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# Simulated car driving in fMRI—Cerebral activation patterns driving an unfamiliar and a familiar route

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ABSTRACT

Understanding the neuronal underpinnings of cognitive processes during car driving is essential to understanding the origin of automobile accidents. Using fMRI we aimed to reveal differences in activation distribution contrasting passively observing an unfamiliar versus a familiar route to analyse the importance of the degree of familiarity of a route on attention process. We developed a special driving simulation software known as "Mechanics & Traffic", which focuses on the physical properties of driving. Sixteen male police-academy students with special driving training were examined while passively watching the car on an unfamiliar route, following a training-period outside the scanner, and passively watching the car on the now familiar route. The driving task revealed activations in frontal, parietal, temporal, occipital lobes, the thalamus, and cerebellum. Direct comparison revealed significant activation for the unfamiliar route in the middle temporal and occipital cortex and in the cerebellum. Correlating activations with the influencing covariates of driving experience, the activation pattern was confirmed and an additional activation for the unfamiliar route was found in the inferior frontal and parahippocampal gyrus. The results give further evidence that driving a car is a complex cognitive skill. A training-period and a familiar, monotonous route seem to lead to a reduction in attention and perception processes which might be associated with a danger for commuters, even in specially trained drivers.



Human error is the most common reason for accidents in modern road-bound traffic. Of the 35,675 accidents in Germany in 2006 that resulted in death or injury, 82% were the result of human error (source: Federal Statistical Office, Wiesbaden, 2007).

Thus gaining insight into the principles and limitations of human information-processing in traffic situations would be a key factor in reducing the number of people killed (1.2 Mio/year) and injured (50 Mio/year) in traffic accidents (Source: Estimations of WHO World Health Organization, 2004). The current study focuses on the influence of unfamiliar versus familiar routes; familiar because studies of traffic-incidents have demonstrated a large number of accidents occurring on short, familiar, everyday routes. This subjective feeling of safety leads to the high risk on monotonous highways out of rush-hour traffic. Fatigue, low cognitive demand and underestimation all can lead to reduced attention [9]. However, a study measuring hemodynamic responses during monotonous simulated driving found evidence that a driver in such a situation may still be stressed resulting in an elevated blood pressure [23].

Past findings have already proven effective to maintain attention while driving on long and monotonous routes and are regularly included in driving training. However, one important question that remains is whether subjects with specialized training can avoid such attention deficits. While some studies have provided empirical support for this hypothesis [22], definitive evidence is still lacking. Furthermore, in some countries driving learning or driving at a younger age is performed with a passenger with long driving experience. A related interesting question is whether this person may also be affected of boredom during driving very familiar routes.

To analyse human error, several approaches are used. Rasmussen [14] introduced a skill-level-based approach, where tasks may require: (a) routine skills, like steering a car along a straight line; (b) rule-based behaviour; or (c) knowledge-based behaviour. Walter et al. investigated the neural correlates of driving, using a commercial speed-race simulator during fMRI. They found reduced activity in the medial superior temporal region while active driving compared to "passive driving conditions" [21]. With fMRI, Uchiyama et al. studied the task of keeping a safe distance in a traffic simulation and found activation in the anterior cingulate gyrus that was not revealed in the study performed by Walter et al. [19]. Brain activation study of a real car trip by performing a

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[18F]2-deoxy-2-fluoro-D-glucose Positron Emission Tomography (FDG-PET)-scan of subjects *after* driving 30 min on Tohoku University Campus showed good correspondence to earlier studies using traffic simulation software, proving the general possibility of the latter method [13]. Furthermore, this study could show that the differences between active and passive driving were only marginal; only the pre-motor areas were less activated during passive driving. Horikawa et al. also investigated driving processes with PET [11]. Other fMRI studies, focusing on special driving actions like starting and stopping, have revealed activation changes in the anterior cingulate and temporo-parietal cortex [3]. Another study used a very realistic driving environment to investigate the varying demands [16].

To provide reliable data for driving training, accident prevention and for traffic system simulation, it is necessary to deconstruct the process of driving a car into certain subtasks and assess the influence of boredom, stress, and difference in the degree of training driving a car on the behaviour of drivers [6,15]. In our driving simulation, we focus on the subtask of taking curves in an environment in which distractions have been reduced as much as possible investigate the risk factors mentioned above. Furthermore, we used the passive task instead of the active driving in the scanner to avoid any emotional reaction due to possible errors in the driving skills with the joystick as we wanted to focus on possible habituation. In very experienced drivers the real driving process normally does not lead to any significant attention to the steering process which is different with a joystick condition.

We hypothesized that regions of activation should be found in parietal and temporal regions for judging attention and extent of the drivers' workload and that there should be differences in activation patterns during driving an unfamiliar route versus a familiar route even in special trained drivers.

As experienced drivers and a relatively homogeneous group, sixteen students of a police-academy (North Rhine-Westphalian Police) were examined. All subjects were right-handed and between 22 and 37 years old (mean 26.9 years). No subject revealed any brain tissue abnormality on structural MRI performed at 1.5 T nor had any history of neurological or psychiatric disease. All participants were screened to insure limited experience playing video-games, which was important to ensure nearly the same starting ability prior to the training-period.

Informed written consent was obtained prior to scanning. All subjects had to complete a short questionnaire concerning handedness, relaxation within the scanner, subjective feeling during driving periods, their driving history including the numbers of years of experience, a yearly mileage-estimate and accidents number for the previous 2 years. The study was approved by the local ethics committee.

All policemen must complete a two-week driver course during their training. This special training consists of two blocks of 84 45-min sessions. The first block takes place in the police education centre and focuses on theory (e.g., the physics involved in driving, reaction time, etc.) and dynamic and static driving-exercises. The second block takes place in actual traffic situations, including high speed driving, navigating rush-hour traffic, etc. (information form the police-department of technique and traffic safety, Neuss).

The software "Mechanics & Traffic" Version 2.0 is a car simulation software developed by the department of physics at the University of Duisburg-Essen. It focuses on the physical properties of driving. The background activity seen on the screen was developed to present a scene with only a few trees passing to imitate conditions of a long, monotonous drive at night. The software allows the car to be viewed in top-down, follower (i.e., chase camera), or a first-person view. It utilizes a physics model that can be easily modified using an integrated model editor.

Images were acquired using a 1.5 T standard scanner (Magnetom Sonata, Siemens Medical Solutions, Erlangen, Germany) with a standard receive-only volume head coil.

A 3D Flash sequence (TR 10 ms, TE 4.5 ms, flip angle 30°, FOV 240 $mm^2$, matrix 512 × 512, slice thickness 1.5 mm) was acquired for individual registration of functional and structural images.

BOLD contrast images were acquired using a gradient echo-planar technique (TR 2840 ms, TE 45 ms, flip angle 90°, FOV 240 $mm^2$, matrix 64 × 64) with 34 transverse slices with 3 mm thickness and 0.3 mm slice gap. Three "dummy" scans were eliminated prior to data analysis to account for T1 relaxation effects. All subjects followed the instruction to avoid movement during the scanning procedure, and any movement was monitored visually during the measurement.

The first task consisted of 6 min of passively watching the output of "Mechanics & Traffic"while the computerized car was driven along a course. In order to compensate post-stimulus-undershoot, an On/Off-Paradigm in a blocked design was used, where a route full of bends (On-Paradigm) was altered with a ride down a straight lane (Off-Paradigm). Thus, cues that would eventually trigger driving actions (e.g. curves) could only be perceived during the On-Paradigm. The "Mechanics & Traffics" Software was new to the subjects until the first fMRI run. Every stimulus began and ended with the Off-Paradigm, with 5 alternating on/off sequences in between.

The subject trained to drive the computerized car in the computer simulator outside the MR-scanner for a minimum of 30 min until the complete track was safely mastered without deviating from the road.

The "Mechanics & Traffics" software stored position and velocity of the car in its internal database automatically. The last successful full training round was transferred from the database of the training console to the projecting console connected to the MRI for the second fMRI run which consisted again of 6 min of passively watching the software while the computerized car was driven along a course in the blocked design mentioned above, but now this route was familiar to the subjects.

For data analysis, SPM 5 software (Wellcome Department of Cognitive Neurology, London, UK) was used. Prior to statistical analysis images were realigned utilizing the sinc interpolation and normalized to the standard stereotactic space corresponding to the template from the Montreal Neurological Institute (http://www.mrc-cbu.cam.ac.uk/Imaging/mnispace.html). The head movement was restricted due to a fixation in the head coil. Residual movements were eliminated in the realignment part of the data pre-processing. The movements were checked, with none having to be excluded due to excessive activity. Bilinear interpolation was applied for normalization. The typical scanner drift due to temperature differences and shim changes was low (less than 0.3 mm over each scanning session). The images were smoothed with an isotropic Gaussian kernel of 7 mm. A voxel-by-voxel comparison according to the general linear model was used to calculate differences in activation between the active and resting condition. The model consisted of a box-car function convolved with the hemodynamic response function (hrf) [7] and the corresponding temporal derivative. High pass filtering with cut-off of 128 s and low-pass filtering with the hrf were applied.

Significant signal changes for each contrast were assessed by means of *t*-statistics on a voxel-by-voxel basis. The resulting set of voxel values for each contrast constituted a statistical parametric mapping (SPM) of the *t*-statistic. The threshold was set to $p < 0.05$ (FWE corrected (Family Wise Error)) for single subject analysis. The effect of interest was defined for each subject with a contrast vector producing a contrast image containing the contrast of the parameter estimated at each voxel [8].