# NEURAL BASIS FOR SOME COGNITIVE RISK OF USING MOBILE PHONES DURING DRIVING

Takashi Hamada (AIST, Japan)

hamada-takashi@aist.go.jp

ABSTRACT: Two studies have been conducted on some cognitive risks of using mobile phones during driving. Our previous study showed that voices received by a mobile phone in a car are often interrupted and replaced by silence due to transmission errors. We found with magnetoencephalography (MEG) that such interruptions of voices activate the right parietal cortex, which suggests that auditory attention can not be fully allocated for driving at moments of the interruptions. Secondly, base on evidence that the dorsal part of the visual system treats 'where' aspects of information and the ventral 'what' aspects, we assumed that driving in a situation is predominated by either of the subsystems. Besides, hearing through a mobile phone was assumed to induce visual imageries which are predominated in a situation by either of the subsystems. Subjects thereby concurrently carried out simplified visual and auditory tasks, each with either 'where' or 'what' aspects. Reaction times were found to be longer when aspects in the auditory task were the same as those in the visual task than when different.

## 1 General introduction

Uses of mobile phones during driving are often risky [1-8]. As a matter of fact, if a hand is used for manipulating a mobile phone, it can not be used for driving; If the eyes gaze at the phone, they can not be directed to the scene in front of the car; If the cognitive resources are used for communicating with a mobile phone, they can not be fully allocated for driving. Thus, the risks of using mobile phones during driving are composed of manual, ocular and cognitive factors. Although the cognitive factors are obviously based on neural activities in the brain, they are only rarely studied from the point of neuroscience.

We studied the neural basis for some of the cognitive factors. Firstly, based on the evidence that voices through mobile phones are often interrupted and replaced by silence in a moving car [9], we asked how the interrupted voices would burden the listener's brain [10]. Secondly, a dichotomy of the visual system that the dorsal subsystem in the parietal cortex treats spatial or 'where' aspect of visual information and the ventral in the inferior temporal cortex for 'what' aspect such as colors and shapes [11, 12] was applied for elucidating one of the cognitive factors. Our assumptions were that driving in a situation would be predominated by either 'where' or 'what' aspects and that hearing through a mobile phone would induce visual imageries which would also be predominated in a situation by either of the two aspects.

# 2 Brain activities to interrupted voices

## 2.1 Introduction

As we experience ourselves, voices through mobile phones are sometimes difficult to be heard. We previously found that this is because the voices are often contaminated by 3 types of noises: delay of transmission, distraction of their spectral structure and silent interruptions [9]. These noises are characterized in common by their sudden starts and sudden ends, and by their durations of several hundreds ms, which presumably result from occasional drops or distortion of packets (compressed segments) of voices while processed digitally [14-16]. We previously found that long voices (vowel) transmitted to a mobile phone in a car were interrupted more frequently, if the car was moving (6.4 times per minutes on average) than at rest (4.8 times per minutes on average); The average of their durations was 424 ms when the car was moving [9]. We asked how these interruptions of voices affect the human brain. We thereby used magnetoencephalography (MEG), which allows to record the magnetic counterpart of the electrical activity in the brain and has spatial and temporal resolutions finer than those in other measures such as behavioural outputs and heart rates.

## 2.2 Methods

Eleven right-handed subjects listened to voices or pure tones, some parts of which were interrupted and replaced by silence for either 200, 500 or 1000 ms at 10 times a minute on average (Fig.1a). Their brain activities were measured with MEG, whose signals were averaged with respect to starts of the interruptions and then analyzed with multiple-dipole model [17].

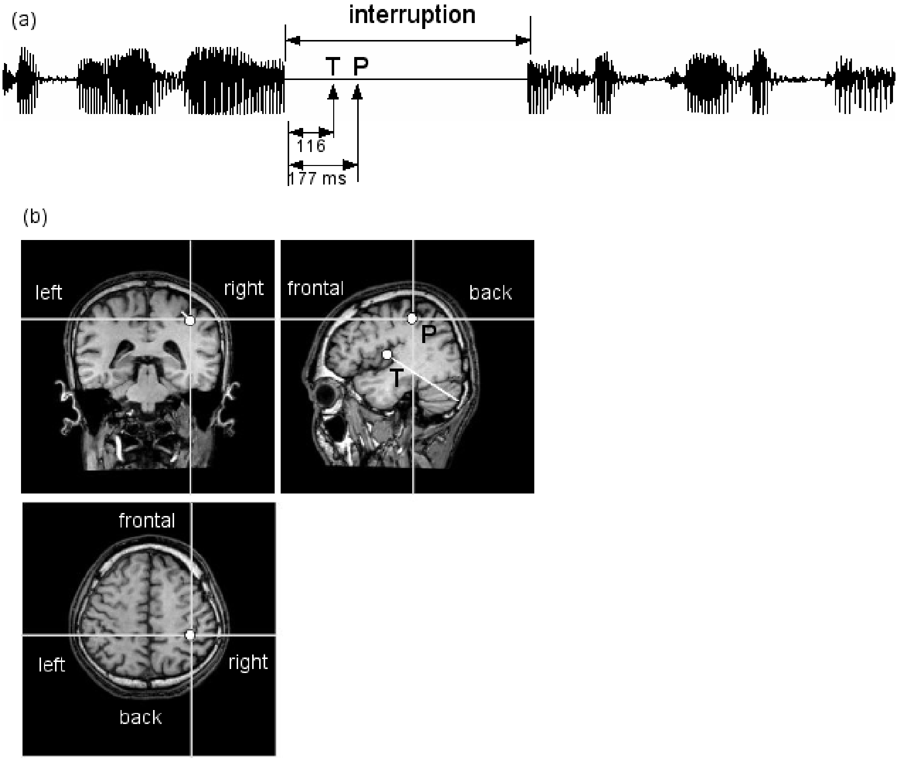


Fig.1.a: Interruptions of voices and times of occurrence of two of the three dipoles, one (T) in the temporal cortex and the other (P) in the right parietal cortex, b: The position and direction of the parietal dipole (P). The dipole in the right temporal cortex (T) is also shown in the sagittal section of the brain (upper right).

## 2.3 Results and discussion

The interruptions of voices elicited neural activities after starts and ends of, but not during, the interruptions. The activities after the starts could be explained by three dipoles in the brain: One in each of the left and right temporal (auditory) cortices (T) and one in the parietal cortex (P) of the right hemisphere (Fig.1b). Ends of the interruptions elicited T's in the temporal cortices, but not P in the right parietal cortex. Interruptions of pure tones also elicited T's, but not P. Thus, T's could be due to offsets or onsets of acoustic energy, while P due to offsets of semantic flow. Previous studies [18, 19] related the right parietal cortex to auditory attention. Since the dipole P was activated after starts of the interruptions, but neither during nor after the interruptions, we hypothesize that auditory attention is solicited by sudden stops of semantic flow, rather than by waiting or by attempts to fill the message etc.

Although vision is essential for driving, audition is also required for driving. As an example, the in-vehicle information systems often utilize auditory cues for navigation and alerting [20, 21]. Audition is also constantly required for the drivers to estimate the vehicle speed [22] and to detect events back of the car. If a driver listens to voices through a mobile phone during driving, a part of his resource for auditory attention should be used by the listening to the phone. The remaining part of the resource should be further reduced at moments when voices through a mobile phone are interrupted, which could become a risk for driving.

# 3 Concurrent visual and auditory tasks with ‘where’ and ‘what’ aspects

## *3.1 Introduction*

Although driving tasks are complex which require both of the dorsal and the ventral visual subsystems (Fig.2), there should be a predominance from one to the other according to a particular situation. For example, the dorsal subsystem would be predominantly used for having the car within the lane or keeping the distance between the cars, i.e. for controlling the car based on locations of visual objects. In other situations, the ventral subsystem would be predominated for identifying obstacles or colors of traffic signals. Besides, hearing through a mobile phone could sometimes induce visual imagery which would again predominantly use either of the visual subsystems depending on situations. For instance, if a partner of the phone explains the place of Institut Lumière by saying "For reaching there, you start from the station Part-Dieu, go straight two blocks, turn to the right and then to the left...", the listener should then mentally image the visual map of the route; The dorsal visual subsystem would then be activated [23]. In another situation, if the partner of the phone says “Her dress yesterday was beautiful, wasn’t it?”, the listener should then visually image its colors; The ventral visual subsystem would then be activated [24]. Thus, the concurrent driving and hearing through a mobile phone in a situation would be schematically reduced to neural activations in one of the four combinations, i.e. two (dorsal or ventral) through vision multiplied by two (dorsal or ventral) through audition. We asked which of the combinations would be more dangerous than the others.

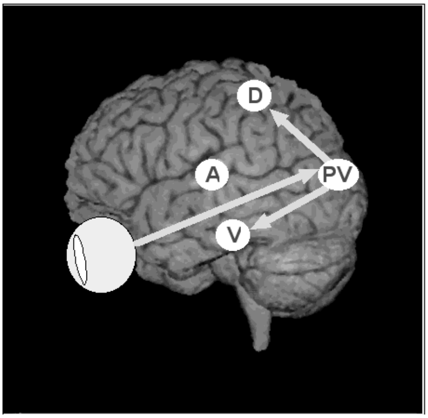


Fig.2. Dorsal (D) and ventral (V) visual subsystem. A: auditory cortex, PV: primary visual cortex.

## 3.2 Methods

Subjects (n=7) concurrently carried out visual and auditory tasks (Fig.3), while their MEG were recorded. A spot light was presented either as red or green at the center of the visual field in the visual color task (vC), whereas at the left or the right position in the visual location task (vL). They differentially pushed one of the two buttons according to the aspects of the visual stimuli with a finger of his right hand (the left button to green or left spots and the right button to red or right spots) . Reaction times (RTs) of pushing the buttons were recorded. In a trial of the auditory color task (aC), they heard the name of a colored object, such as "apple" and "cabbage", and had to push a button with his left hand if the object was red, but not if green. In the first trial of the auditory location task (aL), they visually imaged a pointer at the center of a 3x3 imaged matrix. In each of the trials, they heard a direction word, "left", "right", "up" or "down", and accordingly moved the pointer for one step in the matrix. If the pointer exceeded the matrix, they pushed the button with a finger of his left hand and the trials were reset. Otherwise they only memorized the location of the pointer in the matrix for the next trial.

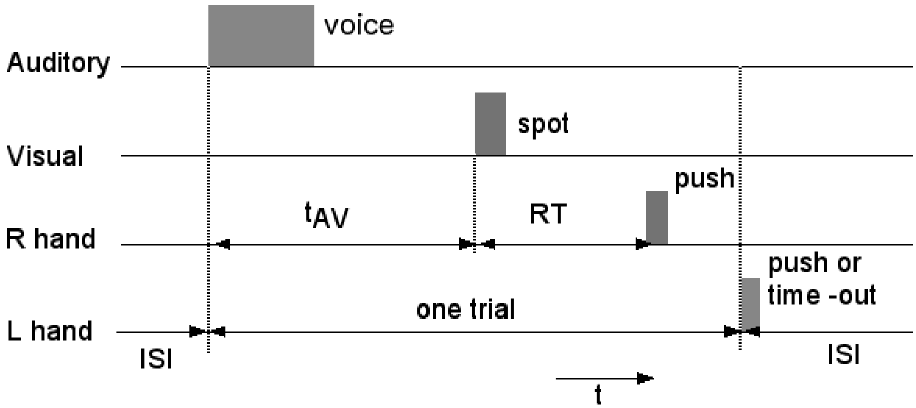


Fig.3. Time sequences of the audiovisual tasks

In an experimental session, one of the auditory tasks (aC or aL) and one of the visual tasks (vC or vL) were combined. Onsets of the former with respect to the latter ($t_{AV}$) were randomly varied between -500 and -250 ms from trial to trial in a session. The subjects carried out the visual tasks with priority over the auditory tasks. Two further sessions only with visual stimuli (vL or vC) were carried out as the controls. More than 250 trials were repeated in a session. Errors in pushing the buttons occurred in trials less than 5 %; RTs in such trials were excluded from analysis. RTs at $t_{AV}$ of -500 and -250 in a session of a subject were combined and finally grand-averaged across the subjects, which were statistically compared among the different sessions.

## 3.3 Results and discussion

Since MEG signals were too complicated to be analysed, only behavioral results are described. Fig.4a shows that RTs in the audiovisual sessions were always longer than that in the control, which suggests that concurrent hearing is dangerous for driving. RTs in aLvL and RTs in aCvL were subtracted by RT in vL in each of the subject. The results represent to what extent RTs in vL were increased by the concurrent auditory tasks (aL or aC) in the subject. These increased amounts were named RT*(aLvL) and RT*(aCvL) of the subject, respectively. Similarly, RTs in aLvC and RTs in aCvC were subtracted by RT in vC, and each of the results was named RT*(aLvC) and RT*(aCvC) of the subject. Grand-averages of these increased amounts are represented by two pairs of two bars (Fig.4b). The figure shows that RT*(aLvL) are significantly longer than RT*(aLvC) (312 ms vs 192 ms, respectively; p<0.05), and RT*(aCvC) are also significantly longer than RT*(aCvL) (152 ms vs 64 ms, respectively; p<0.01).

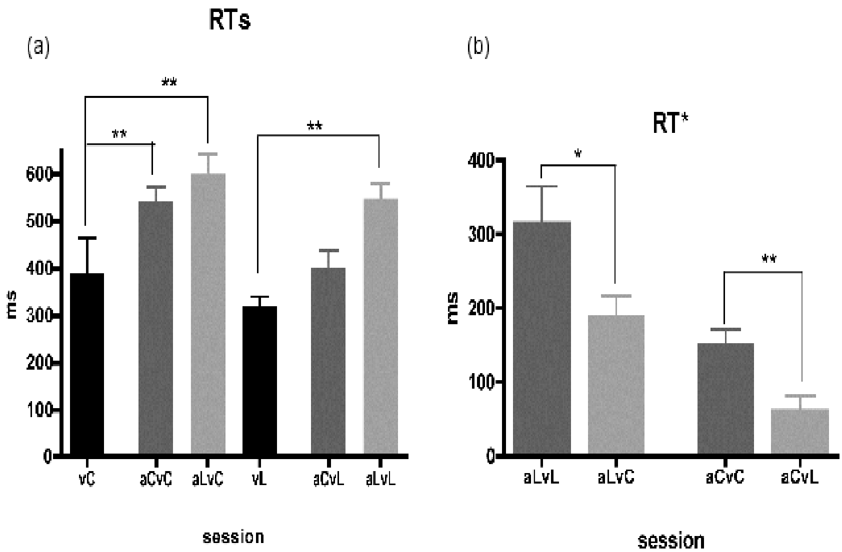


Fig.4.a: Grand-averaged RTs in different sessions. Error bars indicate SD. Two bars connected by a horizontal line have statistically different heights. **: p<0.01, *: p<0.05. b: Grad-averaged RTs in the audiovisual sessions subtracted by RT in the corresponding control session. Others are the same as in a.

In summary, RTs in the visual tasks were more elongated when the concurrent auditory task had the same aspect as the visual task than when different. The dichotomy of the human visual system can account for these results (Fig.5). As an example, since both the tasks in aLvL are supposed to use the dorsal subsystem, the subsystem could not be fully allocated for the visual task vL. In contrast, in the session of aLvC, since the auditory task aL is supposed to use the dorsal subsystem and the visual task vC the ventral, the ventral subsystem could be fully allocated for the visual task vC. These considerations could explain why RTs were more increased by addition of the auditory task in aLvL than in aLvC. Similar arguments apply for the difference of RTs between the sessions of aCvC and aCvL. The results implicate that hearing through a mobile phone during driving would be more dangerous when aspects of information with which hearing and driving should deal are the same than when different.

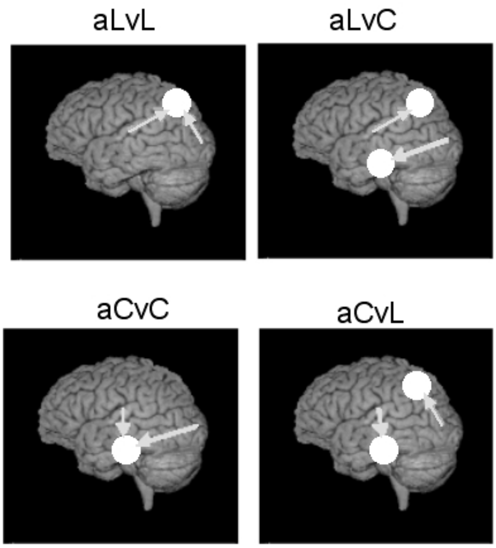


Fig.5. Neural explanations of the results

## 4 General discussion

Two studies tried to elucidate cognitive risks of using mobile phones during driving from the point of neuroscience. The first study used MEG to assess the impact of phone communication interruptions to the brain. The results showed that the right parietal cortex was activated after starts of the interruptions, which suggests that the neural resource for auditory attention could then be less allocated for driving. Behavioral experiments in realistic situations are required for validating this hypothesis. The second study was based on the dichotomy of the human visual system: dorsal subsystem for "where" aspects of information and ventral for "what" aspects, as a new type of the multiple resource models [25]. The experiments used reaction times to asses the possible interference on visual tasks by visual imagery induced by the auditory communication. The results implicate that concurrent driving and hearing through a mobile phone could be more dangerous if aspects of information with which driving and visual imagery induced by hearing should deal are of the same type, i.e. both of color or both of location, than when different.

In the first experiment, brain activities to the interruptions were successfully described by dipoles. However, MEG signals in the second study were too complicated to be analyzed, presumably because the experimental setup was not simple enough. Neural studies have advantages that they have finer spatial and temporal resolutions than behavioral or psychophysiological studies, but have disadvantages that they generally require simplified, not realistic, setups. Thus, these different types of studies have to be combined for fully analyzing cognitive risks of using mobile phones during driving.

# 5 References


[1] Alm, H. and Nilsson, L. :The effect of a mobile telephone task on driver behaviour in a car following situation, Accid. Analy. and Prev., 1995, 27, pp. 707-715

[2] Brookhuis, K. A., de Varies, G. and de Waard, D.: The effect of mobile telephoning on driving performance, Accid. Analy. and Prev., 1991, 23, pp. 309-316

[3] Brown, I.D., Tickner, A.H. and Simmonds, D.C.V.: Interference between concurrent tasks of driving and telephoning, J. Appl. Psych., 1969, 53, pp. 419-424

[4] Consiglio, W., Driscoll, P., Witte, M. and Berg, P.: Effect of mobile telephone conversations and other potential interference on reaction time in a braking response, Accid. Analy. and Prev., 2003, 35, pp. 495-500

[5] Laberge-Nadeau, C., Maag, U., Bellavance, F., Lapierre, S.D., Desjaardins, D., Messier S. et al.,: Wireless telephones and the risk of road crashes, Accid. Analy. and Prev., 2003, 35, pp. 649-660

[6] Törnros, J. and Bolling, A.: Mobile phone use – effects of conversation on mental workload and driving speed in rural and urban environments, Trans. Res. F, 2006, 9, pp. 298-306

[7] Strayer, D.L., Drews, F.A., Crouch, D.J. and Johnston, W.A.: Cell phone and driving, in Walker, W. R. and Herrmann, D. (Eds.): 'Cognitive Technology: Transforming Thought and Society' (McFarland & Company Inc., Jefferson, NC. 2006)

[8] Horrey, W.J. and Wickens, C.D.: Examining the impact of cell phone conversations on driving using meta-analytic techniques, Hum. Fact., 2006, 48-1, pp. 196-205

[9] Kawano, K., Iwaki, S., Azuma, Y., Moriwaki, T. and Hamada, T.: Degraded voices through mobile phones and their neural effects: A possible risk of using mobile phones during driving, Trans. Res. F, 2005, 8, pp. 331-340

[10] Hamada, T., Iwaki, S. and Kawano, T.: Speech offsets activate the right parietal cortex, Hearing Research, 2004, 195, pp. 75-78

[11] Jacob, P. and Jeannerod, M. : 'Ways of seeing' (Oxford University Press, 2003)

[12] Pisella, L., Mohammad, A., and Rossetti, Y.: The timing of color and location processing in the motor context, Exp. Brain Res., 1998, 121, pp. 270-276

[13] Hamada, T., Trans. Res. F, 2008, 11, pp. 75-82.

[14] Enderes, T., Khoo, S.C., Somerville, C.A. and Samaras, K.: Impact of statistical multiplexing on voice quality in mobile networks, Mobile networks and applications, 2002, 7, pp. 153-161

[15] Janssen, J., De Vleeschauwer, D, Buchli, M. and Petit, G. H.: Assessing voice quality in packet-based telephony, IEEE Internet Comput., 6, pp. 48-56

[16] Robinson, H. M.: Voice quality, Packet, 2002, 4, pp. 15-17

[17] Hämäläinen, M., Hari, R., Ilmoniemi, R. J., Knuutila, J., and Lounasmaa, O. V. : Magnetoencephalography - theory, instrumentation, and

applications to noninvasive studies of the working human brain, Rev. Modern Phys., 1993, 65, pp. 413-497

[18] Kasai, K., Nakagome, K., Itoh, K., Koshida, I., Hata, A., Iwanami, A., Fukuda, M., Hiramatsu, K. I. and Kato, N.: Multiple generators in the auditory automatic discrimination process in humans, NeuroReport, 1999, 10, pp. 2267-2271

[19] Levänen, S., Ahonen, A., Hari, R., McEvoy, L. and Sams, M.: Deviant auditory stimuli activate human left and right auditory cortex differently, Cereb. Cortex, 1996, 6, pp. 288-296

[20] Liu, Y.-C.: Comparative study of the effects of auditory, visual and multimodality displays on drivers' performance in advanced traveler information systems, Ergonomics, 2001, 44, pp. 425-442

[21] Wiese, E. E. and Lee, J. D.: Auditory alerts for in-vehicle information systems: The effects of temporal conflict and sound parameters on driver attitudes and performance, Ergonomics, 2004, 47, pp. 965-986

[22] Evans, L.: Speed estimation from a moving automobile, Ergonimics, 1970, 13, pp. 219-230

[23] Mellet, E., Tzourio, N., Crivello, F., Joliot, M., Denis, M. and Mazoyer, B.: Functional anatomy of spatial mental imagery generated from verbal instructions, J. Neurosci., 1996, 16-20, pp. 6504-6512

[24] Howard, R.J., ffytche, D.H., Barnes, J., McKeefry, D., Ha Y., Woodruff, P.W., Bullmore, E.T., Simmons, A., Williams, S.C., David, A.S. and Brammer, M.: The functional anatomy of imaging and perceiving colours, NeuroReport, 1998, 9, pp. 1019-1023

[25] Wickens, C. D.: Multiple resources and performance prediction, Theoretical Issues in Ergonomics, 2002, 3, pp. 159-177.