# Navigating a Car in an Unfamiliar Country Using an Internet Map: Effects of Street Language Formats, Map Orientation Consistency, and Gender on Driver Performance, Workload and Multitasking Strategy

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**Abstract**

Navigating a car in an unfamiliar country becomes one of major concerns with driving safety. Existing studies mainly used survey, focus group, and statistical analysis to study this problem. Although the navigation system (e.g., GPS) gains an advantage in providing navigation assistances, paper maps, and particularly Internet maps are one of major ways for navigating in an unfamiliar area. This study is one of a few experimental studies which addressed a typical multitasking driving behavior (driving and navigation task) in a cross-culture context. Twenty-four native American-English speakers navigated a driving simulator in urban environments which involved three formats of language settings of the street signs (English, Chinese, or no street signs) and two types of map orientation consistency (Driving from South to North vs. Driving from North to South with a North-up map). It was found that female drivers made more wrong turns only with Chinese street signs but not in the other two conditions compared to male drivers. This indicated that female drivers actually behaved differently from male drivers in an unfamiliar driving environment with unfamiliar street names language. Both male and female drivers benefited from English street signs and reported higher driver workload with Chinese street signs. Interestingly, the average glance duration of maps with Chinese street signs was significantly less than that with English street signs, indicating that even though Chinese language belongs to ideograph with graphical information, its graphical information was not that helpful in assisting navigation task. In addition, female drivers had more instances of collisions with other vehicles, a longer distance of deviation from central line position, higher driver workload and a longer time period of map glance duration. For the main effect of map consistency, drivers made more wrong turns and perceived higher driving workload when they drove with inconsistent maps. Further implications of the current study in transportation safety of globalization were also discussed, including improvement of street sign infrastructures and optimal ways of using and designing Internet maps for drivers navigating in an unfamiliar country.

**Keywords:** Navigation, Street Signs, Internet Map, Map Consistency, Multitasking,

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Unfamiliarity, Driver Workload

## 1. Introduction

With globalization of the world in economy and social activities, more people travel and drive a car in unfamiliar countries (Beenstock and Gafni 2000, Huang *et al.* 2006, Zhang *et al.* 2006, Yannis *et al.* 2007). The term "unfamiliar" in this study specifies foreign individuals who are not familiar with the street language format and road signs of a foreign country. Foreign people that familiarize a foreign country including its language format and road signs are not the main focus in this paper. If drivers are not able to find their destinations efficiently, it not only causes problems for drivers themselves increasing their frustration and chances to get to unsafe areas (Barrow 1991), but also raises the chance of traffic accidents for pedestrians and other nearby vehicles: For American drivers in unfamiliar countries, a non-profit global safety campaign studied State Department data and found that crashes killed 31% of healthy Americans who died abroad during 2004-2006 and one of contributing factors is the drivers' unfamiliarity of road signs (Stolloer 2007) (*USA Today, "Foreign road can be deadly for US Travelers"*). For foreign drivers in Greece, the frequency of accidents involving foreign drivers was steadily increased from 1985 and 2000 (Yannis *et al.* 2007) and unfamiliarity with the road environment including unfamiliar street sign and map language could be one of the reasons. For foreign drivers in USA, researchers also found that foreign drivers lack understanding of traffic signs and markings compared to domestic drivers which leads higher accident rates (Dissanayake 2001). In addition, this navigation problem might create potential traffic jams and environmental pollution in the world (King 1986).

Recently, several important cross-culture driving and navigation studies had been conducted using observation, system design, statistical analysis, survey and focus group methods (Huang *et al.* 2006, Zhang *et al.* 2006, Yannis *et al.* 2007, Zhao *et al.* 2008).

Zhang, Huang et al. (2006) conducted a study using focus group method to explore driver attitudes and safe driver characteristics of Chinese and American drivers. They found that the Chinese drivers concentrate more on driving skills and capabilities, whereas the US drivers concentrate more on practical safe driving guidelines. They also investigated the use of safety belts, running lights, headlights, and turn signals of driver behavior in China, proposing the importance of cross-culture driver behavioral studies.

Hierarchical log-linear analysis method was used by Yanis, Golias et al. (2007) to investigate the accident risk of foreign drivers in Greece. They found that a non-saturated second-order model presents a satisfactory overall fit and confirmed that foreign drivers in Greece are at increased risk. However, immigrant permanent residents of Greece appear to have a lower risk compared to tourists, regardless of the road environment.

Zhao, Wu et al. (2008) reviewed the characteristics of Chinese language and characteristics of spatial cognition of native Chinese speakers. For example, compared with English, Chinese characters have their special features including graphical representation of objects. That study also proposed a conceptual framework in designing intelligent Chinese navigation system based on the textual and spatial characteristics of Chinese language and Chinese users.

Huang, Zhang et al. (2006) conducted a comprehensive cross-culture comparison study using focus group of drivers who had driving experience both in China and USA. They summarized major strengths and weaknesses of the transportation systems in the two countries. One of their major finding is that, many roads and highways in China are named only with Chinese words which have multiple/complex Chinese characters, which might create potential safety problems for foreign drivers in driving and navigation.

According to these recent studies, the issue of driving safety for foreign people has received much attention and studies on cross-culture driving and navigating behaviors might be expected. Specifically, a study considering not only driving performance but also language effects on navigation and driving performance might be expected. Moreover, an experimental study which directly manipulates corresponding factors and observe performance and drivers' multitasking strategies under this specific oversea driving context might be helpful to examine the detailed effects of each factor.

The road signs with unfamiliar languages are one of major problems in navigating a car in an unfamiliar country. Many countries in the world mainly use the official language or language which is familiar by most of residents in that country to mark their street signs. One of the possible reasons is that: if a street sign contains several languages of the same street name, with the limited size of the sign, the text font has to become smaller which will create problems for local drivers to perceive the street sign clearly. In human navigation and way-finding behavior, road and street name is one of main navigation cues which inform human being where their current location is and where they need to turn next time (Tom and Denis 2003, Tom and Denis 2004). When navigating a car in an unfamiliar country with unfamiliar street signs and an unfamiliar language map, drivers may not able to allocate a target street in a real driving environment on a map and not able to match a street name on a map with a street on a real road. This creates one of major problems for oversea drivers in allocating their current location on the map and their decision for next turn. Or if the routes and maps are relatively simple, can drivers just count number of blocks and make turns accordingly? These research questions should not be simply answered by intuitions and formal well-controlled experiment is expected to answer these questions. Moreover, how drivers distribute their limited mental resource to coordinate the relatively difficult navigation task and driving task in an unfamiliar area remains unknown—whether drivers will sacrifice their navigation task performance to protect driving performance or their driving performance might be affected due to the relatively difficult navigation task. In cross-culture driving experiments, this important multitask management problem related to transportation safety has not received enough attention; therefore, the different language formats and its effect on driving performance become one of main focuses on the current study.

Even though the navigation system (e.g., GPS) has been used to provide navigational assistance (Burnett *et al.* 2004), paper maps are still one of major aids for navigation in terms of cost, ready availability, static context and visual presentation. In present study, paper maps were defined as paper based artifacts that presented static views of street information, while GPS specified its electronic maps with route-planning and advice facilities which monitor users' position with the help of satellites and offer navigational assistance through turn-by-turn directions. Compared to electronic maps, paper maps are inexpensive or free to produce and easy to manipulate (by rotating, folding, etc) without the constraints by size or weight. Also, paper maps present static and more accessible views, allowing an individual to become familiar with a wider region, which s/he can then refer to with confidence (Reilly *et al.* 2006). Existing research in driving studies using paper maps has been done a lot (Dingus *et al.* 1989, Srinivasan and Jovanis 1997, Lee and Cheng 2008). For example, Dingus, Antin et al. (1989) examined the efficiency of a paper map and compared with that of a navigation system with its electronic map. The results indicated that there were no differences in the driving time and total travel time (including map study time) whether using either an electronic map or paper map.

In addition, one particular type of paper maps, called Internet or online map (e.g., Google Maps, Yahoo Maps, MapQuest, etc) has received much preference and becomes the new medium for cartography. Several existing studies have examined the extent of Internet map usage (Peterson 2001, Peterson 2008). Compared to the traditional paper map, Internet map (See Figure 1 as examples) has two major features: 1) Unlike a traditional paper map purchased from bookstore or other places with no route marked on the map, Internet map allows a user to simply search the destinations online, automatically select/mark an optimal route and print it out. When users are using it, they can just drive or walk following that optimal route marked on the paper. 2) Traditional paper map typically include all streets and road in a city or region with small font size but users usually only need a small portion of the map; while the target region of the map needed by users is optimized (zoomed in) in Internet map so that a user can see the target route clearly. Compared to an electronic map used in GPS, on the other hand, Internet map provides a variety of functionality that dictates the level of interaction between users and the map (Skarlatidou and Haklay 2005). For example, most internet maps offer powerful language translation functions that facilitate navigating in an unfamiliar country. A Native English driver can easily search a Chinese address in English from the Google Map; while local electronic maps used in GPS might not support translating a Chinese address into different languages, and therefore might not be able to find matched Chinese address. Although existing literature on driving research using electronic or traditional paper maps has been well established, few driving studies examine how a driver use an Internet map to navigate in an unfamiliar foreign environment.


a) Driving direction (South to North) is consistent with map orientation (North-up)

b) Driving direction (North to South) is inconsistent with map orientation (North-up)

Figure 1. Examples of Internet map (Show a route from Location A to Location B in Beijing, China) (Obtained from Google Map)

When paper maps are used in navigation task, it might create another problem is the consistency between map orientation (typically north-up for most of paper maps) and current driving directions (called "map orientation consistency" in this paper) (See Figure

1). Navigation studies of drivers (Denis and Loomis 2007) found that when the direction of the route is opposite to the map orientation (e.g., driving from north to south while using a north-up map), it may require greater degree of mental rotation (e.g., on the map it is a turn to the right hand of a map reader, but actually drivers need to turn left), imposing higher mental demand on drivers in mental rotation process in comparison with the situation when map orientation and driving direction are consistent (e.g., driving from south to north while using a north-up map). This consistency between map orientation and driving direction might be another important factor to be addressed in navigation studies involving driving a vehicle in an unfamiliar language environment with a paper map.

In addition, besides the potential effects of street signs languages and map orientation consistency on navigation and driving performance, studies in individual difference in navigation studies also found that male and female driver demonstrated different navigation performance (Burns 1998). Burns (1998) conducted a large-scale questionnaire survey of 1,184 drivers in the United Kingdom and found that female drivers tended to perceive way-finding as being more difficult than did male drivers. This might be due to the gender difference in spatial navigation ability (Burns 1998, Gron *et al.* 2000). Neurological studies in individual difference (Gron *et al.* 2000) demonstrated that gender difference in navigation performance might due to the different brain activities of male and female: during spatial navigation task, distinct activation of the left hippocampus of males, were found, whereas females consistently recruited right parietal and right prefrontal cortex. When male drivers can effectively process navigation task information, they may have more mental resources left to control vehicles compared to female drivers. However, it remains unknown that whether female drivers may actually behave differently or not compared to male driver in an unfamiliar driving environment with unfamiliar street names languages.

In sum, the current experimental study is to address the effects of street language formats (either it is foreign or native language), map orientation consistency and gender on driver on driver performance and workload. Driver performance in this study includes to two parts: navigation performance (e.g., number of wrong turns) and vehicle control performance (e.g., deviation from central line and collision with other vehicles, road obstacles and pedestrians).

This paper studied driving behavior of American-English native speakers in navigating a simulated vehicle in a Chinese driving environment due to the following reasons. First, English and Chinese belong to two totally different language systems: Chinese is a reprehensive language in ideograph—a character or symbol representing an idea or a thing without expressing the pronunciation of a particular word or words for it. Several main language systems in the world (especially in Asia) including Japanese and Korean also belong to ideograph. By contrast, as a branch of Indo-European language system (Streadbeck 1966), English represents many languages in western countries, using limited number of letters to form words with meaning and pronunciation information at the same time. Therefore, the results of this study might be generalized to navigation and driving performance involving these two different language systems. Second, although China now attracts more than millions foreign visitors every year, there was a relatively high rate of traffic accident in China. China Road Traffic Accidents Statistics (CRTAS 2003) reported that 109,381 people died in traffic accident in China which is around 20% of the total traffic fatalities in the world. As a result, how to improve foreigners' driving safety in China has to be well considered. This study might not only inform traffic policy decision maker in China how to create and pass certain laws related to international drivers, but also provide travel suggestions to these oversea visitors to China regarding to how much assistance they might need and precautions for oversea travels (e.g., avoid navigating a car in countries without knowing the street names or at least having a translator on board).

In a multiple task situation, based on experience in daily life that task related to human safety (driving task) will typically receive higher priority than other tasks (e.g., navigation task), it is assumed that drivers will protect their performance in driving (vehicle control) as the primary task and their secondary task (navigation) performance will be affected by the manipulation of the independent variables (Hypothesis related to multitasking management strategy). More specifically, it was hypothesized that driving behaviors (such as the number of collision, the lane deviation from the central line, etc) will remain at the same level no matter how the map consistency or street sign format was manipulated (Hypothesis related to driving safety, H1). Also, the main effects of the three independent variables are expected: First, the main effect of street sign language formats: H2a) Navigation performance will be the best in the English street sign condition compared to Chinese and no street sign condition since participants are native English speakers. H2b) Even though Chinese are foreign language for those participants, part of graphical information of those foreign-language street signs (e.g., strokes, shape or appearance of a Chinese character) may still be utilized by drivers; therefore, it is hypothesized that drivers' navigation performance will be better in Chinese street sign condition than that in no street sign condition. Second, in terms of the main effect of map consistency: due to the extra cognitive load in mentally rotating a map reviewed in the previous section of this paper, it is hypothesized that navigation performance will be deteriorated when the map orientation and the driving direction is not consistent (H3). This deterioration effect will be worse when drivers are not familiar with the language of the street signs. Third, based on Burns (1998)'s study, it is hypothesized that male drivers may have better navigation performance than female drivers (H4).

## 2. Method

### *2.1 Experimental design and variables*

A mixed-factor design is used in this experimental study: Two within-subject design factors: 3 (Street Sign Formats) × 2 (Map Consistency) and one between-subject design factor: 2 (Gender). The independent variables includes: three different street sign formats (English, Chinese and no street signs), two levels of map consistency (driving from north to south with a north-up map and from south to north with a north-up map, see Experimental Material Section in detail) and gender. The no street sign condition is added as a control or baseline condition to see the effect of Chinese street sign in assisting drivers in their navigation task. If drivers' performance do not benefit from the Chinese street sign, their navigation performance in Chinese street sign and no street sign will have no significant difference (also see Research Hypotheses Section).

The dependent variables includes: a) Number of wrong turns automatically recorded by the STISIM as the main index of navigation performance; b) Driving speed, standard deviation of lane position from central line and number of collisions (collision is defined as the event when the simulator collides with other vehicles in the virtual environment) recorded by the STISIM as the indexes of driving and vehicle control performance; c) Driver workload measured by NASA-TLX (NASA-Task Load Index is a classic mental workload measurement tool developed by researchers in NASA, and it has six dimensions to measure workload in various tasks including the current driving and navigation multitasking situation: mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart and Staveland 1988). NASA-TLX has been widely used in driving domain (Wu and Liu 2007a, Wu and Liu 2007d, Wu *et al.* 2008, Wu *et al.* 2008c, Wu and Liu 2009)); d) Map glance duration and frequency recorded and measured by a video recording system.

### *2.2 Equipment and experimental material*

A STISIM® driving simulator (STISIMDRIVE M100K, See Figure 2a) was used in the experimental study. The STISIM simulator was installed on a Dell Workstation (Precision 490, Dual Core Intel Xeon Processor 5130 2GHz) with a 256MB PCIe x16 nVidia graphic card, Sound Blaster® X-Fi™ system, and Dell A225 Stereo System. The driving scenario was presented on a 27-inch LCD with 1920X1200 pixels resolution. The driving simulator also included a Logitech Momo® steering wheel with force feedback and a gas and a brake pedal.

a) STISIM driving simulator b) Labjack

Figure 2. Equipments used in the current study

The map used in present study was simulated in accordance with the two major features of Internet map: 1) It displays the route from the departure location to the destination; 2) The target region is optimized (zoomed in) so that a user can see the target route clearly. Six maps (3 language formats × 2 consistency levels) matched to the street signs displayed within the driving simulator were used in this experimental study and each had the same size and the same amount of turns (but the order of left turn, right turn and go straight were randomized). Moreover, to control potential confounding factors related to font size, length of street name and word frequency of street names, all of the street names had the same font size and all of the English street names were 5-letter or 6-letter frequently-used English words. And all of the Chinese street names were 3-character high-frequency Chinese street names (the range of number of strokes is 15-22) so that the complexity of these street names were kept at the same level (See Figure 3).

All of the three language formats (English and Chinese street names and no street names) were implemented in an urban driving environment (Chinese urban driving environment used Chinese as the street sign's language and English urban driving environment used English as the street sign's language; and the driving difficulty in these three language formats were at the same level[1]).

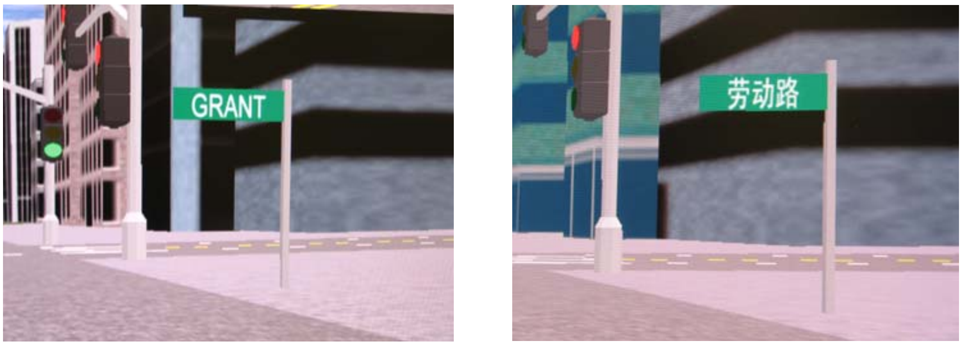


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Figure 3. Driving scenario with (a. English street signs; b. Chinese street signs)

The map was displayed on a 12.1 inch ELO screen which was located at 50 cm from the right hand of the participants and 91 cm from the eyes of participants. The visual angle of the touch screen is 13.1 degree. This screen was controlled by a Dell PC (OPTIPLEX 745) which was connected with the driving simulator via Labjack® system (See Figure 2b).

### *2.3 Participants*

Twenty-four Native American-English speakers from State University of New York (SUNY) at Buffalo got involved in this experiment (average age: 23.3 years old; SD of age: 4.6; 14 male and 10 female). All participants had corrected far visual acuity of 20/40 or better and midrange (80 cm) visual acuity of 20/70 or better. Prescreening of all participants ensured that they had good driving records and were physically healthy. On

[1]If we do not control the driving difficulty in these two driving environments, it is hard to tell the different navigation and driving performance was due to the manipulations of the three independent variables in this experiment or the different driving difficulty as a potential confounding variable in these two driving environments.

average, the participants have 13,000 miles driving experience (SD=6300 miles)[2] and they received payment as a compensation to participate this experiment. In addition, all participants reported that they never learned any ideograph languages before (e.g., Chinese, Korean or Japanese) and they never traveled or drove a vehicle in countries using these languages before.

### *2.4 Experimental procedure*

After filling in the pretest forms and taking vision tests, participants first practiced a single driving task (8 miles) without the navigation task so that they got familiar with the driving simulator. Then participants practiced a dual task with a driving task and a navigation task at the same time. There was 30 turns and it took around 15-20 min to complete this practice block. During this dual task, participants were asked to drive the simulator as they are driving on a real-world road and navigate it to a destination following a route marked on the map. The detailed instruction was: "Please operate the driving simulator as a real vehicle and navigate it following the route on the map to the destination". To avoid the learning effect, in each combination condition of the two within-subject design factors (3: Street Sign Formats × 2: Map Consistency), participants drove a different route on map. Right after the practice session, participants were instructed to answer the NASA-TLX workload questionnaire in order to let them get familiar with this questionnaire. After participants finished the practice session, they took a 3-minute break and started the formal test session. Each participant went through six blocks and each block matched to one of the six maps as described in the experimental material following Latin Square Design. Right after each trial, participants answered the NASA-TLX to report their subjective workload in that trial. The whole experiment lasted for 2-2.5 hours and all participants were paid at a rate of $10.00 per hour. In addition, participants were allowed to take a break and even quit the study anytime if they feel

[2]The driving experience between male and female driver were not significant $t(22)=.56$, $p>.05$.

uncomfortable.

## 3. Results

All dependent variables were analyzed by Street Sign Formats (Chinese, English or No Street Sign) × Map Consistency (Consistent or Inconsistent) × Gender (Male or Female) mixed design analyses of variance. Analysis of variance (ANOVA) was used to examine potential group differences in dependent variables. Significance testing was set for an alpha level of .05. Moreover, descriptive statistics (sample mean and standard deviation) were provided to describe the main features of the sample for each measure (see Table 1 in the Appendix).

### *3.1 Navigation performance*

The number of wrong turns throughout the whole trial was regarded as a major index of navigation performance. The interaction effect of gender × street sign formats for the number of wrong turns was significant, ($F(2, 132)=4.166$, $p=.018$) (See Figure 4). Follow-up analysis showed that female drivers made significantly different number of wrong turns among three levels of street sign formats, ($F(2, 57)=6.388$, $p=.003$), while it was not the case for male drivers, ($F(2, 81)=1.719$, $p=.186$). More specifically, female driver were more likely to make a wrong turn in Chinese street sign condition compared to English street sign condition, (95%CI: 2.25 (.73, 3.77), $p=.002$). No significant difference was observed for female between Chinese and no street sign condition, or between English and no street sign condition.

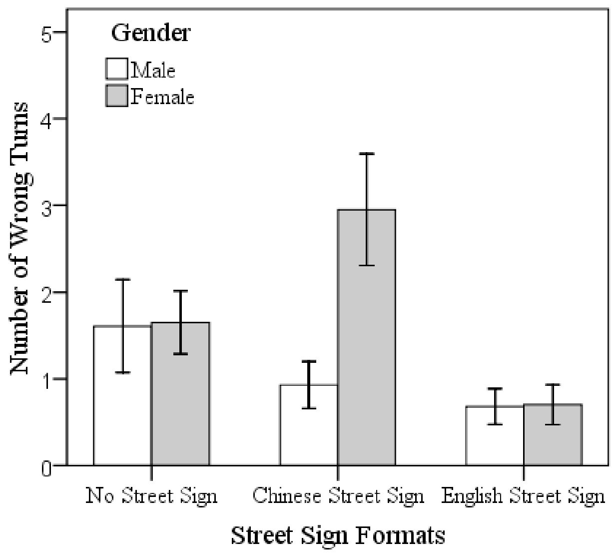


Figure 4. A significant interaction effect of gender × street sign formats for the number of wrong turns (The error bars indicate ±1 SE)

There were two significant main effects: gender ($F(1, 132)=4.579$, $p=.034$) and street sign formats ($F(2, 132)=5.35$, $p=.006$) for the measurement of the number of wrong turns. For the main effect of street sign formats, it was observed that both male and female drivers profited from English streets signs compared to the condition where there were no street signs (95%CI: -.94 (-1.87, -.001), $p=.048$).

In addition, the main effect of map consistent was significant for the number of wrong turns, ($F(1, 132)=7.352$, $p=.008$), indicating that participants made more wrong turns when they drove with inconsistent maps (See Figure 5). The other two-way interactions and the three-way interaction of the three independent variables were not significant: street sign formats × map consistency, ($F(2, 132)=.422$, $p=.657$); gender × map consistency, ($F(1, 132)=.134$, $p=.715$); street sign formats × map consistency × gender , ($F(2, 132)=1.967$, $p=.144$).

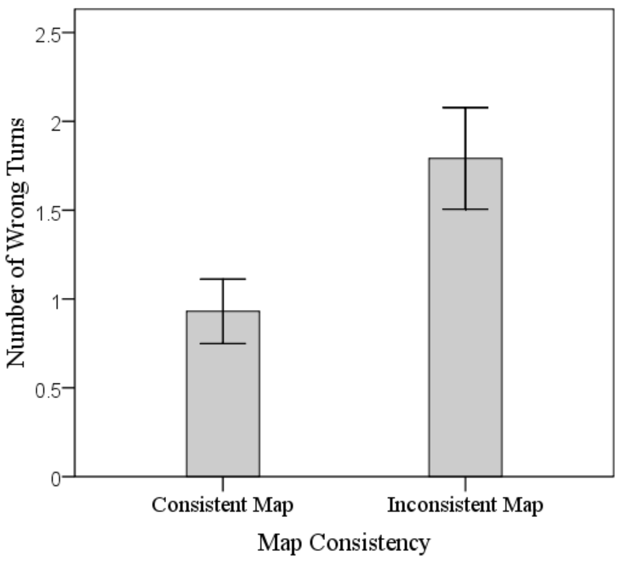


Figure 5. A significant main effect of map consistency on the number of wrong turns (The error bars indicate ±1 SE)

### *3.2 Vehicle control performance*

Three variables were examined serving as indicators of vehicle control performance: driving speed, standard deviation of lane position from central line and number of collisions. First, only the main effect of street sign formats was significant for driving speed, ($F(2, 132)=3.721$, $p=.027$). Pair-wise comparison was further conducted but there was no significant difference between any two levels of street sign formats for driving speed at alpha level of .05. Moreover, the other two main effects were not significant: gender, ($F(1, 132)=1.742$, $p=.189$), map consistency, ($F(1, 132)=1.6$, $p=.208$). Two-way and three-way interactions were not significant: street sign formats × map consistency, ($F(2, 132)=.064$, $p=.938$); gender × map consistency, ($F(1, 132)=1.184$, $p=.279$); gender × street sign formats, ($F(2, 132)=.714$, $p=.491$); street sign formats × map consistency × gender , ($F(2, 132)=.133$, $p=.875$).

The main effect of gender was significant for the standard deviation of lane position from the central line, ($F(1, 132)=10.497$, $p=.002$), and the number of collision, ($F$(1, 132)=18.195, *p*=.000), indicating that female drivers had more instances of collision with other vehicles (See Figure 6a) and a longer distance of deviation from its central position at the road compared to male drivers (See Figure 6b). The other two main effects were not significant for the standard deviation of lane position from the central line: street sign formats, (*F*(2, 132)=1.087, *p*=.34), map consistency, (*F*(1, 132)=.605, *p*=.438). Two-way and three-way interactions were not significant: street sign formats × map consistency, (*F*(2, 132)=.673, *p*=.512); gender × map consistency, (*F*(1, 132)=.029, *p*=.864); gender × street sign formats, (*F*(2, 132)=.152, *p*=.859); street sign formats × map consistency × gender, (*F*(2, 132)=.023, *p*=.978). Similarly, the other two main effects were not significant for the number of collision either: street sign formats, (*F*(2, 132)=1.453, *p*=.238), map consistency, (*F*(1, 132)=.76, *p*=.384). Two-way and three-way interactions were not significant: street sign formats × map consistency, (*F*(2, 132)=.109, *p*=.896); gender × map consistency, (*F*(1, 132)=1.651, *p*=.201); gender × street sign formats, (*F*(2, 132)=1.01, *p*=.367); street sign formats × map consistency × gender , (*F*(2, 132)=.331, *p*=.719).

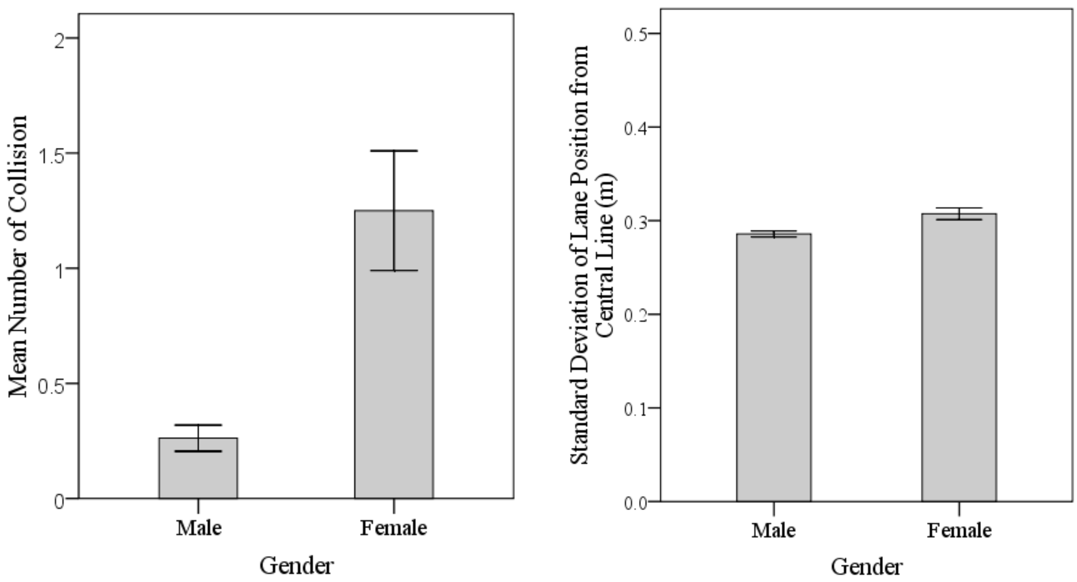


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Figure 6. Significant main effects of gender on: a) number of collision; b) standard

deviation of lane position from central line (The error bars indicate ±1 SE)

### *3.3 Driver workload*

The main effect of street sign formats on driver workload measured by NASA-TLX was significant, ($F(2, 132)=4.941$, $p=.009$) (See Figure 7). Pair-wise comparison was performed and it was showed that the overall driver workload was significantly higher in Chinese street sign condition compared to English street sign condition (95%CI: 9.43 (2.37, 16.49), $p=.005$). No street sign condition was not different from Chinese or English street sign condition for the measurement of driver workload.

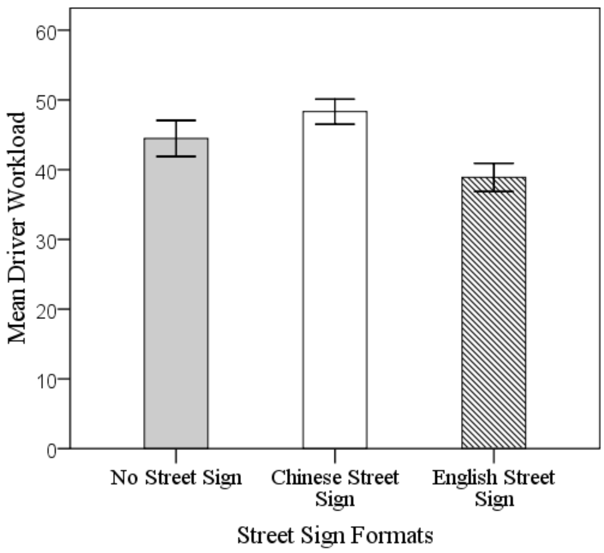


Figure 7. A significant main effect of street sign formats on driver workload (The error bars indicate ±1 SE)

Moreover, both gender ($F(1, 132)=6.199$, $p=.014$) and map consistency ($F(1, 132)=4.341$, $p=.039$) had significant effects on driver workload. Female drivers reported higher driving workload than male drivers (See Figure 8a). Also, both male and female drivers perceived higher driving workload when using inconsistent maps compared to consistent ones (See Figure 8b). In addition, two-way and three-way interactions were not significant: street sign formats × map consistency, ($F(2, 132)=.435$, $p=.648$); gender ×

map consistency, ($F(1, 132)=.213$, $p=.645$); gender × street sign formats, ($F(2, 132)=.052$, $p=.95$); street sign formats × map consistency × gender , ($F(2, 132)=1.37$, $p=.258$).

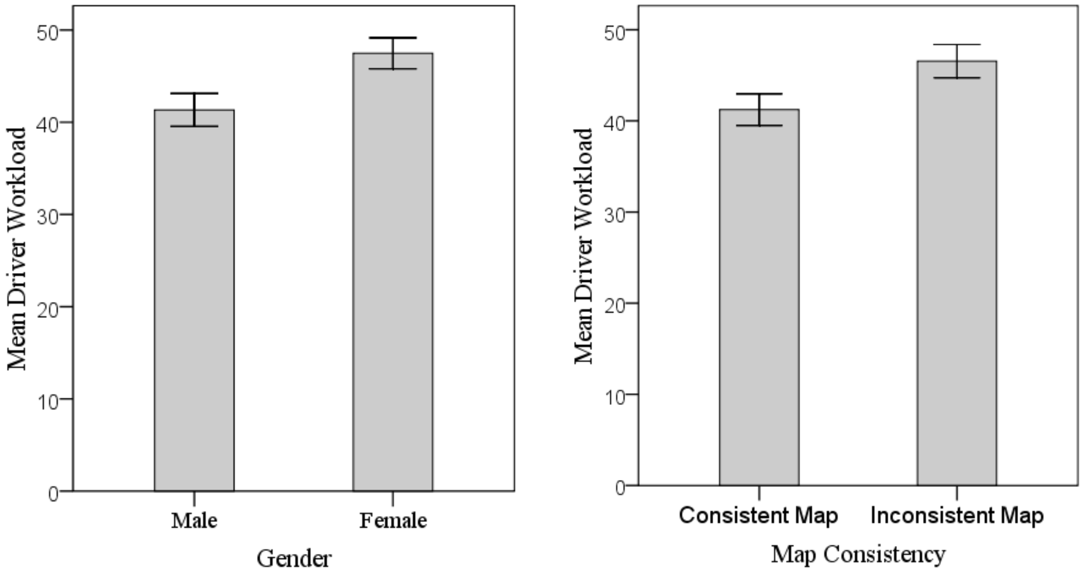


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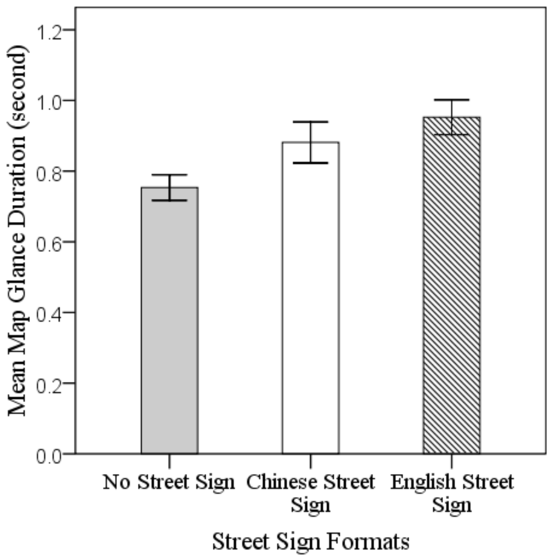
Figure 8. Significant main effects of: a) gender; b) map consistency on driver workload (The error bars indicate ±1 SE)

### *3.4 Map glance duration and frequency*

The main effect of street sign formats on the mean map glance duration was significant, ($F(2, 132)=4.497$, $p=.013$) (See Figure 9a). Interestingly, further analysis indicated that drivers spent a longer time period in viewing maps with English street name (95%CI: .2 (.036, .362), $p=.012$) compared to those without names. No significant difference was revealed between Chinese and English or between Chinese and no street sign for the measure of mean map glance duration. Further, gender had a significant main effect on the mean map glance duration, ($F(1, 132)=6.532$, $p=.012$), indicating that female drivers spent more time taking a glance over the maps than male drivers (See Figure 9b).

There was no significant difference between consistent and inconsistent maps for the mean map glance duration, ($F(1, 132)=1.43$, $p=.23$). Two-way and three-way interactions were not significant: street sign formats × map consistency, (*F*(2, 132)=.049, *p*=.952); gender × map consistency, (*F*(1, 132)=.015, *p*=.903); gender × street sign formats, (*F*(2, 132)=.222, *p*=.801); street sign formats × map consistency × gender, (*F*(2, 132)=.272, *p*=.762).

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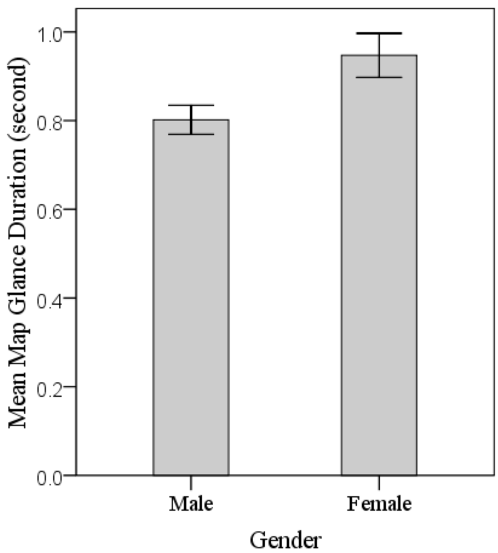


b

Figure 9. Significant main effects of: a) street sign formats; b) gender on the map glance duration (The error bars indicate ±1 SE)

For the next index—map glance frequency, all main effects, two-way as well as three-way interaction were not significant: gender, (*F*(1, 132)=1.683, *p*=.197), street sign formats, (*F*(2, 132)=.103, *p*=.902), map consistency, (*F*(1, 132)=1.349, *p*=.248), street sign formats × map consistency, (*F*(2, 132)=.004, *p*=.996); gender × map consistency, (*F*(1, 132)=.585, *p*=.446); gender × street sign formats, (*F*(2, 132)=.007, *p*=.993); street sign formats × map consistency × gender, (*F*(2, 132)=.132, *p*=.877).

## 4. Discussion

This study is one of a few experimental studies which examined the cross-culture driving and navigation behavior using an Internet map. And it studied the effects of different language formats of the street signs, map orientation consistency and gender on drivers' navigation and vehicle control performance and driver workload. In this experiment, female and male participants recruited were native American-English speakers and never drove in Asian countries before. They navigated a simulated vehicle in urban environments which involved three formats of language settings of the street signs (English, Chinese, or no street signs) and two types of map orientation consistency (Driving from South to North vs. North to South with a North-up map).

It was found that when native American-English speakers were driving with Chinese street signs, female drivers made more wrong turns but not in the other two conditions compared to male drivers. Although both male and females reported higher driver workload with Chinese street signs, male drivers demonstrated better navigation performance when navigating a car in an unfamiliar area. Previous studies indicated that female drivers tended to perceive way-finding as being more difficult than did male drivers (Burns 1998, Gron *et al.* 2000). Such gender difference in navigation might due to the different activation of brain areas based on neurological findings (Gron *et al.* 2000). However, the current findings showed that female drivers did not behave differently from male drivers in either English street sign or no street sign condition. Only in an unfamiliar driving environment with unfamiliar street names languages, female drivers failed to process navigation task information effectively. In addition, both male and female drivers get benefit from English street signs. This was consistent with H2a Hypothesis.

Interestingly, the average glance duration of maps with Chinese street signs was significantly less than that with English street signs, indicating that even though Chinese language belongs to ideograph with graphical information, its graphical information was not that helpful in assisting navigation task. In addition, female drivers had more instances of collisions with other vehicles, a longer distance of deviation from central line position, higher driver workload and a longer time period of map glance duration. For the main effect of map consistency, drivers made more wrong turns and perceived higher driving workload when they drove with inconsistent maps. This indicated that drivers' navigation performance were deteriorated when the map orientation and the driving direction was not consistent, which was consistent with H3 Hypothesis.

According to these experimental results, in practice, it is suggested that certain assistances, including improvement of streets sign infrastructures and optimal ways of using and designing Internet maps, are needed for drivers (especially for female drivers) who navigate a vehicle in an unfamiliar country with an Internet map to reduce the number of wrongs and driver workload: 1) Adding foreign language information on street signs for those areas where foreigners travel frequently (even though on Internet map most of foreign street names have been translated to Pinyin or other alphabetic terms, See Figure 1). Additional information on the street signs might also create problems for drivers as the letters might become smaller, which may be interesting for further investigation; 2) Printing or adding direct driving directions (turn right, left or go straight) for each intersection and mark their orders (e.g., first intersection, turn left; second, go straight) on Internet map rather than just marking the route on the map; 3) Showing real-road street view of each intersection on the Internet map so that drivers can also use landscape and other non-text graphical information to figure out their current location (Currently, most of Internet map can only show real-road street views in developed countries, e.g., USA, Canada, and countries in Europe). Moreover, drivers can travel with a local translator who can read the Internet map and streets signs with local languages. In addition, Internet map can be always designed in north-up format, since it was found that map orientation consistency did not affect navigation and driving performance. Though some of these suggestions may be obtained by intuitive judgments, this experimental study provided first-hand data regarding the necessary of these assistances which might be a useful reference for safety policy maker and travel recommendations for drivers.

It was shown that the number of collisions and standard deviation of lane position from central line were not affected by the street sign formats. These findings were consistent with H1 Hypothesis and might be related to the effective task management of drivers in the experiment (Hypothesis related to multitasking management strategy proposed in the Research Hypotheses section). This task management involved two parts: 1) Inter-task management (mental resource allocation between driving and navigation task): the measurement of drivers' map viewing pattern during this experiment—average glance duration of maps with Chinese street names was significantly less than maps with English street name (the glance frequency remains almost at the same level) indicated that, in the Chinese street format condition, participants might give higher priority to driving task and sacrifice the navigation performance. Due to the limited mental resource of drivers (Wu and Liu 2007a), if drivers allocated more attention and mental efforts in perceiving the Chinese street names on maps and matching them in the driving environment, their driving performance could be deteriorated in this condition. 2) Inner-task management (distribution of mental resource within driving task): To avoid hitting other vehicles or obstacles in the Chinese street sign condition, within driving task itself, participants also significantly reduced their driving speed due to the relative high workload in processing unfamiliar language information.

These two task management mechanisms of normal drivers were also supported by other researchers in surface transportation domain (Hickman 2005). However, it was also found that sometimes normal drivers can be distracted by a secondary task (e.g., interacting with in-vehicle information technology system such as GPS, cell phone) (Ward and Hirst 1997) and some special driver populations (e.g., heavy drinkers) (Hingson and Winter 2003) were not able to effectively manage multitasks very well, which indicated that when normal drivers were distracted or these special driver populations were navigating a car in an unfamiliar country, they may experience more safety problems than normal drivers.

The current results suggested no difference of navigation performance—number of wrong turns between Chinese and no street sign condition, which is not consistent with H1b hypothesis. This result indicated that for both Chinese and no street sign conditions, participants may use the same navigation strategy without relying on street signs. For example, they may count the number of blocks and decide which way they turn accordingly. One possible reason that street signs with foreign language were not helpful in assisting navigation task is due to the time pressure during this driving and navigation multitasking. In the real driving condition with normal traffic flow, it is not allowed for a driver to slow down and view the street sign for a long time. As a consequence, a driver may not have enough time to perceive and process the graphical information on the street signs in detail, which in turn, resulting in deteriorated navigation performance.

There were several limitations of the current study which will be addressed in future work. First, only two different language systems (Ideograph vs. Indo-European) were taken into consideration in this experiment; while whether drivers will behave differently if they navigate a car in a different language environment but belong to same language system (e.g., a native Chinese speaker navigates a car in Korea) remains unknown. Future experiments might be conducted to address this aspect. Second, our finding in gender difference was only based on the data from the specific task in the current experiment. We did not claim that male drivers have better performance than female drivers in general and maybe female drivers may have better performance than male drivers in other tasks. Studies in future may recruit larger sample size to exam the gender difference in this specific task. Third, to study the effects of language formats and map orientations on driver behavior, other potential confounding factors (e.g., the mixture of traffics: pedestrians and bike) were controlled and kept the same in the English and non-English driving scenarios in the current study. Future studies may include these factors since they may interact with the independent variables in this study. Forth, in spite of the small sample size and unbalanced gender distribution, the observed power (β) for the gender × street sign formats interaction as well as significant main effects were at least 0.73 in the current study, but future studies should benefit from a larger sample size and a balanced design. In addition, this whole study was conducted using a driving simulator due to safety reason and the relatively high expense to transport many native English speakers to another country. Future studies might be carried out directly in an unfamiliar country to increase the external validity of the experimental results.

We are conducting cross-culture experimental studies in surface transportation to address the transportation safety issues in globalization. This study is one step towards our ultimate goal to improve global transportation safety.

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## Appendix

Table 1. Means and standard deviations for dependent variables

| | Number of wrong turns | Driving speed (mph) | SD of lane position (m) | Number of collisions | Driver workload | Map glance duration (s) | Map glance frequency |
|---|---|---|---|---|---|---|---|
| Male Drivers | | | | | | | |
| No Street Sign | | | | | | | |
| Consistent Map | .79 (1.76) | 20.5 (2.15) | 6.24 (.31) | .14 (.36) | 34.83 (15.03) | .68 (.22) | 34.71 (13.63) |
| Inconsistent Map | 2.43 (3.48) | 19.38 (2.67) | 6.34 (.41) | .14 (.36) | 49.93 (24.87) | .75 (.27) | 39.79 (16.39) |
| Chinese Street Sign | | | | | | | |
| Consistent Map | .79 (1.58) | 19.81 (1.66) | 6.22 (.53) | .14 (.36) | 44.83 (14.38) | .74 (.22) | 32.86 (10.99) |
| Inconsistent Map | 1.07 (1.33) | 18.79 (1.77) | 6.39 (.68) | .36 (.5) | 46.1 (8.67) | .88 (.42) | 39.07 (18.61) |
| English Street Sign | | | | | | | |
| Consistent Map | .5 (.76) | 20.16 (1.27) | 6.34 (.34) | .36 (.63) | 34.93 (15.24) | .88 (.26) | 33.93 (14.15) |
| Inconsistent Map | .86 (1.35) | 19.63 (2.25) | 6.37 (.42) | .43 (.76) | 37.4 (11.42) | .88 (.34) | 37.21 (12.23) |
| Female Drivers | | | | | | | |
| No Street Sign | | | | | | | |
| Consistent Map | 1.5 (1.51) | 19.59 (2.62) | 6.63 (.27) | .9 (1.2) | 46.77 (7.32) | .77 (.23) | 39.4 (16.9) |
| Inconsistent Map | 1.8 (1.8) | 19.82 (2.5) | 6.5 (.47) | .8 (1.03) | 48.07 (14.05) | .85 (.29) | 40.8 (21) |
| Chinese Street Sign | | | | | | | |
| Consistent Map | 1.9 (2.28) | 18.31 (2.01) | 6.53 (.32) | 2.1 (2.96) | 50.3 (15.06) | .97 (.5) | 39.9 (18.16) |
| Inconsistent Map | 4 (3.13) | 18.01 (3.15) | 6.47 (.33) | 1.3 (2.87) | 54.33 (9.82) | .99 (.45) | 39 (11) |
| English Street Sign | | | | | | | |
| Consistent Map | .4 (.52) | 19.84 (1.48) | 6.58 (.36) | 1.5 (1.51) | 39.37 (14.26) | 1.01 (.42) | 37.8 (12.63) |
| Inconsistent Map | 1 (1.33) | 19.71 (3.13) | 6.47 (.33) | .9 (1.85) | 46.03 (13.95) | 1.1 (.35) | 40.3 (9.57) |