TOWARDS AN EXPERIMENTAL PLATFORM FOR FUTURE DRIVER BEHAVIOR
RESEARCH BASED ON THE INTEGRATION OF ENGINEERING AND
NEUROSCIENTIFIC KNOW-HOW

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ABSTRACT

The problem of how the mind relates to the brain stands as one of the greatest challenges today, transforming the approach to social problems based on discoveries of how human experience and culture arise in cerebral activity. However, within the field of driver behaviour a gross disregard of the neural underpinnings of such behaviour tied to a behaviouristic approach, is endemic. A stalemate exists with numerous disputed qualitative psychological models.

In stark contrast, recent knowledge gained within neuroscience has already been fruitfully applied within other human factors’ fields. Being a human driver incorporates a broad complement of interrelated brain systems to perform driving tasks (or psychological functions) at hand, such as risk perception and obstacle avoidance. Accordingly, the proper level of analysis of such a psychological function is the level at which that function is represented in the brain.

Driver behaviour research is an integral element in providing a neurally-inspired computational model of general human behaviour. Consequently, driver error will be understood better, driver education enhanced, and computer-aided telekinesis for driving realised. The experimental platform within the driving environment provides proving grounds for models of general human behaviour.

To further driver behaviour modelling, collaboration is needed among investigators from the fields of neuroscience, psychology, mathematics, computer science, and engineering. In this process, the use of modern brain-imaging techniques will be invaluable. For example, from psychiatric evidence, brain imaging and (amygdala) activation could hold the key to solve a pressing question, relating to which environmental stimuli serve to instigate aggression.
STATE-OF-THE-ART TECHNOLOGIES FOR EXPERIMENTATION

Traffic Engineering

Given the diverse circumstances leading to motor vehicle crashes and the associated problem areas and issues, effective collision avoidance countermeasures can best be realized through comprehensive knowledge and understanding of both the events leading to crashes and the contributing driver, vehicle, roadway, and environmental factors. Likewise, with increasingly complex technologies being incorporated into vehicles, such as navigation systems, driver information systems, and wireless communications, there has been an associated increase in the demands placed on the driver and, as a consequence, a potential for increased risk of a crash. In an effort to enhance the capability to study wide-ranging problems and issues associated with the design and implementation of both crash avoidance systems and in-vehicle systems of convenience, a variety of analytical and hardware-based tools have been developed. These tools allow the assessment of driver performance and behavior under a variety of circumstances and conditions in settings that either approximate the real world or are in fact the real world.

An associated problem that has become increasingly apparent in the development of models of driver behavior over the last few years is the absence of reliable data with which simulated processes, such as car following, may be compared. Obtaining such data, and the associated increase in model validity that this would allow, is clearly becoming of greater importance since a reliable baseline is required against which improvements in traffic flow and safety produced by many advanced transport telematics systems can be judged. Variations in behavior between drivers and differences in acceleration and deceleration performance of vehicles result in perturbations in traffic flow, which in turn increase accident risk and reduce capacity. Measurement of such behavior can help in the understanding of the processes involved and the identification of remedial measures, for instance, driver training or advanced transport telematics, and a database of such knowledge could be used for direct analysis or as input to a microscopic simulation model.

An alternative to on-road data collection is the use of laboratory-based simulators in which the driver is placed in a fully controlled virtual environment where his/her reactions to external stimuli can be accurately measured in a systematic manner over as long a period as desired. However, the main drawback is the uncertainty about whether the measured driver responses reflect those that would occur in the real world. Regardless of its complexity, the simulator will always be unable to present the rich sensory patterns that occur in real driving, and if an error should be made, it will have little direct consequence on the driver. Nevertheless, such simulators have a significant role to play in research, particularly in the assessment of the effects of alcohol and drugs on driver performance and other factors that would be unsafe to test in a real vehicle surrounded by traffic.

Another alternative method of gaining information on behavior, however, is the use of an instrumented vehicle, which is driven in the traffic stream as a platform from which to observe the behavior of a test driver or adjacent drivers. This approach is realistic, accurate and relatively inexpensive (compared with simulators) and may be the only method that can produce a sufficient quality and quantity of data to allow the continued development and validation of simulation models.

Significant advances in computational and sensor technology have resulted in capabilities that for the first time allow the evaluation of drivers and systems under truly naturalistic, in situ
driving conditions (1). The need for such a capability is obvious given the frequent criticism of research in which the circumstances of data collection are questionable on the basis of realism and the highly controlled settings that are frequently used in such research. Furthermore, the need for field and operational testing of new in-vehicle technologies from the standpoint of effectiveness and safety often demands as realistic a setting as possible. With these requirements in mind, the US National Highway Traffic Safety Administration (NHTSA), for example, has developed a family of vehicle instrumentation systems which allow a wide range of on-the-road testing and evaluation of both conventional and advanced technologies. These systems are portable in that they can be installed in virtually any vehicle. This feature provides desirable versatility (off-the-shelf technology and extensive upgrade flexibility) and allows research to be carried out on a variety of test beds with a minimal investment in instrumentation.

Naturalistic data are viewed as falling into three categories, that is baseline, focused, and near-miss/incident data. In each of these areas, data collection is associated with its own characteristic set of requirements and constraints for an acquisition system (1). On most occasions, the onset and evolution of an event are not the only or primary data of interest. Therefore, instrumentation systems have the capability to pre-trigger data collection or, in other words, record antecedent data which define the conditions and actions preceding the event itself. The availability of these capabilities provides an invaluable tool for addressing a host of vital design and safety issues, and provides an excellent mechanism for validating laboratory-based simulators.

A vehicle instrumentation system can be composed of a diverse variety of sensors in order to allow collection of a variety of parameters and their derivative measures. To meet specific testing requirements, researchers can choose from amongst vehicle positioning and headway sensors, pedal and steering wheel sensors, accelerometers, head position measurement, and audio/video capturing.

Throughout the 1970s and 1980s, work on dynamic data collection was extended to allow the collection of a greater range of predominantly driver-based variables, such as heart rate, electro-dermal response, and electro-myographic measures of muscle tension in order to obtain a physiological measure of driver response to situational stimuli (5). Another area of interest is in examining the driver’s visual search pattern by using records of the driver’s eye movements. Until recently, the best way to undertake such an analysis was to use an ‘eye mark’ camera mounted on a helmet worn by the driver, though because of their bulk these were generally only applied in simulator experiments. Recent developments have now resulted in the availability of non-contact (dashboard-mounted) units, mainly in use by vehicle manufacturers (2).

A vehicle instrumentation system is an economical and versatile tool to support the data collection needs for research in a wide variety of transportation fields. Such a system is unique in that it can actually be installed into a subject’s personal vehicle, be inconspicuous to other drivers, and be unobtrusive to the driver. System features, such as extended video data collection, event triggering, and the system’s ability to pre-trigger data collection, allow researchers the flexibility to collect operational field data over long time periods without intervention. The ability to collect truly naturalistic data over extended periods of time is viewed as an important capability for supporting both human factors and vehicle engineering research covering conventional technologies, advanced technologies, as well as high-visibility driver behavior, such as aggressiveness and intoxication.
Neuroscience

Neuroscience has undergone explosive growth. New brain-imaging technologies have allowed researchers to address questions which were in the realm of aimless speculation two decades ago. The manner in which the brain computes in various tasks is being probed at a deep level by these brain-imaging techniques, with an increasing appreciation of the different networks being used to solve these tasks. There is simultaneously developing a neural modeling technology, which attempts to explain the underlying computations being performed by this set of networks. Furthermore, better computers have contributed to improved, more detailed models of neural function. It is becoming increasingly possible to link perception, attention, memory, and other aspects of cognition to neurobiology – which allows the fruits of modern neuroscience to bear on the nature of higher mental function. The study of cognition has moved firmly into the domain of biological science (6).

For example, recent efforts to integrate psychometric and neurobiological data about personality have stimulated diverse interdisciplinary applications. The dissociation of major brain systems linked to procedural and propositional memory and learning has clarified the clinical distinction between two components of personality: temperament and character. For example, temperament is defined in terms of individual differences in percept-based habits and skills (related to procedural memory and learning), which are regulated by the amygdala, hypothalamus, striatum, and other parts of the limbic system. In contrast, character can be defined in terms of individual differences in concept-based goals and values (related to propositional memory and learning), which are encoded by the hippocampal formation and neocortex. Recent descriptive, developmental, genetic, and neurobehavioural studies indicate that at least four dimensions of temperament (harm-avoidance, novelty-seeking, reward-dependence, and persistence) and three dimensions of character (self-directedness, cooperativeness, and self-transcendence) can be uniquely described and functionally dissociated (7).

Brain-Imaging Technologies

Perception, action, cognition and emotion can now be mapped in the brain by a growing family of techniques. Positron emission tomography (PET), functional magnetic resonance imaging (fMRI), event-related electrical/magnetic fields, and other non-invasive imaging techniques are rapidly evolving and providing an increasingly rich literature on the functional organization of the human brain. Spatially, temporally, physiologically and cognitively accurate computational models of the neural systems of human behavior are the ultimate objective of functional brain mapping.

PET and fMRI machines investigate the underlying neural activity in the brain indirectly, the first by measuring the two photons emitted in the positron annihilation process occurring during the radioactive decay of a suitable radio-nuclide, such as $\text{H}_2^{15}\text{O}$ injected into a subject at the start of an experiment; the second from the uneven distribution of nuclear spins (effectively that of the proton) when a subject is in a strong magnetic field (usually of 1.5 T, although a 12 T machine is being built especially for human brain imaging studies) (8). The PET measurement allows determination of regions of largest blood flow, corresponding to the largest 2-photon count. The fMRI measurement is termed that of blood oxygen level dependent (BOLD). This signal stems from the observation that during changes in neuronal activity there are local changes in the amount of oxygen in tissue, which alters the amount of oxygen carried by hemoglobin,
thereby disturbing the local polarisibility. In this system, a giant magnet surrounds the subject's head (Figure 1(a)). Changes in the direction of the magnetic field induce hydrogen atoms in the brain to emit radio signals. Much excitement surrounds the newer technique of fMRI in that no radioactive materials are needed and produces images at a higher resolution than PET. Since the method is non-invasive, researchers can do hundreds of scans on the same person and obtain very detailed information about a particular brain’s activity, as well as its structure.

The sensitivity of the two types of machines is not comparable. Spatially they have a few millimeters accuracy across the whole brain. However, temporally they are far less effective. PET measurements need to be summed over about 60-80 s, limiting the temporal accuracy considerably, while fMRI is far more sensitive to time, with differences in the time of activation of various regions being measurable down to a second by the ‘single event’ measurement approach. This has already produced the discovery of startling dissociations in the time domain, for example, between posterior and anterior cortical sites in working memory tasks (9).

Many cognitive studies have been performed using PET; there are now as many using fMRI, some duplicating the PET measurements. These results show very clear localization of function and the involvement of networks of cortical and subcortical sites in normal functioning of the brain during the solution of tasks. At the same time there has been considerable improvement in the understanding of brain activity in various mental diseases, such as schizophrenia, Alzheimer’s and Parkinson’s diseases. There have also been studies of patients with brain damage, to discover how the perturbed brain can still solve tasks, albeit slowly and inefficiently in many cases (8).

The magnetic field around the head, due to neural activity, although very low, is measurable by sensitive devices, such as superconducting quantum interference devices (SQUIDs). Starting from single coils to measure the magnetic field at a very coarse level, magnetoencephalography (MEG) measurements are now being made with sophisticated whole-head devices using 148 or even 250 measuring coils, leading to ever greater spatial sensitivity. Although it does not have the same spatial sensitivity as the other two, it has far better temporal sensitivity – down to a millisecond. Messages from the senses travel so swiftly through the brain that PET and fMRI cannot keep up. Thus, MEG fills in the temporal gap on the knowledge gained by PET and fMRI. This is also done with electroencephalography (EEG) (Figure 1(c)), which is being consistently used by a number of groups in partnership with PET and fMRI so as to determine the detailed time course of activation of known sites already implicated in a task by other devices (8).

This next generation of imaging technology, based on simultaneous measurements of fMRI in various combinations with MEG and EEG, will help researchers examine how various parts of the brain exchange information. One of the first experiments in which fMRI was used jointly with MEG produced a three-dimensional map of the areas of the brain that are activated by touching the five fingers of one hand. A New York University research team headed by Llinás found this map to be distorted in the brain of a patient who had two webbed fingers since birth. A few weeks after the man’s fingers were separated by surgery, however, parts of his brain reorganized and the map became almost normal (Figure 1(d)).

In another example, depicted in Figure 2, the rapidly shifting patterns of activity in the images reflect what goes on in the brain of a woman who is looking at a letter on a screen during a test at the EEG Systems Laboratory, California. The woman’s task is to decide whether the letter is located in the same place as a letter she has seen before. In the ‘low load’ test she
compares the new letter's location to a previous one. In the ‘high load’ test she compares the new location to three previous ones. The brighter colors reflect a higher degree of brain activation. A strong electrical signal sweeps across the frontal cortex of her right hemisphere 320 milliseconds after a new letter has appeared on the screen, as she compares the letter's location to three locations that she has seen before (Figure 2(a)). The same areas of her brain are activated, but less intensively, in the second image, as she compares a new letter's location to only one location that she has seen before. Only 140 milliseconds later (Figure 2(b)), a different set of electrical signals is recorded from the volunteer's brain, as recreated in these images. This time the frontal cortex of her left hemisphere is activated as she enters the location of the new letter into her working memory. After the screen goes blank (Figure 2(c)), the volunteer rehearses the new memory. This activity produces yet another electrical signal over her right hemisphere. The signals are more intense in the high-load than in the low-load condition.

**Output States**

Based on the understanding of the functioning of the brain systems for vision, the concept of output states in the brain can be put in perspective. Vision is the most extensively studied of the senses, and, in humans, the most valuable. A much simplified schematic diagram of the visual pathway is shown in Figure 2(d). Visual information gathered by the retina is first conveyed to neurons in the lateral geniculate nucleus (LGN), a structure in the thalamus. From there about a million neural fibers go to a region in the cortex called V1, the first cortical area devoted to vision. A prominent feature – but one rarely discussed by physiologists – is the fact that perhaps 10 times as many fibers descend from V1 and send information back to the LGN. From V1 the visual information travels along several parallel pathways to centers called V2, V3, V4, and many others. Some 30 different visual centers have been identified in monkey cerebral cortex. Again, practically all connections between different cortical centers are reciprocal.

The ubiquity of such loops of connectivity in the central nervous system blurs the distinction between higher and lower cortical centers. There is no strict hierarchy of sensory processing. The ‘higher’ centers receive information from the ‘lower’ centers, but these sources are modified, augmented, and censored by the ‘higher’ centers. The prominence of these return pathways, especially the massive fiber bundle from V1 to LGN, has been one of the great puzzles of cerebral architecture. The cortex is clearly more bent on introspection and confabulation than on forming an unbiased view of the outside world. Mental processes are therefore appropriately called reflective, and concomitant neural activity is cyclic, self-referent.

What distinguishes the thinking brain from computers, and from most artificial neural networks, is the fact that in thought processes there are no final, or output states (10).

**SETUP AND APPLICATION OF AN INTEGRATED EXPERIMENTAL PLATFORM**

**Integration – A Next Step**

From the author’s extensive literature study (11), to explore the multi-faceted research on drivers’ behavior, it can be concluded that gross disregard of the neural underpinnings of such behavior tied to a behavioristic approach is endemic to the field. In general, a stalemate exists with numerous disputed qualitative psychological models (12). Psychological research has been extremely valuable, but an approach where cognition and emotion are studied as brain functions is far more powerful. Additionally, studying the way cognition and emotion work in the brain
can help to choose between alternative psychological hypotheses – amongst all possible solutions to the question of how cognitions and emotions might work, the only relevant one (in understanding human behavior) is the solution which was put into the brain with creation (13). Being a human driver incorporates a broad complement of interrelated brain systems to perform driving tasks (psychological functions) at hand, such as lane keeping, speed choice, risk perception, and obstacle avoidance. The proper level of analysis of such a psychological function is the level at which that function is represented in the brain.

However, there are still those researchers maintaining that neurophysiological plausibility is irrelevant to psychological theorizing, and that the gap between knowledge of what brain structure is and how it produces behavior is so wide that any endeavor to make psychological theories neuronally plausible is at best unhelpful, and at worst positively misleading. These views, together with the fond hopes of opportunistic minimalists (like ‘strong AI’) (14) have been dashed – they had hoped they could leave out various detail, like functional neuroanatomy and neurochemistry, and they have learned that no, if one leaves out x, or y, or z, one cannot explain how the mind actually works. To understand what humans actually do while exposed to various traffic environments as opposed to what humans are capable of doing, it is of utmost importance to let the fruits of modern neuroscience bear on the nature of driver behavior models.

Integration Process
As discussed in a previous section, state-of-the-art technologies within transportation engineering offer advanced capabilities for data and parameter measurement and extraction from driver behavior experiments. A rich set of data can currently be obtained in such experiments performed in a simulator or instrumented vehicle, such as video and audio capturing, as well as spatial and temporal characteristics of objects forming part of the driving environment, especially those for the driver. Notwithstanding the diverse variety of data types available from driver behavior experiments, data mining is essentially based on the underlying behavioristic models presently applied in transportation engineering. The aim of a traditional model, such as a psychological or AI model, is to describe the performance of the subject, not the way that the performance is achieved. This puts such models in stark contrast to what has been an ongoing revolution in the understanding of how the human brain, given streams of input from a structured world by its sensory receptors, can perform functions and learn novel facts in a humanlike manner by means of a system which computes with simple neuron-like elements, acting in parallel. Thus, the neuroscientific approach is the reverse. In general, it starts with a model which incorporates brain-like processing and sees whether behavior emerges, which mimics that shown by people.

At the moment, the principal source of information on the global brain in action involves the discipline of functional brain imaging. Together with descriptions of the functions performed by the various brain areas, observed active while human subjects solve various tasks, these experimental paradigms are currently spearheading an attack on the modus operandi of the brain in toto (8). Thus, in order to align research on driver behavior so that contemporary neuroscience can bear on the knowledge and understanding of such behavior, a necessary step would be to incorporate brain-imaging devices into the sensor suite of driver behavior experiments. Accompanying the implementation of brain imaging, an imperative further step, needed to be taken by driver behavior modelers, would be to develop neural network simulations which give overall agreement in activations with that observed in brain-imaging experiments. These mentioned steps will contribute towards bringing driver behavior research on par with the
level of advanced knowledge on human behavior offered in modern neuroscience, and introduce the well-instrumented and closely-monitored experimental platform offered by driver behavior research into mainstream neuroscientific experimentation.

To illustrate the advances achievable in better understanding and modeling driver behavior through integration of neuroscientific principles and know-how into driver behavior experimentation, consider the collection of driver-based variables, such as heart rate and electrodermal response in order to obtain a physiological measure of driver response to situational stimuli. Not only can neuroscience provide an explanation of how the autonomic nervous system (ANS) and hormonal responses (leading to changes in heart rate and sweating) are brought about (13), but it can also shed light on the rather low utility of monitoring such driver-based variables in isolation. These visceral responses have relatively slow actions, too slow to be the factor determining which emotion the driver experiences at a given moment. A far more robust methodology currently available for linking up driver response to specific situational stimuli, would incorporate brain imaging and neuroscientific know-how of the specific brain networks been activated sequentially (down to milliseconds) to produce the mentioned visceral responses.

It is also important to note that in preparing driver behavior experimentation in order to incorporate principles and knowledge from neuroscience, the sensor suite for the collection of driver-based data should be capable, inter alia, to capture the environmental stimuli impinging on the human senses. Everything humans know about their world comes to them through their senses of sight, hearing, smell, taste, and touch. Although scientists recognize that there are several additional kinds of sensations, such as pain, pressure, temperature, joint position, muscle sense, and movement, these are generally included under ‘touch’. (The brain areas involved are called the somatosensory areas.) An example of capturing such a stream of input on a sensory receptor involves driver sight or vision. As mentioned in a previous section, recent developments have resulted in the availability of non-contact (dash-board-mounted) video cameras to tract driver’s eye movements. These records allow researchers to examine the driver’s visual search patterns and to extract which part of the driving scene is projected onto the driver’s retinas (in real-time).

**Final Remarks**

To further driver behavior modeling through the implementation of the envisaged integrated platform for experimentation, collaboration is needed among investigators from the fields of neuroscience, psychology, mathematics, computer science, and engineering. In this process, the use of modern brain-imaging techniques will be invaluable in establishing and applying knowledge in terms of the neural correlates of particular driving subtasks and different driver behaviors. Providing a neurally-inspired computational model of general human behavior is a challenge for decades to come. Driver behavior research should be seen as an integral element in achieving this quest. Consequently, driver error will be understood better, driver education enhanced, and computer-aided telekinesis for driving realized. Above and beyond, the experimental platform within the driving environment provides proving grounds for models of general human behavior. However, in doing so, the extent of structural impacts on the brain of each individual, brought about by a lifetime of interaction with the environment, may not be overlooked or disregarded.
Towards the Better Understanding of an Important Issue in Transportation Engineering: Aggressive Driving

Aggressive driving can be defined in terms of the frustration-aggression model (15). In this context aggressive driving is a syndrome of frustration-driven behaviors, enabled by the driver’s environment filled with experiences of stress, anxiety, anger, antagonism, and fear (16). These behaviors can either take the form of instrumental aggression – that allows the frustrated driver to move ahead at the cost of infringing on other road users’ rights (for example, by weaving and running red lights) – or hostile aggression which is directed at the object of frustration (for example, cursing other drivers). Interestingly, Dollard et al. (15) chose to illustrate the frustration-aggression model with the behavior of a hypothetical college student who is stopped and berated by a police officer (the frustration source) in front of his girlfriend. Once he drove away, the student “grated the gears frequently in shifting, refused to let other cars pass him, and made insulting comments about every policeman who came in sight”. This link of aggression to frustration is very important, since it implies that a frustrating situation, behavior, or event instigates all aggressive behaviors (17).

While these behaviors may be reflective of individual differences in aggression, it can be argued that the exclusive focus on the characteristics of the aggressive drivers and how to control them (for example, through enforcement) is short-sighted. Efforts that focus exclusively on restraining driver instrumental aggression through enforcement may actually contribute to road (or off-road) rage and displaced aggression. Although surveys suggest that aggressiveness characterizes the majority of drivers (symptomatic of perhaps a bad system design), Shinar (17) proposes that over the past few decades drivers have not changed their personality to become more aggressive. Instead, the conditions that elicit aggressive behaviors – especially on the road – have changed, so that the level of frustration is above the ‘aggression threshold’ for more and more drivers. As an example, consider the role of congestion as a common source of frustration and aggression.

In light of this, it is rather unfortunate that the focus of the aggressive driving issue has been almost exclusively on who are the aggressive drivers and what aggressive behaviors they display, rather than on why drivers in general are more aggressive now than before, and what can be done (not necessarily to the drivers) to ameliorate the situation. However, to implement the ergonomic-oriented approach, in order to reduce or eliminate aggressive driving through changes in the environment that breeds aggression, rather than its carriers, researchers need to first identify the sources of the frustration. This viewpoint of aggressive behavior does not negate the existence of individual differences in aggression, but it does highlight the contribution of the environment (in frustrating the drivers’ goals) to aggressive behavior.

Evaluation of Existing Measures of Aggression

From research results it appears that overt behaviors, such as affective (horn honking, vocalizations, and gesturing) and instrumental (acceleration) responses, currently employed in experiments, bring about concerns of reliability when employed as indicators for signaling driver frustration and aggression. For example, consider gender differences in aggression and violent behavior, which have been studied ad-nausea (17). In a meta-analysis of 143 studies, Hyde (18) found that while none of the studies showed that women were more aggressive than men, and many studies showed that men are more aggressive, the gender differences explained only 5% of the variance, once other individual characteristics were taken into account. However, the
discrepancy between this result and the over-involvement of males in violent crimes is due to the fact that in most psychological studies, the aggressive behavior being measured does not take into account that women are less likely to exhibit extreme aggression, but, although possibly just as likely to be frustrated, they exhibit aggression in more subtle terms. In driving, aggressive behaviors span a wide range from muttering, through yelling and making obscene gestures, and all the way to violent actions with the car. Furthermore, the horn honk response, used predominantly because the latency, duration, and frequency of a honk can be easily measured and readily elicited as a form of aggression, is also questionable as a measure of aggression (19).

In addition, consistent with knowledge from neuroscience (discussed in a previous section), physiological responses do not correlate reliably with overt aggressive behaviors. Although one expects that drivers who respond more aggressively to provocation (another factor apart from frustration that elicit aggression) will also exhibit heightened physiological responses, McGarva and Steiner (19) did not observe changes in heart rate and blood pressure to vary as a function of driver aggression. Taken together, the failure to observe the expected reliable relationships amongst aggression, overt behaviors, and visceral arousal raises questions about the soundness of the present experimentation paradigm. Thus, despite efforts to provide a robust definition of aggressive driving, Shinar (17) believes that there remains a need for a more operational, useful, and commonly agreed-upon definition of aggressive driving. Overt behaviors and physiological responses are just not specific enough.

To summarize, research on aggressive driving to-date demonstrates that a significant amount of aggressive driving can probably be reduced by a careful, user-friendly, and ergonomically oriented design of the driving environment. Also, from an effective public health perspective the way to reduce road aggression should be to control the situations that give rise to it, rather than focus exclusively on driver education and mass media campaigns. Although some of the mediating factors cannot be that easily manipulated to reduce stress, such as time of day, and geographically and culturally based norms, and still other factors – such as congestion producing factors – are costly to affect, it is critical to consider these factors if aggressive driving is to be reduced (17). However, before these results can be applied, they should be validated extensively. Apart from difficulties with present measures of aggression, much more data are needed on the relationship between environmental stimuli, individual differences and aggressive driving, before action oriented large-scale programs can be justified.

Incorporating Neuroscientific Know-How

In order to revitalize and advance not only research and the subsequent knowledge-base on driver aggression, but also on all other driver-related issues, the author proposes a shift towards the integrated experimental paradigm, as discussed previously. Such an endeavor calls for close collaboration between specialists from a number of mentioned fields in the short term, as knowledge from a diverse set of fields will be called upon in such a process of integration. This is a premium for worthwhile insights and progress to stem from such a research program. However, the proposed experimental paradigm for future research on driver aggression can be further illuminated from the perspective of neuroscience, based on what is known about brain imaging, neural models, depression, and fear.

Consider the fact that previous psychological research suggests that depressed individuals engage in prolonged elaborative processing of emotional information (20). Armed with a computational neural network model of emotional information processing and event-related fMRI, Siegle et al. (20) found that activity in response to emotional stimuli in a region of the
brain called the amygdala was sustained in depressed individuals, even following subsequent
distracting stimuli. Since the amygdala is known to be involved in processing emotion, that is
not altogether startling. The difference in sustained amygdala activity to negative and positive
words was only moderately related to self-reported rumination (filling in questionnaires).

Amygdala activity was also inversely related to activity in dorsolateral prefrontal cortex
(DLPFC), which is consistent with the idea that depression could involve, in part, decreased
inhibition of the amygdala by cortex. This study has a number of potentially important clinical
implications. Depressed individuals are frequently observed to have difficulty in life situations
not considered to be inherently emotional. Results suggest that a depressed person’s experience
of an emotional stimulus could persist well beyond that stimulus, and in fact, could persist into
the time they are expected to be engaging in other activities, leading to interference with these
subsequent activities. Observations also suggest that understanding brain mechanisms
underlying sustained processing of emotional information may be important to understand the
phenomenology of depression. It can also have implications for treatment of depression,
providing a mechanism behind which the action of therapies can be explained. For example, re-
engaging inhibition from DLPFC through Wells’ (21) attentional control training can decrease
sustained amygdalar activity.

A great deal of evidence suggests that emotional information is processed in parallel by
brain systems responsible for identifying emotional aspects of information (the amygdala
system) and other brain areas primarily responsible for identifying non-emotional aspects of
information (the hippocampal system) (13). These systems are highly interconnected and
subject to feedback. Ingredients of an emotional feeling needed to turn an emotional reaction
into a conscious emotional experience, like depression, fear, or aggression, can be summarized
as:

- A specialized emotion system which receives sensory inputs and produces behavioral,
  autonomic and hormonal responses.
- Cortical sensory buffers which hold on to information about the currently present
  stimuli.
- A working memory executive (prefrontal cortex) which keeps track of short-term
  buffers, and interprets retrieved information from long-term memory.
- Cortical arousal keeping conscious attention directed towards the emotional situation.
- Bodily feedback – somatic and visceral information which returns to the brain during
  an act of emotional responding.

The fear system is understood as well or better than other emotional systems (13). The
fear system is not, strictly speaking, a system that results in the experience of fear. It is a system
with the function of detecting danger and producing responses which maximize the probability
of surviving a dangerous situation in the most beneficial way. Interactions between this defense
system and consciousness underlie feelings of fear.

The discovery of a pathway which could transmit information directly to the amygdala
from the thalamus suggested how a conditioned fear stimulus could elicit fear responses without
the aid of the cortex. The direct thalamic input to the amygdala simply allows the cortex to be
bypassed. In addition, emotional learning can be mediated by pathways which bypass the
neocortex, suggesting that emotional responses can occur without the involvement of the higher
processing systems of the brain, systems believed to be involved in thinking, reasoning and
consciousness.
Neurons in the area of the thalamus which projects to the primary auditory (and visual) cortex are narrowly tuned. However, cells in the thalamic areas, which project to the amygdala, are broadly tuned and respond to a much wider range of stimuli. Although the thalamic system cannot make fine distinctions, it has an important advantage over the cortical input pathway to the amygdala in terms of time (Figure 2(e)). In a rat, the thalamic pathway is twice as fast. However, because the direct pathway bypasses the cortex, it is unable to benefit from cortical processing and can only provide the amygdala with a crude representation of the stimulus. This quick and dirty processing pathway allows a person to begin to respond to potentially dangerous stimuli before he/she fully knows what the stimulus is. However, its utility requires that the cortical pathway be able to override the direct pathway. It is possible that the direct pathway is responsible for the control of emotional responses unbeknownst to a person. This may occur in all humans some of the time, but may be a predominant mode of functioning in individuals with certain emotional disorders.

The responsibility of the cortex is to prevent the inappropriate response rather than to produce the appropriate one. For example, consider driving along a highway and seeing a number of thin parallel lines running across the surface of the road. The cortex would be needed to distinguish a speed trap from among many other possibilities. However, responding immediately through braking could save the driver a speed fine.

The amygdala is like the hub of a wheel, receiving low-level inputs from sensory-specific regions of the thalamus, higher level information from sensory-specific cortex and still higher level (sensory independent) information about the general situation from the hippocampal formation. Through such connections, the amygdala is able to process the emotional significance of individual stimuli as well as complex situations, and where stimuli do their triggering.

To summarize, it is not unreasonable to suggest that by knowing what the different inputs to the amygdala are, and having some idea of what function those areas play in cognition, one can get some reasonable hypotheses about what kinds of cognitive representations can arouse certain emotional responses. By the same token, if it is known how the brain achieves some cognitive function, and it can be determined how the brain regions involved in that function are connected with the amygdala, one can explain in a plausible way how such emotions might be aroused by that kind of cognition. Thus, by knowing which cortical areas project to the amygdala, and knowing the functions in which those areas participate, one can make predictions about how those functions might contribute to emotional responses. Anatomy can, in other words, illuminate psychology, thereby enhancing the understanding of human behavior.
REFERENCES


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LIST OF FIGURES

FIGURE 1 (a) A normal volunteer prepares for an fMRI study of face recognition. She will have to match one of the faces at the bottom of the display with the face at the top. The researcher adjusts the mirror which will allow her to see the display from inside the magnet. (b) The volunteer’s brain is particularly active in an area of her right hemisphere called the fusiform gyrus (arrow) as she matches the faces. This ‘slice’ of her brain is seen as through looking through her face (National Institute of Mental Health, Maryland). (c) The positions of 124 EEG recording electrodes (attached to a soft helmet) are carefully plotted on an MRI model of the head (EEG Systems Laboratory, California). (d) Each of the color-coded areas in this combined MRI/MEG image of the brain responds to the touch of a different finger of the right hand (Llinás, NAS).

FIGURE 2 Images (a), (b), and (c) are based on data from 124 recording electrodes positioned in a soft helmet that covered the subject’s head. The resulting images clearly show that various areas of the subject's brain are activated in turn (EEG Systems Laboratory, California). (d) Schematic of the visual pathways from retina to visual cortex (10), and (e) the low and high roads to the amygdala (13).
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