be seen in Appendix B.

Feeling of Risk, Feeling of Task Difficulty and Feeling of Comfort. Feeling of risk, feeling of task difficulty and feeling of comfort will be measured by the 7-point Likert scales as shown in Appendix B. This survey is retrieved from Lewis-Evans, De Waard, and Brookhuis's study (2010). The higher score in the feeling surveys, the better driving performance the participants have.

Confidence of Driving Ability Test. Confidence of driving ability is measured by three questions in 7-point Likert scales as shown in Appendix B. The survey was retrieved from Matthews and Moran's study (1986). The total score of all three questions was calculated as the summary scores for data analysis. The higher score in the feeling surveys, the better driving performance the participants have.

Demographics. Surveys included participant's gender, age, and the amount of time they have had a valid driver's license were measured as the demographics. The demographics were measured at the end of the study and at the end of the survey to maintain an immersive environment to keep the measuring effect of the surveys above. The whole part of the demographics can be seen in Appendix B.

The situational awareness, feeling of risk, feeling of task difficulty, feeling of comfort and confidence of driving ability were served as self-report surveys, as well as the demographics, were measured through an iPad Mini 2 placed on a holder in front of the participant in the driving simulator using Google Forms.

Motion Sickness Questionnaire. The Motion Sickness Questionnaire was used to find out if the participant was susceptible to suffer motion sickness during the study. This was used to avoid foreseeable risks, discomforts, or inconveniences related to participation in the study. Participants that score higher than 20 were suggested not to participate in the study. The Motion Sickness Questionnaire was implemented before the experiment started using the paper-based questionnaire. The whole questionnaire can be seen in Appendix C.

Procedure

In the first phrase, the experimenter will introduce the overall procedure to the participants, then the participants will be asked to complete the inform consent form. After that, the participants were asked to finish the Motion Sickness Questionnaire to make sure they would not suffer motion sickness during the experiment. This part of the experiment took about 10 minutes.

After that, the participants were asked to practice in the driving simulator for about 5 minutes. After the practice section, the participants would have a 2-minutes break time to rest. Then participants were asked to finish the car-following task. During this task, the participant's reaction time and headway-time, as well as variable error were collected by the system as the baseline. The task lasted for about 8 minutes. After this, the participants would have a 2-minutes break time to rest to prepare for the next car-following task again. The total procedure of the task took for about 17 minutes to complete.

In the second phrase, participants were randomly assigned to either the ego-moving condition, time-moving condition or the control condition. In the ego-moving condition, participants were primed using the ego-moving priming materials. Participants in the time-moving condition were primed using time-moving priming materials. Participants in control condition were primed using control priming materials on the screen. The priming procedure took about 5 minutes.

After this, participants were asked to finish the car-following task again. Participant's reaction time and headway-time were measured by the system again as the post-measurement. Then the participants were asked to finish the survey that included situational awareness, feeling of risk, feeling of task difficulty, feeling of comfort, confidence of driving ability assessments and demographics as the post-test. This procedure took about 20 minutes.

After the experiment finished, the participants were debriefed. The experiment totally took approximately sixty minutes per participant.

CHAPTER 5

RESULTS

Data Analysis Introduction

Because driving experience was considered as an impact for the variables, ANCOVA analysis with driving experience as co-variance were chosen to analyze the data. The following section introduce the results of different variables.

Situational Awareness, Feelings of Risk, Task Difficulty and Comfort, and Confidence of Driving Ability. A series of ANCOVA analysis was conducted for the situational awareness, feelings of risk, feeling of task difficulty, feeling of comfort and confidence of driving ability (the self-report variables) to determine if there were any significances among conditions. All means and standard deviations can be found in Table 1 (N means all valid data). However, there were not any significant differences in these variables in each condition. This means that using ego-moving instruction or embodied instructions did not have any impact on situational awareness, feelings of risk, feeling of task difficulty feeling of comfort and confidence of driving ability.

Table 1

Means and Standard Deviations for the Self-Report Variables.

	N	Ego-moving M (SD)	Time-moving M (SD)	Control M (SD)
Situational Awareness	37	5.25 (.62)	5.69 (.85)	5.58 (.79)
Foreground Recall	39	1.38 (.87)	1.38 (.65)	1.54 (1.05)
Car Deviation	34	1.58 (1.00)	1.55 (.69)	1.55 (1.29)
Feelings				
Risk	39	3.15 (1.73)	3.69 (1.32)	3.69 (1.75)
Difficulty	39	4.31 (1.11)	4.31 (1.18)	3.77 (1.64)
Comfort	39	4.23 (1.48)	4.15 (1.57)	3.92 (1.66)
Confidence	39	15.46 (3.50)	13.00 (4.22)	14.08 (4.44)

Post Reaction Time, Post Constant Error and Post Variable Error. To determine if there were significant differences on the pre-test measures of reaction time, constant error and variable error, a series of ANCOVA was conducted. Results showed that there were not any significant differences in the pre-tests. All means and standard deviations can be found in Table 2 (N means all valid data). Therefore, a series of ANCOVA analysis were conducted for the post measures of reaction time, constant error and variable error. Results showed there was not any significant difference for the post-reaction time and variable error. However, there was the significant difference for the constant error with a medium effect size, F (2, 34) = 4.412, p = .02, η_p^2 = .206). LSD post hoc tests indicated that participants with time-moving metaphor instruction were significantly underperformed participants receiving control instruction with a large effect size (M_d = .290; p = .006; *Cohen d* = 1.102) in the post constant error, while participants with ego-moving metaphor outperformed participants receiving time-moving condition but just have a marginal significance with a medium effect size (M_d = .172; p = .070; *Cohen d* = .650). Participants receiving ego-moving instruction did not have any significance with participants receiving control condition but have a large effect size (M_d = .118; p = .220; *Cohen d* = 1.079). This means that the driver's accuracy in the ego-moving group has the same level of performance as the control group, but hurts in the time-moving group.

Table 2
Means and Standard Deviations for Participant's Reaction Time, Constant Error, Variable Error in Each Instruction Condition.

	Reaction time		Constant Error		Variable Error	
	Pre-test (N=34)	Post-test (N=29)	Pre-test (N=39)	Post-test (N=38)	Pre-test (N=39)	Post-test (N=38)
Ego-moving	.90 (.30)	0.87 (.19)	0.83 (.20)	0.79 (.12)	0.25 (.07)	0.24 (.03)
Time-moving	1.08 (.30)	1.00 (.24)	0.94 (.30)	0.96 (.35)	0.22 (.09)	0.20 (.07)
Control	0.94 (.36)	0.98 (.23)	0.81 (.20)	0.68 (.08)	0.24 (.06)	0.29 (.18)

Change Scores of Reaction Time, Constant Error and Variable Error. A series of ANCOVA analyses were conducted on the change scores of reaction time, constant error and variable error to determine if there were any significances among conditions. All means and standard deviations can be found in Table 3 (N means all valid data). There was not any significant difference in the change score of reaction time and constant error. However, there was a marginal significant difference for the variable error with a medium effect size, F (2, 34) = 3.222, p = .052, η_p^2 = .159. LSD post hoc tests indicated that participants with time-moving metaphor instruction significantly outperformed participants receiving control instruction with a medium effect size (M_d = .125; p = .019; *Cohen d* = .574), while participants in ego-moving metaphor marginally outperformed participants receiving control instruction with a medium effect size (M_d = .090; p = .073; *Cohen d* = .471). Participants receiving time-moving instruction did not have any significance with participants receiving the ego-moving condition and with a small effect size (M_d = .035; p = .461; *Cohen d* = .24). This means that using embodied instructions can help to improve variable error for the safe headway concept learning.

Table 3

Means and Standard Deviations for the Change Scores

	N	Ego-moving M (SD)	Time-moving M (SD)	Control M (SD)
Chng of RT	27	.13 (.23)	.13 (.38)	.02 (.26)
Chng of HT-acc	38	-0.03 (.25)	0.02 (0.14)	-0.13 (.21)
Chng of PC	38	0.01 (.06)	0.03 (.10)	-0.05 (.17)

CHAPTER 6

DISCUSSION

The current study hypothesized that an ego-moving metaphor can help drivers to integrate both environment and body resources to solve problem triggered by the environment to avoid risk. If so, then inducing embodied self-awareness when driving can help to improve safe driving behavior. In accordance with the hypotheses, driver receiving embodied training in headway learning will report a higher situational awareness (prediction 1_a), higher feeling of risk, task difficulty, comfort, and confidence of driving ability (prediction 1_b). While drivers should perform at a lower constant error and reaction time in breaking performance (prediction 1_c) when primed with an ego-moving metaphor during training.

The current study found some support that embodied cognition can support driver training. However, the overall support for the ego-moving metaphor predictions were limited. First, the current study did not support prediction 1_a: participants did not report a significant difference in situational awareness among conditions. In the situational awareness measurement, participants received an average of five score with similar standard deviations. This means that drivers receiving different instructions did not affect their attention to the outer environment, that embodiment did not help drivers to update their mental model from the body experience with environment compared to the control condition. However, because participants across conditions reported almost the same high scores (5-points), the non-significant differences for situational awareness may come from the ceiling effect of the limited situational awareness questions or the limited information elements in the driving environment. As a result, driving environment with more environmental elements that help to report more information of the environment can be used to dig out more effects for the further study.

Second, the current study did not support prediction 1_b: participants did not report significant differences in feeling of risk, task difficulty, feeling of comfort and confidence of driving ability. In Lewis's experiment (2010), participants were asked drive at a series of shorter headways and to report their feeling of risk, feeling of comfort and task difficulty in each headway times. What their research found out was that closer headway that induce sharply higher feeling scores can help to define the safe headway time, while did not compare whether using different kinds of body awareness induction can help to make a difference in safe headway margin decision. Because the current study compared the difference of different training instruction that asked participants to follow at the same headway, while not compared the effect of the length of the headway time, if adding the length of the headway time as an additional variable for the study, then a clear effect of using different training instructions in safe headway learning could be seen.

For the confidence of driving ability, although based on the previous study that, feeling body united with the vehicle was positively related with drivers' confidence in driving ability (Tronsmoen, 2008), confidence in driving ability was found to negatively related to feeling of risk (Cestac, Paran, & Delhomme, 2011; Rosenbloom, 2003). This means that, if feeling of risk, (feeling of task difficulty and comfort) are higher in embodied conditions, confidence in driving ability may still get higher if the prediction works, but its score differences among conditions may get less distinguishable, which could make it an insensitive index to measure the differences of learning scores among instructions.

However, the current study did find some evidence to support the hypotheses. It was observed that using ego-moving metaphor instruction can help drivers have a more accurate safe headway-time while following cars, while using time-moving metaphor can help to improve participants' performance stability. This means that the results provided support for part of the prediction 1_c: participants receiving embodied metaphor will have a lower data score of constant error and reaction time, the lower the data, the better the participants performed. For the constant error that represents the headway time accuracy first, such a result can be an analogy that that using physical feedbacks like haptic device (Proffitt, Bhalla, Gossweiler, & Midgett, 1995) and self-avatar (Mohler et al., 2010) to induce the awareness of body existence will increase people's perception accuracy with the real world, because using the pronoun "I" can help to inform participants that they, with their body, were presented in the present of the driving cab in an environment when they were driving. This means that human's awareness of the "existence" of their own body can serve as a reference to evaluate their position with the physical environment. This phenomenon helps human to increase their accuracy in evaluating physics-based features (like slant and distance) in the environment, which also corresponded with the embodied theory (Proffitt, 2006). As a result, the findings of using ego-moving instruction improve driver's constant error serves a positive impact in the hypotheses.

Additionally, variable error also provide evidence that using embodied-related instruction can help to increase driving performance stability. This means that if viewed body as a resource to interact with the environment (Barsalou, 2008; A. D. Wilson & Golonka, 2013; M. Wilson, 2002), than it can help to make people's behavior more stable to avoid making behaviors come into hazard to induce accidents (Brown, Willis, & Prussia, 2000). Such a finding also serves a positive impact on the current hypotheses.

To summarize, this study found out that using embodied-related instruction can help to provide a new method to help drivers perform more accurate and stable headway concept related to the safe time headway. These can help to reduce the potential risk of drivers to crash into a car accident, which increases the traffic safety. As it can see, embodiment theories views body as a resource to interact with environment to learn (M. Wilson, 2002). If participants' performance increase in the accuracy and behave more stable in embodied instructions, then participants reflect a more accurate and stable perception with their actual world (Proffitt, 2006), which reflect a stronger learning outcome compares to the traditional learning methods. Such an effect supports embodied theories' assumption that human mind, as well as the languages and the concepts, are grounded in mechanisms that involve for interacting with the environment (Barsalou, 2008; M. Wilson, 2002). Additionally, because time headway is a quantity concept (2-seconds), it is a concept to represent the physical distance between vehicles based on vehicles' speed. The current study found that, using an embodiment effect to increase sensorimotor involvement will increase driver's physical perception of a quantity, and abstract concept (2-seconds). This result is also in line with the magnitude theory, the processing of time, space and quantity shared a same cortical metrics, and it is this kind of process that facilitates the formation of an abstract concepts (2-seconds that presented by the symbols) using from the input of sensorimotor consequences of processing magnitude (Walsh, 2003).

Additionally, this study also transfer Boroditsky's (2000) two-dimensional ego-moving and time-moving metaphors into a three-dimensional environment, and prove their effects in embodied learning. Such a transfer provides a way to prime ego-moving and time-moving schema from two-dimension to three-dimension, which adds a new dimension to the study of Boroditsky's metaphoric structuring theory. This new dimension of ego-moving and time-moving metaphors priming can also serve as a new method to increase participant's accuracy and performance stability in virtual world-based research except for just using self-avatar (Ries, Interrante, Kaeding, & Anderson, 2008).

Limitations and Future Study

Although the study found that using embodied-related instruction facilitates driver's safe headway learning, there are still some limitations in the study. The following section discusses about the limitation of the current study in three areas of validity: Internal validity, power issues (statistical conclusion validity), and generalizability (external validity).

For the internal validity, the following-task's settings to trigger participants' braking performance is not precise enough. When the lead car began to stop in the task, participants just sometimes follow too far away that do not need an immediate stop to trigger the breaking response. Therefore, a portion of data was missing in reaction time compared to other variables, which may have caused the non-significant effects in breaking performance. Second, the gradations to measure situational awareness and feeling of risk, task difficulty and discomfort is not sensitive enough to detect differences due to the original limited gradation scale. The original scale of the situational awareness, feeling of risk, task difficulty and comfort just have 7-points. If using a scale with a more gradation, like the NASA Task Load Index that has 21 gradation on each scale (Hart, 2006), then a better discrimination of the impact of each condition may be found.

For the power (statistical conclusion validity), this study suffered from a small sample size (a totally 40 valid data were collected). So, the underpowered nature of the study raised the possibility that some of the marginal difference and analyses approaching significance could be real effects. So, the current interpretation is at risk of making a type II error. Given the observed effect sizes (i.e. the marginally significant effect of change score of variable error with a large effect size of $\eta_p^2 = .159$), it is highly plausible that a larger simple size would have produced significant effects for the change score of variable error. So, future studies should try to collect enough data to avoid the risk of making type II error.

Although driving experience was used as a covariant in all analysis, this could still limit the generalizability of the findings. Participants that recruited from the study were not all novice drivers. Some of them have rich driving experience, which may lead to under-interpreting the impact of using different kinds of instructions. If there is a possible opportunity to recruit novice drivers for the study, then a clear impact of how using different metaphor instruction affects driver's safe headway concept learning can be seen.

Finally, for the problems to generalizability (external validity), there still two issues to generalize the findings of the study – the issue to explain the concept of "safe" in safe headway training and the issue to transfer study findings from a simulate environment to the reality.

First, for generalizability (external validity) area, it is not clear whether following a more close and accurate headway time to 2-seconds, or a farther and less accurate headway time to 2-seconds is safer to the drivers. If drivers follow a more close and accurate 2-seconds headway time, then there will be less zone for drivers to react to brake to avoid a collision compared to a farther and less accurate 2-seconds time headway. However, the purpose of the study is that, to educate driver to have the concept of safe margin, which means that the 2-seconds headway time is the closest margin. Once they get closer than 2-seconds, they will not be much safer as original. As it can see, the current study found that drivers used ego-moving instruction perform to follow a headway time more close and accurate to the 2-seconds, while drivers in the control condition followed at a headway time which was farther and less accurate than the to the 2-seconds time headway, this means that drivers receiving ego-moving instruction have a deeper understand of the 2-seconds time headway, while it is not clear that following such a closer and more accurate means “safer” to the driver. As a result, here will be an issue to generalize the findings to safe headway training.

Additionally, there is still an issue to transfer the current findings to the real and changing driving environment. As it can see, the current study is experimented in a driving simulator, which is resulted from examining a simple car-following model. Although using the driving simulator can provide a most similar environment for driving study, it is still lacking the full fidelity as the real environment (Kemeny & Panerai, 2003). For example, the image display frequency of the driving simulator may be different from the reality that caused some behavior errors to transfer the learning effect in embodied instructions from simulation to reality application. In addition, because the study just using the simple car-following model to research about the effect of embodied learning, the real-world traffic environment may be more complex. If want to apply embodied learning in a more practical education way except for just using it to learn the safe headway concept, then further studies considering the complexity of traffic systems should be held.

Conclusion

This study investigated embodiment effects in driver's safe headway concept learning and found a modest effect for using embodied self-awareness instruction can encourage safer and more consistent driving behaviors. In that, drivers had a better headway-following accuracy for the 2-seconds safe time headway, and have the effect of increasing the performance stability during the task. Such a finding provides supports for embodied cognition theory (Barsalou, 2008; Proffitt, 2006; A. D. Wilson & Golonka, 2013), which provides the theory with another practical application. This result can serve as a further direction for future embodied cognition research to determine practical applications.

REFERENCES

Antle, A. N., Corness, G., & Droumeva, M. s (2009). What the body knows: Exploring the benefits of embodied metaphors in hybrid physical digital environments. *Interacting with Computers, 21* (1), 66-75.

Barsalou, L. W. (2008). Grounded cognition. *Annu. Rev. Psychol., 59*, 617-645.

Bedny, G., & Meister, D. (1999). Theory of activity and situation awareness. *International Journal of cognitive ergonomics, 3* (1), 63-72.

Boroditsky, L. (2000). Metaphoric structuring: Understanding time through spatial metaphors. *Cognition, 75* (1), 1-28.

Brown, K. A., Willis, P. G., & Prussia, G. E. (2000). Predicting safe employee behavior in the steel industry: Development and test of a sociotechnical model. *Journal of Operations Management, 18* (4), 445-465.

Casasanto, D., & Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition, 106* (2), 579-593.

Cestac, J., Paran, F., & Delhomme, P. (2011). Young drivers' sensation seeking, subjective norms, and perceived behavioral control and their roles in predicting speeding intention: How risk-taking motivations evolve with gender and driving experience. *Safety science, 49* (3), 424-432.

Damasio, A. (2008). *Descartes' error: Emotion, reason and the human brain*: Random House.

Damasio, A. R. (2004). *Looking for Spinoza: Joy, sorrow, and the feeling brain*: Random House.

Dijkstra, K., Eerland, A., Zijlmans, J., & Post, L. S. (2014). Embodied cognition, abstract concepts, and the benefits of new technology for implicit body manipulation. *Frontiers in psychology, 5*.

Endsley, M. R. (1988a). *Design and evaluation for situation awareness enhancement.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Endsley, M. R. (1988b). *Situation awareness global assessment technique (SAGAT).* Paper presented at the Aerospace and Electronics Conference, 1988. NAECON 1988., Proceedings of the IEEE 1988 National.

Fuller, R. (1981). Determinants of time headway adopted by truck drivers. *Ergonomics, 24* (6), 463-474.

Fuller, R. (1984). A conceptualization of driving behaviour as threat avoidance. *Ergonomics, 27* (11), 1139-1155.

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention, 37* (3), 461-472.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic bulletin & review, 9* (3), 558-565.

Hart, S. G. (2006). *NASA-task load index (NASA-TLX); 20 years later.* Paper presented at the Proceedings of the human factors and ergonomics society annual meeting.

Homburger, W. S., Keefer, L. E., & Mcgrath, W. R. (1982). *Transportation and traffic engineering handbook.*

Howison, M., Trninic, D., Reinholz, D., & Abrahamson, D. (2011). *The Mathematical Imagery Trainer: from embodied interaction to conceptual learning.* Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.

Johnson-Glenberg, M. C., Koziupa, T., Birchfield, D., & Li, K. (2011). *Games for learning in embodied mixed-reality environments: Principles and results.* Paper presented at the Proceedings of the 7th international conference on Games+ Learning+ Society Conference.

Kemeny, A., & Panerai, F. (2003). Evaluating perception in driving simulation experiments. *Trends in cognitive sciences, 7* (1), 31-37.

Klemmer, S. R., Hartmann, B., & Takayama, L. (2006). *How bodies matter: five themes for interaction design.* Paper presented at the Proceedings of the 6th conference on Designing Interactive systems.

Lewis-Evans, B., De Waard, D., & Brookhuis, K. A. (2010). That's close enough—A threshold effect of time headway on the experience of risk, task difficulty, effort, and comfort. *Accident Analysis & Prevention, 42* (6), 1926-1933.

Matthews, M. L., & Moran, A. R. (1986). Age differences in male drivers' perception of accident risk: The role of perceived driving ability. *Accident Analysis & Prevention, 18* (4), 299-313.

May, A. D. (1990). *Traffic flow fundamentals*.

Mayer, R. E., Fennell, S., Farmer, L., & Campbell, J. (2004). A Personalization Effect in Multimedia Learning: Students Learn Better When Words Are in Conversational Style Rather Than Formal Style. *Journal of Educational Psychology, 96* (2), 389.

Mohler, B. J., Creem-Regehr, S. H., Thompson, W. B., & Bülthoff, H. H. (2010). The effect of viewing a self-avatar on distance judgments in an HMD-based virtual environment. *Presence: Teleoperators and Virtual Environments, 19* (3), 230-242.

Näätänen, R., & Summala, H. (1974). A model for the role of motivational factors in drivers' decision-making∗. *Accident Analysis & Prevention, 6* (3), 243-261.

Peltzman, S. (1975). The effects of automobile safety regulation. *The Journal of Political Economy*, 677-725.

Proffitt, D. R. (2006). Embodied perception and the economy of action. *Perspectives on psychological science, 1* (2), 110-122.

Proffitt, D. R., Bhalla, M., Gossweiler, R., & Midgett, J. (1995). Perceiving geographical slant. *Psychonomic bulletin & review, 2* (4), 409-428.

Ranney, T. A. (1999). Psychological factors that influence car-following and car-following model development. *Transportation research part F: traffic psychology and behaviour, 2* (4), 213-219.

Ries, B., Interrante, V., Kaeding, M., & Anderson, L. (2008). *The effect of self-embodiment on distance perception in immersive virtual environments.* Paper presented at the Proceedings of the 2008 ACM symposium on Virtual reality software and technology.

Risto, M., & Martens, M. H. (2013). Time and space: The difference between following time headway and distance headway instructions. *Transportation research part F: traffic psychology and behaviour, 17*, 45-51.

Rosenbloom, T. (2003). Risk evaluation and risky behavior of high and low sensation seekers. *Social Behavior and Personality: an international journal, 31* (4), 375-386.

Smiley, A., Moskowitz, H. M., & Ziedman, K. (1985). *EFFECTS OF DRUGS ON DRIVING. DRIVING SIMULATOR TESTS OF SECOBARBITAL, DIAZEPAM, MARIJUANA AND ALCOHOL*. Retrieved from

Smiley, A. M., Moskowitz, H., & Zeidman, K. (1981). *Driving simulator studies of marijuana alone and in combination with alcohol.* Paper presented at the Proceedings: American Association for Automotive Medicine Annual Conference.

Stanton, N. A., Chambers, P. R., & Piggott, J. (2001). Situational awareness and safety. *Safety science, 39* (3), 189-204.

Summala, H. (1988). Risk control is not risk adjustment: The zero-risk theory of driver behaviour and its implications. *Ergonomics, 31* (4), 491-506.

Taieb-Maimon, M. (2007). Learning headway estimation in driving. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 49* (4), 734-744.

Taieb-Maimon, M., & Shinar, D. (2001). Minimum and comfortable driving headways: Reality versus perception. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 43* (1), 159-172.

Todorov, E. (2004). Optimality principles in sensorimotor control. *Nature neuroscience, 7* (9), 907-915.

Tronsmoen, T. (2008). Associations between self-assessment of driving ability, driver training and crash involvement among young drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 11* (5), 334-346.

van Winsum, W. (1998). Preferred time headway in car-following and individual differences in perceptual-motor skills. *Perceptual and motor skills, 87* (3), 863-873.

Walker, G. H., Stanton, N. A., Kazi, T. A., Salmon, P. M., & Jenkins, D. P. (2009). Does advanced driver training improve situational awareness? *Applied ergonomics, 40* (4), 678-687.

Walsh, V. (2003). A theory of magnitude: common cortical metrics of time, space and quantity. *Trends in cognitive sciences, 7* (11), 483-488.

Wilson, A. D., & Golonka, S. (2013). Embodied cognition is not what you think it is. *Frontiers in psychology, 4*.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic bulletin & review, 9* (4), 625-636.

Zahavi, D. (2002). First-person thoughts and embodied self-awareness: Some reflections on the relation between recent analytical philosophy and phenomenology. *Phenomenology and the Cognitive Sciences, 1* (1), 7-26.

APPENDIX A

PRIMING SCRIPT

Time-moving metaphor

<Screen One>

Please read aloud the following PowerPoint slide by slide.

<Screen Two>

Traditional safe time headway is two seconds.

In this headway, drivers should follow the lead car at a two second time manner.

<Screen Three>

Now a method to help better control the car to follow a two second time headway will be presented in the following section.

<Screen Four>

When a car is slowing, environmental elements can be used to determine the headway time.

These elements should be used to determine the headway time.

<Screen Five>

After this is determined, press the brake panel to prevent crashing into the car.

<Screen Six>

Now, practice it once again through reading the following PowerPoint.

<Screen Seven>

When a car is slowing, environmental elements can be used to determine the headway time.

These elements should be used to determine the headway time.

<Screen Eight>

After this is determined, press the brake panel to prevent crashing into the car.

<Screen Nine>

Please use this technique to follow the lead car at a safe two second time headway.

Ego-moving metaphor

<Screen One>

Please read aloud the following PowerPoint slide by slide.

<Screen Two>

Traditional safe time headway is two seconds.

In this headway, I should follow the lead car at a two second time manner.

<Screen Three>

Now a method to help better control the car to follow a two second time headway will be presented in the following section.

<Screen Four>

When a car is slowing, it will become closer to me. I need to determine the headway time between myself and the car.

<Screen Five>

After I determined this, I will press the brake panel to prevent crashing into the car.

<Screen Six>

Now, practice it once again through reading the Following PowerPoint.

<Screen Seven>

When a car is slowing, it will become closer to me. I need to determine the headway time between myself and the car.

<Screen Eight>

After I determined this, I will press the brake panel to prevent crashing into the car.

<Screen Nine>

Please use this technique to follow the lead car at a safe two second time headway.

Control condition

<Screen One>

Please read aloud the following PowerPoint slide by slide.

<Screen Two>

Traditional safe time headway is two seconds.

In this headway, drivers should follow the lead car at a two second time manner.

<Screen Three>

Now a method to help better control the car to follow a two second time headway will be presented in the following section.

<Screen Four>

When a car is slowing, the distance between two cars is decreasing. The headway time needs to be determined.

<Screen Five>

After determined, press the brake panel to prevent crashing into the car.

<Screen Six>

Now, practice it once again through reading the following PowerPoint.

<Screen Seven>

When a car is slowing, the distance between two cars is decreasing. The headway time needs to be determined.

<Screen Eight>

After determined, press the brake panel to prevent crashing into the car.

<Screen Nine>

Please use this technique to follow the lead car at a safe two second time headway.

APPENDIX B

SELF-REPORT SURVEYS

Situational awareness

Please answer the following questions based on the virtual reality driving environment you just immersived in the car-following task.

1. What is the speed limit of the road?
2. What is the color of the lead car?
3. Was there any trees beside the road?
4. At some points, could you pass the lead car legally?
5. What was the scenery of the foreground?
6. How many lanes were there on the road?
7. How many cars have passed towards you going in the opposite direction?

Feeling of risk, task difficulty and feeling of comfort scale

How much risk did you experience following the lead vehicle at this time headway?

1 2 3 4 5 6 7

No Risk Maximum Risk

How difficult did you find it to follow the lead vehicle at this time headway?

1 2 3 4 5 6 7

Not Difficult Very Difficult

How comfortable did you feel following the lead vehicle at this time headway?

1 2 3 4 5 6 7

Very comfortable Very uncomfortable

Confidence of driving ability test

How confident in your ability to maintain control of the vehicle at this time headway?

1 2 3 4 5 6 7

Very poor Excellent

How confident in your ability to make safe vehicle-handling decisions at this time headway?

1 2 3 4 5 6 7

Very poor Excellent

How confident that you possess the driving reflexes necessary to avoid accident involvement?

1 2 3 4 5 6 7

Very poor Excellent

APPENDIX C

MOTION SICKNESS QUESTIONNAIRE

Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short)

1. Please State Your **Age** .... Years. *2.* Please State Your Sex (tick box) **Male** [$_1$] **Female** [$_2$]

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. Sickness here means feeling queasy or nauseated or actually vomiting.

Your CHILDHOOD Experience Only (before 12 years of age), for each of the following types of transport or entertainment please indicate:

3. **As a CHILD (before age 12)**, how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Your Experience over the LAST 10 YEARS (approximately), for each of the following types of transport or entertainment please indicate:

4. **Over the LAST 10 YEARS**, how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3