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P300 Amplitude Reflects Individual Differences of Navigation Performance in a Driving Task

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Abstract

Even though individual differences in navigation performance has been found in driving studies at behavioral level, few studies have explored the cognitive mechanisms of this individual difference at neural level with the technique of ERP (Event-related Potential). This study recruited two groups of navigators with good and poor navigation performance in a driving task and measured their P300 amplitude while two types of triggers were presented to subjects (intersections and street signs). Poor navigators showed larger P300 amplitude than good navigators on the left hemisphere, the right hemisphere, the temporal, the parietal and the occipital sites when intersection triggers were presented, and on the occipital site when street sign triggers were presented, reflecting different levels of mental resource needed to process the spatial information between these two groups.

Keywords: Navigation; Event-related Potential; Driving; P300 amplitude; Individual Differences

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1. Introduction

Navigating a vehicle and reaching a destination are daily tasks with practical and theoretical importance. If drivers are unable to navigate successfully (poor navigational ability), there is a range of individual and societal consequences, including driver frustration and anxiety (Barrow, 1991), increased driver workload (Liu et al., 2006; Wu and Liu, 2006), reduced traffic mobility (Burns, 1997) and environmental pollution due to unnecessary vehicle travel distance and potential traffic jam (King, 1986). Theoretically, the ability to find one's way in a complex environment represents one of the most fundamental cognitive functions. Navigation involves a multisensory process in which information needs to be integrated and manipulated over time and space, and humans differ widely in this ability (Wolbers and Hegarty, 2010). Navigation, in this paper, was defined as a process of monitoring and controlling the movement of a motor vehicle from one place to the destination.

Many researchers have studied individual differences in spatial ability in a variety of non-driving navigation tasks (such as simple object-based mental rotation or wayfinding in a maze) and driving navigation tasks. In a driving navigation task, several behavioral measures (such as number of wrong turns, trip-planning time, and travel time) were used to assess individual differences in navigation performance; number of wrong turns was the most widely accepted one (Dingus et al., 1997; Uang and Hwang, 2003). In this paper, a wrong turn was defined as any deviation from the predefined path. This definition was consistent with previous study of navigation performance (Dingus et al., 1997). Individual differences in navigational ability arise at multiple stages, including the precision with which spatial information is encoded from sensory experiences, the ability to form spatial representations of external environments, and the efficacy with which they are used to guide navigational behaviors (Wolbers and Hegarty, 2010). Compared to behavioral measures, psychophysiological measures (e.g., ERP and EEG) can better and more sensitively assess individual differences in navigation abilities, especially when searching for neural correlates of mental processes (Kosslyn et al., 2002).

At neural level, existing studies have examined the distinct patterns of brain oscillations in the Electroencephalography (EEG is the recording of electrical activity along the scalp produced by the firing of neurons within the brain) of human while they perform various non-driving navigation tasks. There is a consistent finding that human theta activity in a frequency range of 4-8 Hz increases during the navigation task (Bischof and Boulanger, 2003; Caplan et al., 2001; de Araujo et al., 2002; Kahana et al., 1999). Additionally, theta activity is likely to occur at points where new navigation clues (e.g., hallway in a maze) come into view (Bischof and Boulanger, 2003). However, in these studies, researchers focused on a person's navigation performance in a maze or virtual reality. They did not examine individual differences in navigational abilities in a normal driving and navigation task.

As EEG reflects thousands of simultaneously ongoing brain processes, the brain response to a single stimulus or event of interest is not usually visible in the EEG recording of a single trial. In contrast, the Event-Related Potential (ERP) is an alternative technique which is regarded as manifestations of brain activities that occur in preparation for, or in response to, discrete events, be they internal or external to the stimuli (Fabiani et al., 2000). Previous research has measured ERPs in various non-driving navigation tasks (e.g., mental rotation tasks that use alphanumeric characters, polygons, letter-like symbols, and common objects). There is a general agreement about the negative correlation of the amplitude of ERP with navigation task performance (Beste et al., 2010; Lamm et al., 2005; Peronnet and Farah, 1989; Vitouch et al., 1997). That is, poor navigators (low-performers) exhibit larger amplitude of the ERPs compared to good navigators (high-performers). This finding is in accordance with the neural efficiency hypothesis, which assumes that the central nervous system of individuals with higher spatial abilities is functioning in a more efficient way than the one of individuals with lower abilities (Lamm et al., 2005).

The P300 component in ERPs (evoked by the presentation of the character in mental rotation tasks) is the most reliable index due to its great ecological validity and endogenous range of psychological correlates, compared to other ERP components (Heil, 2002; Pritchard, 1981). The P300 is a positive deflection in electro-cortical activity that occurs approximately 300 ms after stimulus onset (Houston et al., 2004). The literature on the utility of P300 in studies of mental rotation suggests that the amplitude of P300 becomes relatively more negative as more mental rotation has to be executed (i.e., amplitude modulation, Heil, 2002; Heil et al., 1998; Wijers et al., 1989). Also, some researchers have examined individual differences in the P300 during the performance of a visual-spatial attention task (Vaquero et al., 2004) and the P300 features elicited in working memory (Morgan et al., 2010; Wijers et al., 1989).

Additionally, previous studies have investigated the neural basis of navigation by human with functional neuroimaging of brain activity. Neuropsychological results suggest that the right hippocampus is more active than the left during navigation, while the reverse pattern during episodic memory retrieval (Burgess et al., 2002). The activation of the right hippocampus in particularly associated with accuracy of navigation (i.e., know accurately where places are located and navigating accurately between them) (Maguire et al., 1998). In addition to the hippocampus (located inside the medial temporal lobe), navigation by human generally activates lateral and medial parietal regions, and the medial occipital region (Gron et al., 2000). The activation of the parietal regions is associated with the translation of stored allocentric information into the egocentric representations required to guide movement or to support imagery of the retrieval products (Burgess et al., 2002). The medial occipital cortex is activated by visually guided eye movements and the performance of motor actions (Astafiev et al., 2004).

Although separate lines of research exist on navigation and mental rotation tasks using EEG or ERP, few studies have measured ERP in driving and navigation tasks and considered its differences in the navigation performance between good and poor navigators. In this study, navigation performance referred to the level of performance required for making a correct turning when approaching an intersection given the predefined route (marked map direction). This driving and navigation task may require the navigation ability to sense self-motion, maintain and updated one' position and orientation on the basis of sensing self-motion over time. Driving and navigation task itself has two unique features, which are not the same as those of a simple navigation task in a maze or mental rotation. First, driving and navigation task involves a serial of time-sharing activities. A driver needs to control his/her speed while steering, viewing outside roadway and navigating the car at the same time, rather than a single task of driving or a single mental rotation of maps to reach the destination. Due to this multitasking property of driving, drivers with poor navigational ability have to spend more time checking maps with greater resources investment than good navigators, and their driving task might be affected (Wickens et al., 1983). Secondly, because driver safety must receive higher priority than other tasks (e.g., navigation task), drivers are expected to protect their performance in driving as the primary task by sacrificing their navigation performance, whereas people can hit the wall on a maze without an accident. As a result, how good or poor navigators distribute their limited mental resource to coordinate the navigation task and driving task remain unknown. Finally, studying human performance in a driving and navigation task might address human behavior in a real-world context and even affect the design of navigation systems, which to date is not supported by existing psychological studies using artificial mental rotation tasks.

The objective of this study was to obtain the ERP correlates reflecting the individual differences of navigation performance in a driving navigation task. We first differentiated good navigators and poor navigators based on their performance in this navigation task. Then, we analyzed the ERP data for these two groups of navigators. Finally, we discussed the possible applications of the current findings in the design of a real intelligent transportation system.

The navigation maps used in this work was paper based maps. Compared to other navigation system such as the global positioning system (GPS), paper maps are still one of major aids for navigation in terms of cost, ready availability, static context and visual presentation (Dingus et al., 1989; Lee and Cheng, 2008; Reilly et al., 2006; Srinivasan and Jovanis, 1997). More importantly, GPS monitors users' dynamic position with the help of satellite and offers navigational assistance through turn-by-turn directions. As a result, drivers could successfully navigate a vehicle without the need for route-planning, mental rotation, etc by themselves. In order to exhibit a driver's own navigation abilities, paper maps that present static views of street information were used accordingly.

2. Methods

2.1. Participants

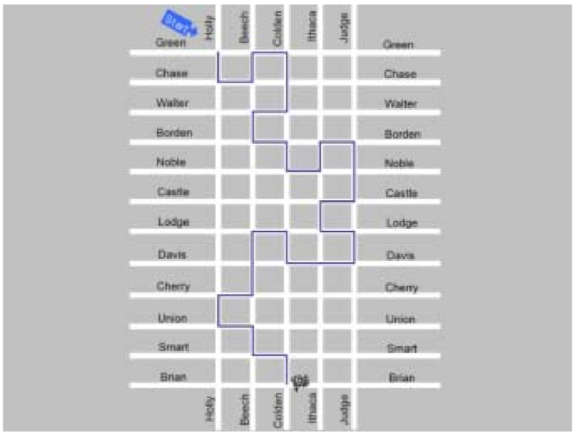
Seventeen healthy participants (10 males, 7 females), ranging from 19 to 27 (M=21.9, SD=2.77) years of age, took part in this study. The averaged number of years since they obtained their first valid US driver licenses was 3.94 (SD=1.89), and averaged estimated annual mileage was 10676.47 miles (SD=5361.73). All participants had normal or corrected-to-normal vision, a valid driver's license, and reported being free of psychiatric or neurological disorders. Written informed consent was obtained prior to the study.

2.2. Experiment setup

A STISIM® driving simulator (STISIMDRIVE M100K, Systems Technology Inc, Hawthorne, CA) was used in the experimental study (see Figure 1a). The STISIM simulator was installed on a Dell Workstation (Precision 490, Dual Core Intel Xeon Processor 5130 2GHz) with a 256MB PCIe×16 nVidia graphic card, Sound Blaster® X-Fi™ system, and Dell A225 Stereo System. It includes a Logitech Momo® steering wheel with force feedback, a gas and a brake pedal. The driving scenario was presented on a 27-inch LCD with 1920×1200 pixels resolution.

A map (8.5×6 inches) with a marked route, consisting of 30 randomly distributed turns, was used in this study (see Figure 1b). This map, in nature, was a paper based map because it presented static views of street information but showed it on a computer display. This map was simulated by a 19-inch Dell LCD (1098FP model) which was located at 50 cm from the right hand of the subjects and 91 cm from the eyes of subjects. The visual angle of the touch screen was 13.1 degree vertically. This screen was controlled by a Dell PC (OPTIPLEX 745) that was connected with the driving simulator via a Labjack® system. All street names on the map were frequently-used English words that with five or six letters. A Neuroscan system including one Quik-Cap, Nuamps Express, and SCAN software, was used to record and analyze EEG in this experiment. Nuamps Express is a 40-channel digital EEG recording system, and SCAN provides a full research-grade-data processing tool to remove noise and artifacts or decompose complex signals.

a. The driving simulator and map



b. Map used in the experiment

Figure 1. The driving simulator and map used in the experiment

2.3. Procedure

Participants were seated in a comfortable chair and wore a fitted cap (Quik-Caps, Neuroscan) including 40 channels. After the EEG cap was set up, all participants first went through a Practice session in which they could get familiar with the control of the driving simulator, including steering wheel, speedometer, gas, and brake pedal. Also, participants drove with a map provided to them, to give them some feel of driving while following certain directions. Before the driving task, all participants were informed that: 1) you have to follow the traffic laws and behave as you are driving a real vehicle on the road; 2) when approaching a signalized intersection, you have to make a decision (go straight, turn left or turn right) following the marked path on the map. If you make a wrong turn, collision will occur[1] and the system will restart after 3 seconds. Then, you have to try another turn until it is correct.

The Practice session included four trials and each of them consisted of 15 randomly distributed turns. The whole Practice session lasted for 30-40 minutes. In the following Test Block, participants followed the same instructions and drove with a map of 30 randomly distributed turns. The Test Block lasted for 20-25 minutes and the whole experiment was completed within 2 hours. All participants were paid at a rate of $10.00 per hour and allowed to take a break and even quit the study anytime if they feel uncomfortable.

2.4. Experimental design

A 2×2 mixed factorial design was used in this study: Types of Navigators versus Types of Triggers. The participants were divided into two groups, based on the 50 percentile of navigation performance in the experiment (Parens et al., 1966): Good Navigator (people who made two or less than two wrong turns in the Test Block, n=9) versus Poor Navigator (people who made more than two wrong turns in the Test Block, n=8).

Participants were asked to navigate a vehicle following the marked/predefined path on the map (see Figure 1b) rather than select a path to a destination by themselves (i.e. the shortest path). This path-following task was quite common in daily life and similar path following

[1] Although unrealistic, the design of making collisions when drivers made a wrong turn could help drivers be aware of their mistakes and allowed them to make a correction. Otherwise, they might continue this mistake and misinterpret the map in the following intersections.

navigation settings could be found in previous studies (Caplan et al., 2001; Kahana et al., 1999). Therefore, any deviation from the predefined path is defined as a wrong turn.

The ERP-eliciting paradigm consisted of two visual oddballs (triggers) which were programmed in the driving simulator: 1) Intersection Trigger: the presentation of an intersection (indicated by a traffic light) which showed up 500 feet before the driver approached it; 2) Street Sign Trigger: the presentation of a street sign with a street name appeared when subjects' simulator vehicle arrived at 200 feet before an intersection (see Figure 2).

a b

Figure 2. Screenshots of two types of triggers in the experiment (a. presentation of an intersection indicated by a traffic light; b. presentation of a street sign)

2.5. Measurement

Navigation performance was calculated according to the number of wrong turns in navigating the driving simulator to the destination. Several driving behavioral measures were also reported here. These were driver's longitudinal velocity (feet/second), number of collisions, lateral lane position with respect to the roadway dividing line (feet), and frequency of central line crossing.

In order to measure ERPs in response to the secondary task, the EEG was recorded during the navigation task. The reference electrodes were placed on the left and right mastoids and the ground electrode was placed mid-forehead. The horizontal and vertical electrooculogram (EOG)[2]

[2] Electro-oculogram (EOG) measures the amplitude of the standing potential and light response.

were recorded with electrodes placed 10 mm away from the outer canthi of both eyes and below and above the left eye. Signals were digitized at 250 Hz.

Along with markers indicating stimulus and response onsets, the EEG and EOG channels were routed to an A/D converter. The EEG data were digitally filtered with 35 Hz lowpass and 0.1 Hz highpass and were epoched into periods of 1000 ms (including a 100 ms prestimulus baseline). During off-line computations, single trial data were sorted by electrode and stimulus types. Before averaging, ocular artifacts were removed from the EEG signal using a regression procedure implemented in the Neuroscan software (Semlitsch et al., 1986). The ERPs were then averaged separately for all experimental conditions. The peak amplitudes and latencies of P300 waveforms, identified between 250 and 650 ms following stimulus onset (Houston et al., 2004) were measured at the following sites: Fp1, Fp2, F3, F4, F7, F8, Ft7, Ft8, Ft9, Ft10, Fc3, Fc4, T3, T4, C3, C4, Tp7, Tp8, Cp3, Cp4, T5, T6, P3, P4, Po1, Po2, O1, O2, Fz, Cz, Pz, Oz. The left hemisphere contained the channels of Fp1, F3, F7, Ft7, Ft9, Fc3, T3, C3, Tp7, Cp3, T5, P3, Po1, O1, and the right hemisphere included the channels of Fp2, F4, F8, Ft8, Ft10, Fc4, T4, C4, Tp8, Cp4, T6, P4, Po2, O2. P3, P4, Pz were representative of the parietal lobe, T3, T4, T5, T6 were representative of the temporal lobe, F3, F4, F7, F8, FZ were representative of the frontal lobe, and O1, O2, Oz were representative of the occipital lobe.

2.6. Data analysis

Analysis of variance (ANOVA) was first performed to examine potential group differences in demographic factors including age, the number of years since a driver obtained his/her first driver license and estimated annual mileage. Chi square analysis was used for gender (categorical variables). A multivariate analysis of variance (MANOVA) was then conducted with navigation and driving behavioral variables serving as dependent measurement. In the next step, repeated measures analysis of variance was performed to analyze P300 amplitude and latency in order to detect the effect of types of navigators, types of triggers, different hemispheres, and different location. Finally, we analyzed the effect of types of navigators and types of triggers on each different hemispheres and locations.

3. Results

3.1. Descriptive statistics

There were no significant differences between good and poor navigators in terms of age, [$F(1,15)=1.83$, $p>0.05$], the number of years since a driver obtained his/her first driver license [$F(1,15)=1.39$, $p>0.05$], estimated annual mileage [$F(1,15)=2.0$, $p>0.05$], or gender [Pearson $\chi^2(1) = 2.84$, $p>0.05$] (see Table 1).

Table 1. Mean and standard deviations for demographic, driving history, navigation and driving performance variables

	Good navigators	Poor navigators
Demographic and driving history variables		
Age (years)	22.78 (3.3)	21 (1.77)
Gender (% Male)	0.78	0.38
Year license (years)	4.44 (1.74)	3.38 (1.99)
Annual mileage (miles)	12361.11 (6375.14)	8781.25 (3392.32)
Navigation performance variable		
Number of wrong turns	0.89 (1.05)	8.38 (5.01)
Driving performance variables		
Average speed (feet/s)	16.02 (2.47)	13.38 (2.53)
Frequency of central line crossing	4.67 (4.09)	8.75 (10.7)
Frequency of collision with other vehicles	1.44 (1.59)	3.38 (3.74)

3.2. Navigation and driving performance analysis

In the second step, a Multivariate Analysis of Variance (MANOVA) with an alpha level of 0.05 was conducted to examine the group differences in navigation and driving performance. Types of navigator (good vs. poor) were entered as an independent variable. The level of navigation performance was measured with the number of wrong turns; while driving performance was estimated according to three driving behavioral measures: average speed (feet/second), frequency of central line crossing, and frequency of collision with other vehicles.

As expected, good navigators had less number of wrong turns than poor navigators, [$F(1, 15)=19.27$, $p=0.001$; Wilks Lambda=0.41, $p<0.05$]. Moreover, there was a significant difference between good and poor navigators in the average driving speed [$F(1, 15)=4.74$, $p<0.05$; Wilks Lambda=0.41, $p<0.05$]. However, no significant differences were revealed for the frequency of central line crossing [$F(1, 15)=1.13$, $p>0.05$; Wilks Lambda=0.41, $p<0.05$], or frequency of collision with other vehicles [$F(1, 15)=2.01$, $p>0.05$; Wilks Lambda=0.41, $p<0.05$].

3.3. Repeated measures analysis on P300

Repeated measures analysis of variance (ANOVA; SPSS) was performed to analyze P300 amplitude and latency with types of navigator (good vs. poor) as a between-subject factor. The experiment design used for P300 amplitude was: 2 types of navigator (good vs. poor) × 2 types of trigger (intersection vs. street sign) × 2 hemispheres (left vs. right) × 4 electrode locations (frontal, temporal, parietal and occipital), where types of trigger, hemisphere, and electrode location were used as within-subject factors. The Geisser-Greenhouse conservative F-test was utilized as a correction in all cases to guard against violations of the sphericity assumption. Post hoc comparisons of the means were carried out by Duncan's multiple range tests.

Repeated ANOVA computed on P300 amplitude showed the following effects: (1) types of triggers [$F(1, 15)=7.10$, $p<0.05$, observed power=0.70]; (2) types of navigators [$F(1, 15)=11.10$, $p<0.05$, observed power=0.88]; (3) types of navigators × types of triggers [$F(1, 15)=4.79$, $p<0.05$, observed power=0.54]; (4) types of navigators × location [$F(3, 45)=3.91$, $p<0.05$, observed power=0.86]. No significant result of P300 latency was found through repeated ANOVA.

3.4. Simple effect analysis on P300

Analysis of simple effects indicated that good navigators exhibited smaller P300 amplitudes than poor navigators when intersections were presented on group averaged channels [$F(1, 15)=4.99$, $p<0.05$] (see Figure 3).

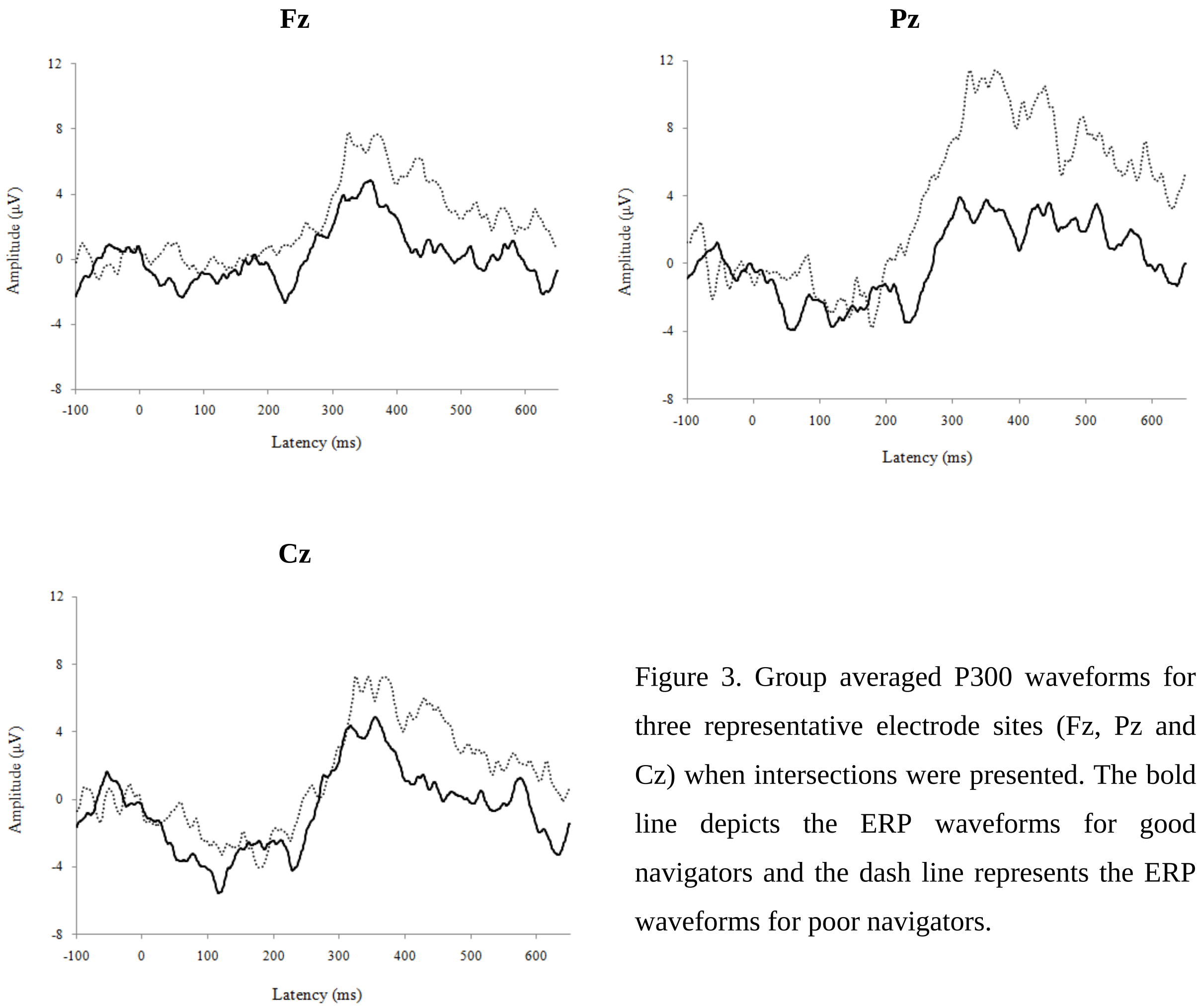


Figure 3. Group averaged P300 waveforms for three representative electrode sites (Fz, Pz and Cz) when intersections were presented. The bold line depicts the ERP waveforms for good navigators and the dash line represents the ERP waveforms for poor navigators.

Compared to poor navigators, good navigators also showed smaller P300 amplitudes on the left hemisphere [$F(1, 15)=9.20$, $p<0.05$, observed power=0.81], and the right hemisphere [$F(1, 15)=8.70$, $p<0.05$, observed power=0.79] when intersections were presented (see Figure 4 and 5).

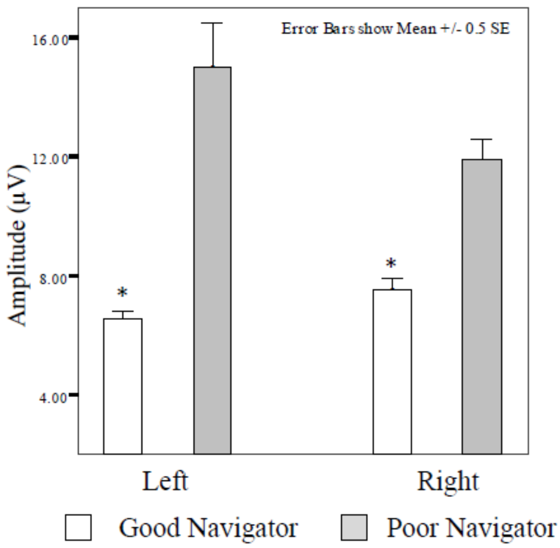


Figure 4. Comparison of mean P300 amplitude between good and poor navigators on the left and right hemispheres when intersections were presented (* denotes significant difference between good and poor navigators).

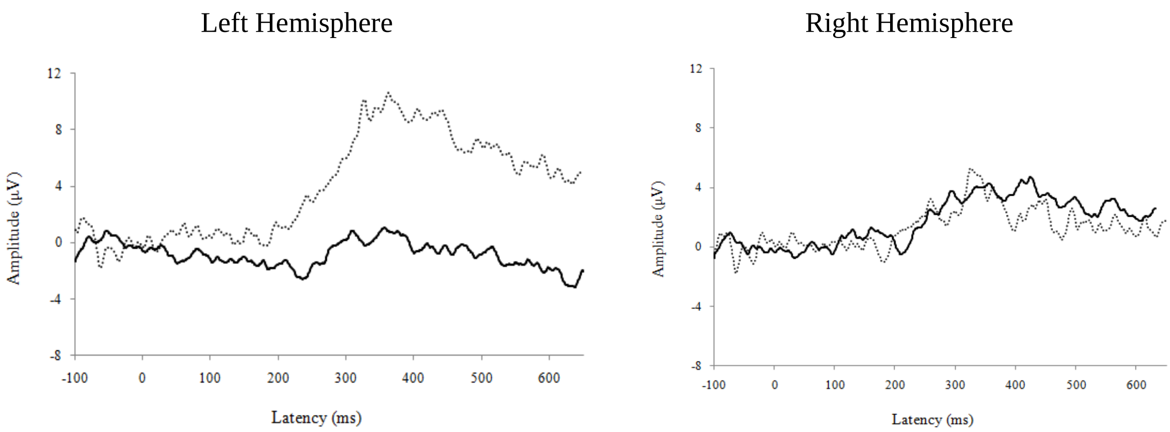


Figure 5. Grand mean P300 waveforms on the left hemisphere (left panel) and on right hemisphere (right panel) when intersections were presented. The bold line depicts the ERP waveforms for good navigators and the dash line represents the ERP waveforms for poor navigators.

Further analysis indicated that good navigators exhibited smaller P300 amplitudes than poor navigators on the temporal site [$F(1, 15)=5.50$, $p<0.05$, observed power=0.59], the parietal site

[*F*(1, 15)=7.08, *p*<0.05, observed power=0.70] and the occipital site [*F*(1,15)=20.79, *p*<0.05, observed power=0.99], but not on the frontal site when intersections were presented. When street signs were presented, this effect only occurred at the occipital site [*F*(1, 15)=6.05, *p*<0.05, observed power=0.63] (see Figure 6 and 7).

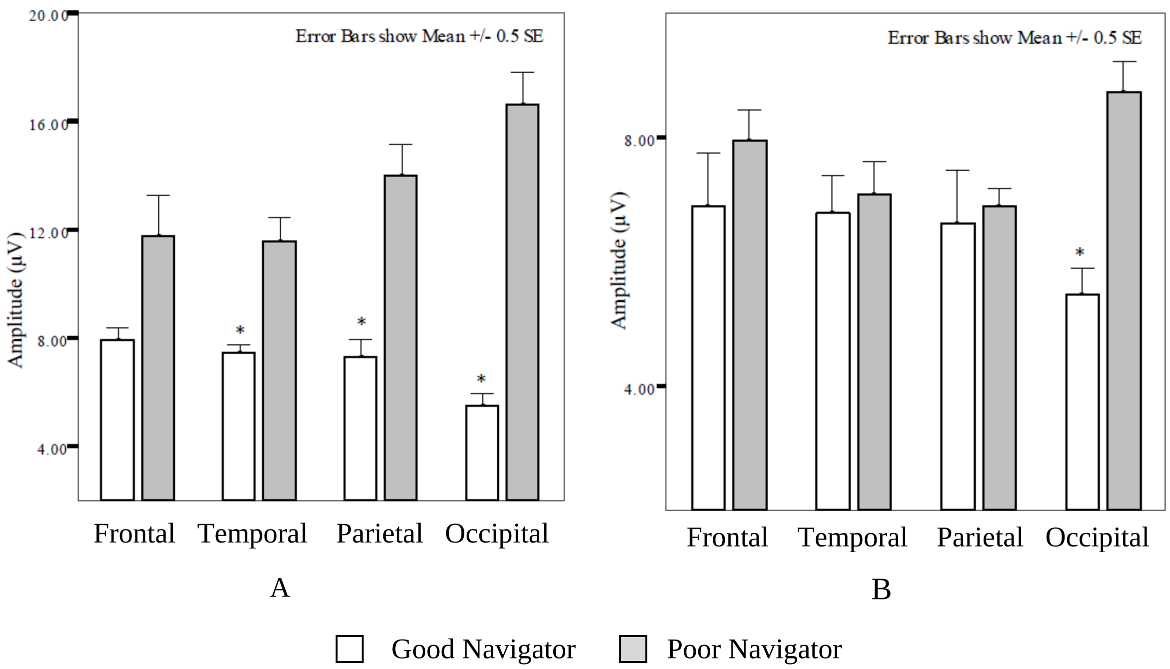
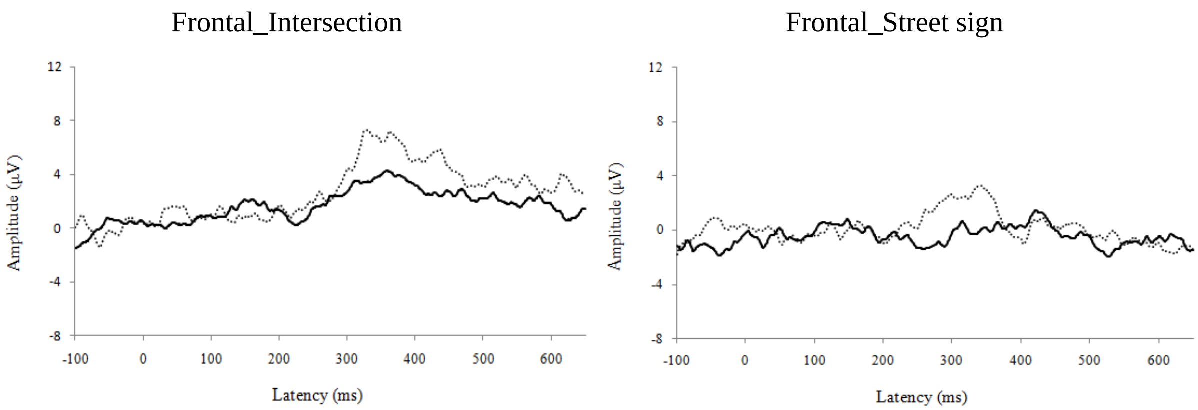


Figure 6. Comparison of mean P300 amplitude between good and poor navigators on the frontal, temporal, parietal and occipital sites. Panel A depicts mean P300 amplitude when intersections were presented. Panel B depicts P300 amplitude when street signs were presented (* denotes significant difference between good navigators and poor navigators).



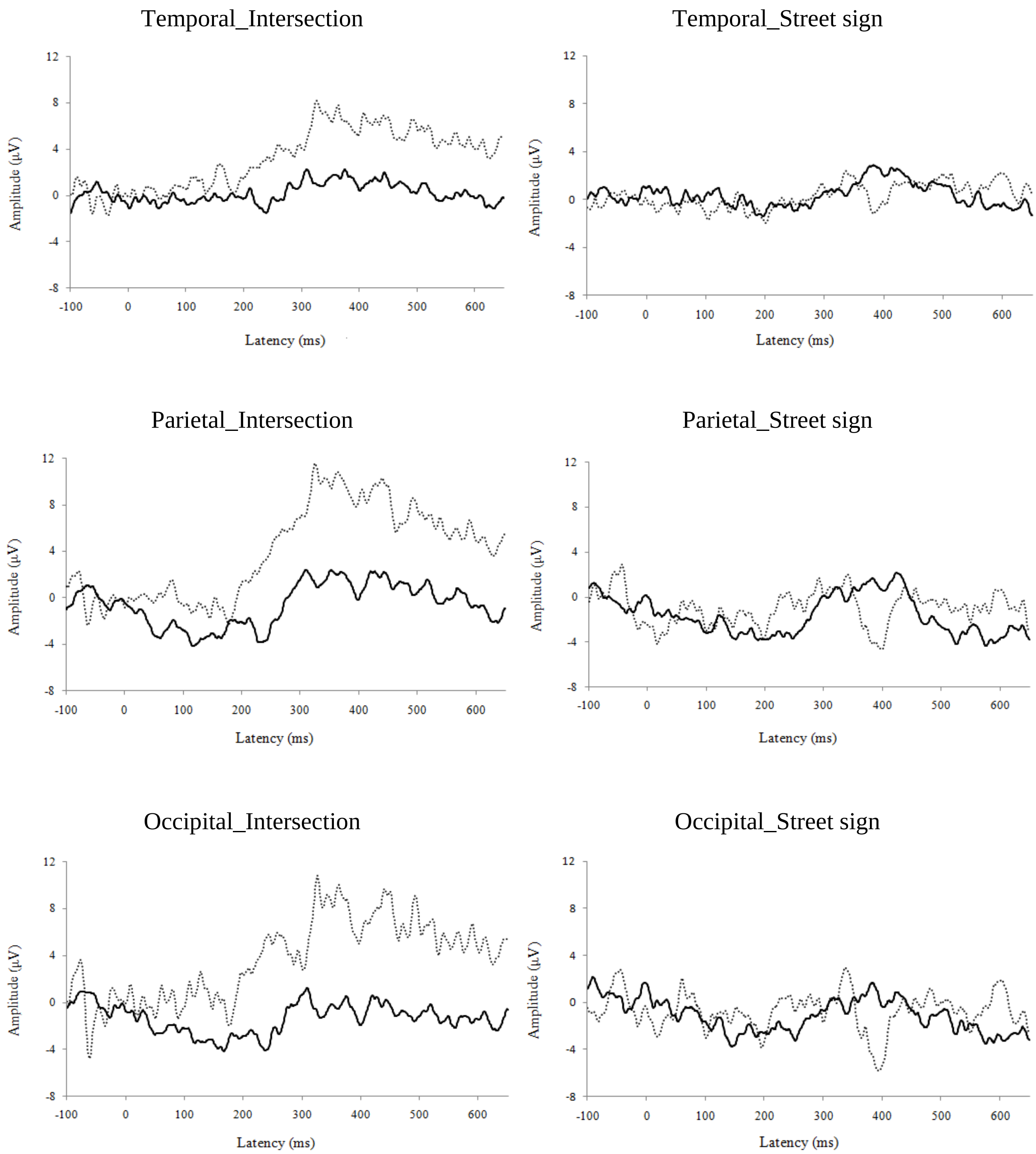


Figure 7. Grand mean P300 waveforms at the frontal, temporal, parietal, and occipital electrode sites. Left panels depict ERP waveforms when intersections were presented. Right panels depict ERP waveforms when street signs were presented. The bold line represents the ERP waveforms for good navigators and the dash line represents the ERP waveforms for poor navigators.

4. Discussion

The current study found that individual differences in navigation performance were reflected by the amplitude of the P300: poor navigators showed larger amplitude than good navigators on group averaged channels, the left and right hemisphere, the temporal, parietal and occipital regions when intersection triggers were presented to participants. When street signs were presented, the P300 amplitude of poor navigators was larger than that of good navigators on the occipital site.

The finding regarding the amplitude of the P300 was consistent with the neural efficiency hypothesis which has been widely tested in non-driving tasks (Beste et al., 2010; Lamm et al., 2005). This phenomenon is interpreted according to the neural efficiency hypothesis. According to this hypothesis, the central nervous system of good navigators is functioning in a more efficient way than the one of poor navigators (Lamm et al., 2005). Additionally, previous studies also indicate that P300 amplitude increases when the demand for mental resources increases (Sirevaag et al., 1989; Wickens et al., 1983). It is possible that the navigation task in driving was more difficult for poor navigators than good navigators, requiring more mental resources for poor navigators to process spatial information when they saw the intersection and planned the next turn. As a result, their P300 amplitudes were larger than those of good navigators and the individual differences between poor and good navigators can be explained by the different levels of mental resource needed to process the spatial information between these two groups.

Significant differences in the P300 amplitudes were found between good and poor navigators on the temporal, parietal, and occipital sites when intersection triggers were presented, which was consistent with the literature. First, previous neuropsychological studies find that the activation of the right hippocampus in particularly associated with accuracy of navigation (Maguire et al., 1998), while the left hippocampus is more active during episodic memory retrieval (Burgess et al., 2002). Because the current task involved navigation and memory retrieval (i.e., update a driver’s position and orientation on the basis of sensing self-motion over time), both left and right hippocampuses (located inside the medial temporal lobe) were activated. Second, the activation of the parietal regions is associated with the translation of stored allocentric information into the egocentric representations required to guide movement or to support imagery of the retrieval products (Burgess et al., 2002). According to the literature, the standard ERP effects most reliably obtained at parietal regions consists of the pronounced P300 evoked by the presentation of the navigation cues (Heil, 2002). Finally, The medial occipital cortex is activated by visually guided eye movements and the performance of motor actions (Astafiev et al., 2004). In this study, because two types of triggers (intersection and street sign) are visual stimuli, the activation of the occipital lobe is within our expectation. Good navigators may have better abilities in the navigation, memory retrieval, and visual stimuli processing than poor navigators, the amplitudes of P300 are smaller for good navigators on the temporal, parietal and occipital sites.

On the other hand, significant differences in the P300 amplitudes were obtained on the occipital site only when street sign triggers were presented. This was might due to the absence of mental rotation (i.e., the navigation task could be solved without mental rotation). Specifically, both good and poor navigators did not rely on street signs and, for example, they may count the number of blocks and decide which way they turn accordingly (Wu et al., 2011). If street signs were not necessary to help the driver make a correct turn, the P300 would not be evoked by the presentation of the street sign, and the temporal and parietal regions would not be activated accordingly. However, people may still look at the street sign when it appeared. As good navigators had better ability in visual stimuli processing than poor navigators, the occipital site was activated when street signs were displayed and the amplitudes of P300 were larger for poor navigators.

The difference of navigation performance between the two groups was not affected by driving performance. The driving performance of the two groups did not reveal any significant difference in terms of frequency of central line crossing and frequency of collisions with other vehicles. In other words, the good navigators had better spatial navigation abilities than the poor navigators, rather than sacrificing their driving performance to reach the better navigation performance. Moreover, although good navigators drove faster than poor navigators, it was probably because poor navigators made more wrong turns and had to stop and turn around in the intersections more frequently.

In the current study, the difficulty levels of navigation and driving task were the same for two groups of subjects. In future study, different levels of navigation and driving difficulty may be considered to examine the difference between these two groups in processing spatial information, with different demands as a within-subject variable. Although the sample size was not large (Similar amount and even less number of subjects were also used in other P300 studies, e.g., Murata et al., 2005; Yagi et al., 2009), the analysis conducted did present the encouraging possibility that the poor navigators had larger P300 amplitude than good navigators. However, more subjects and stimuli triggers in each map are also expected in future study to replicate the results of the current study. Also, we could employ the ERP technique to study the individual difference in navigation performance for drivers in other age groups (e.g., elder drivers) and compared to the current findings obtained from a relatively young population. In addition, we currently simulated a paper-based map and showed it on a computer display. There might be a difference between a real paper map and what we showed drivers in this study. Therefore, individual differences of brain potentials in using real paper maps will be examined in the next step. Other navigation assistance systems (e.g., GPS with an electronic map) might be expected as well along this line of work (Ma and Kaber, 2007).

Moreover, in this study, when drivers made a wrong turn, collision will occur and drivers had to try other directions until it is correct. Although unrealistic, the design of placing unseen collision bar on the road for each wrong turn was necessary to avoid the serious system failure. In STISIM, all events (e.g., intersection, signal light, street sign, etc) must be predefined in order based on the distance (e.g., an intersection at 1000 feet; an approaching vehicle at 1200 feet, etc). If drivers made a wrong turn and continued to drive without immediate interventions, all the following events will be reordered, and the driving scenario will no longer match the map we showed drivers. We acknowledged that it is not realistic to make a collision and driver might have different behaviors if they know they might collide when making a wrong turn. Also, the current study using a driving simulator may produce different feelings of risk-taking behaviors for subjects compared with real-road driving. Thus, real road tests may be needed in future studies to validate these findings.

We were working towards the goal to explore individual differences in human performance not only by behavioral measurement, but also by psychophysiological indexes. The latter reflected the cognitive and neurological difference between the individuals and could help researchers understand the neurological mechanism in individual differences as well as design better adaptive systems for different users.

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