

Potential of subliminal information displays to change drivers' behavior

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Abstract

Due to a rising operation complexity of vehicular interfaces, driving draws more and more attention from the driver. To counteract, attentive interaction is increasingly being replaced by implicit means of information exchange. The problem is, however, that task difficulty still often exceeds resources available by the driver and the emergence of new technology further aggravates the trouble. Backed by recent findings in neuroscience, we suggest to adopt subliminal stimulation to avoid cognitive overload – data from our own studies have provided evidence for a detectable behavioral change of drivers in realistic situations. It is, however, important to reassess achieved results as this type of research is highly sensitive and it cannot be taken for granted that findings are methodically acceptable. Furthermore, it is hard to prove whether the observed effect can be attributed to subliminal perception or not and it is also difficult to measure the effectiveness of such an interface as one cannot ask subjects about it, because they do not know the process under their level of awareness. In this work we introduce a theoretical taxonomy of mental processing states related to driving, discuss subliminal approaches for different sensory channels, recap the findings from our studies, and finally identify research challenges.

Keywords

Subliminal support; Vehicle-driver feedback; Cognitive load; Unconscious cognition; Human attention; Workload reduction.

1 COGNITIVE LOAD AND DRIVING PERFORMANCE

Studies have substantiated that vehicle accidents are to more than ninety percent caused by driver error. One might immediately point the finger at the “usual suspects” such as tailgating, sudden and abrupt lane changes or overestimation of one’s driving skills. In fact, studies point to drivers who have reduced situation awareness while driving with high workload levels [1, p. 59f.]. Although a broad range of diverse assistance systems are on the market for conventional driving mistakes (tailgating and sudden lane changes for example), almost none are made available to tackle situations where accidents are caused by drivers’ limitations in cognitive resources. This is really a problem, as the constant surge of information conveyed by the diverse driver information/assistance systems, together with more and more cars on the road and traffic signs adjacent to the streets, result in higher attention required for car operation. Unfortunately, human attention and cognitive abilities of a driver are limited resources, and this divergence (limited resources available, demand for increased attention) calls for new ways and means of interaction to prevent information overload and overexertion of cognitive workload. The fact that solutions based on multimodal feedback or implicit operation also hit their limits strengthen this request even more to foster safe vehicle operation in future and to reach targets defined by administration and road safety policy makers.

In the ubiquitous context of driving, cognitive overload occurs when task difficulty exceeds resources available by the driver; in this case the performance of driving starts to decline, initiated by interruption from the primary task of vehicle operation. To detect this situation and warn the driver in advance is not easy, as the capacity available by a driver is not constant while driving and because it would be almost impossible to determine the exact point where cognitive overload starts to occur.

Indeed, information between the driver and its environment is exchanged via different sensory channels (Table 1). While human sensory processing in nature is affected by various sorts of cross-channel interactions the whole sensory system is commonly used as simplified model of aggregated independent channels. This representation also applies to this work – stimuli are understood as to excite only associated receptors, e.g., light brightness innervates only retinal photoreceptor cells or vibrations are detected solely by mechanoreceptors in the skin.

Looking at the information processing capacity of the human mind (Table 1) it can be assessed that it has the potential to handle about 11 million bits per second [3]. Information processing in humans is measured in terms of time units and information units (bits). The information unit ‘1 bit’ is allocated to each decision in a dichotomous

| Channel | Information capacity | | | Advantages - | Disadvantages - |
|--|----------------------|-----------|--------------|--|---|
| | bit/s | % | perceptual | | |
| Visual | 1×10^7 | 80-90% | 30-45bits/s. | fast, private | visibility problems, cognitive overload (while driving) |
| Auditory | 1×10^6 | 10-15% | 40bits/s. | eyes free use, rapid detection, omnidirectional | interference with other acoustic sources, perception (acoustic range) changes with age, annoying/distracting, lack of absolute values |
| Vibrotactile | $4 - 5 \times 10^3$ | < 10% | 2-56bits/s. | new modality, non-disturbing, private, whole-body perception | learning required, intuitive mapping activity → tactogram required (subjective?) |
| Olfactory | 20 | $\ll 1\%$ | ? | sedative/relaxant influence, driver vitalization shown | problem of odor generation, subjective interpretation, saturates entire space slow alteration |
| Other channels, such as Gustatory, Temperature, or Kinesthetic senses are less significant for driving, and are not considered here. | | | | | |

TABLE 1
Capabilities of different sensory modalities (Source: [2], [3]).

partition on a 'yes or no' or 'true or false' basis [4]. The number of bits processed *consciously* is, however, much lower; in [3] a (optimistic) maximum of about 50 bits/s is indicated, but the exact number of bits to be processed explicitly (or consciously) actually depends on the task and goes down to 45 bits (reading silently), 40 bits (spoken speech), 12 bits (calculating in the head) and tactile information is processed at 2–56 bits/s. Compared to our total capacity these numbers are very small, confirming that the information processed consciously only deals with a very small fraction of all incoming information and that all the rest is processed without awareness. The almost unemployed area of information processed unconsciously further motivates to make it accessible, at least in workload sensitive scenarios. Due to limitations in information processing inherent to our physical system we may not be able to perceive the entirety of the information around us, but what seems more unsettling is that we may not even be able to 'experience all that we perceive'. This coincides with our own observations made in user studies, where we experienced that race car drivers (or other highly experienced drivers) are likely to be better equipped to process information and adapt steering behavior using a minimum of cognitive resources as compared to regular drivers [5, pp. 138].

1.1 Research Approach

In order to mitigate driving problems caused by excessive information, we propose to induce a behavioral change in drivers by employing subliminal techniques as a feasible approach to implicitly provide the driver with added information for driving support without dissipating available attention resources. These techniques are inspired by a body of work in neuroscience addressing the neural correlates of non-conscious perception in the brain.

The background and definitions of the presented work are grounded in neuroscience, particularly on the theoretical taxonomy of Dehaene [6]. In this specific field of research, subliminal perception (etymologically '*below the threshold*' or '*outside conscious awareness*') "is inferred when a stimulus is demonstrated to be invisible (no conscious reportability) while still influencing thoughts, feelings, actions, learning, or memory" [7]. In this work, we build on the concepts of the science of non-conscious perception and apply the taxonomy into an automotive context. In addition to a discussion of our preliminary findings in this field of research, one particular objective of this work is to provoke a active debate on the adequacy of information provided below active awareness as well as to discuss potential problems as this is delicate and challenging research. Subliminal information processing raises elementary questions such as "*How good is the mind at extracting meaning from stimuli of which one is not consciously aware?*" or "*How something presented subliminally would persuade a driver if he/she did not consciously attend to it?*" (as it is generally accepted that such stimuli are weak and often presented at very low intensity). Due to the fact that exact values/boundaries for information transmitted subliminally is still a major challenge, we point out that only noncritical information should be subliminally communicated to the driver.

Outline

In section 2 we start with a definition of terms related to '*subliminal*' as used in this work to avoid confusion or misunderstanding, and present the application of the theoretical taxonomy of mental processing states to driving. In section 3, we briefly summarize related work on subliminal perception and give recommendations of how it can be used in the automotive domain. Section 4 describes the results of a study, conducted to substantiate the positive effects of implicitly conditioning drivers with the aim to show the potential of subliminal perception. The last section finally lists some research questions identified to push on research in this domain.

2 SUBLIMINAL SUPPORT THROUGH NON-CONSCIOUS PROCESSING

The research presented in this article focuses on subliminal processing in the automotive context to improve driver-vehicle interaction. The idea is to support the driver by “injecting” information into the human mind below aware perception, thus transferring supplementary information without adding load on the cognitive channel. Indeed, sending relevant information for a driver below active awareness can be done through one or all of the sensory channels presented in Table 1. As an example, one technique applied to the visual sensory channel relies on the existence of a threshold of visual stimuli to be perceived consciously [7]. When a stimulus (“target”) is projected under a defined threshold (around 33ms) and followed by a second stimulus (“mask”), subjects fail to consciously perceive the first, but the targeted cerebral regions are activated nonetheless (e.g. Amygdala activated by fearful stimulus); below this threshold the stimulus remains non visible (or invisible). We will be presenting in this paper a study where we subliminally conditioned drivers through the vibrotactile sensory channel.

The main benefit of this approach would be the reception of additional, essential driving relevant information even in the case where no capacity is left for information transmission in a traditional way. It is anticipated that precarious driving situations or other events of sudden danger will benefit from using such technique.

Before pushing on further, the terms as understood in the present case need to be clearly defined (failing this differentiation, usage of notions related to “subliminal” can lead to confusion and misunderstanding). Although our terminology is grounded in neuroscience, the general confusion around the usage of the word “subliminal” needs to be addressed. We hope this section will help clear things up in two ways: First, we propose a quick flashback through time to help explain the origins of the misplaced negative attitude or skepticism towards the science of subliminal perception for it is often confused with subliminal persuasion. (The latter aims at changing the behavior or influence the decision of an individual without him/her being aware of it which is unethical, e.g., persuasion of people to spend their money, without them being aware of it.) Second, we will briefly explain the neuroscience behind non-conscious perception (also called unconscious cognition) as well as the taxonomy we are using and present a relevant example to driving and the automotive domain.

2.1 Disenthralling from Cargo-Cult Science

The notion that stimuli presented outside conscious awareness can involuntarily affect human beings has captivated the imagination and interest of a wide audience. One of the first experiments, however, suggesting the existence of non-conscious influences on behavior can be traced to a landmark paper by Peirce and Jastrow (1884). The authors used an introspective approach on themselves to report that they could perceive small differences in pressure to the skin without conscious awareness of different sensations. Since then, similar studies on perception without awareness were conducted until the 1950's. The *fear* regarding the unwanted influences of subliminal perception came in the first half of the 1950's when advertising companies, following Vicary's fallacious subliminal experiment “*eat popcorn, drink coke*”, claimed that subliminal stimuli can not only influence behavior, but also have a long-term effect on consumer choices. These advertising claims were later proven to be false. In the mean time however, strong reactions were fusing from all circles of society ranging from the scientific community to the political arena where bills to banish the use of subliminal techniques in public broadcasting were voted. From this point on, what was the science of subliminal perception became known to the general public as the *cargo-cult science* of subliminal persuasion. In his review, Kouider describe cargo-cult science as “*a science that has all the trappings of science-the illusion of objectivity, the appearance of careful study, and the motions of an experiment-but lacks one important ingredient: skepticism*” [7]. Following major criticism from Holender [8], the field of subliminal perception began improving its research methodologies leading to two landmark papers in *Science* and *Nature* where robust subliminal priming methodologies showed that genuinely invisible primes could influence processing at a semantic level [9], [10]. Furthermore, the work of Dehaene [10] was the first study using brain imaging techniques to show that subliminal stimuli can elicit not only a behavioral influence, but also a detectable neural activity in the motor cortex. Nowadays, contemporary research in multiple fields from human-computer interaction to neuroscience has taken advantage of the advances in technologies to demonstrate that invisible stimuli can serve for just-in time memory support [11] as well as elicit motor responses and reach orthographic, lexical and motor levels of representations [7].

2.2 Non-conscious Perception: A Taxonomy

Where the previous section described the science behind subliminal perception, it is important to clarify that while the existence of subliminal perception is no longer challenged from a neuroscientific point of view, the neural mechanisms of consciousness is still a major challenge in neuroscience.

The taxonomy proposed by Dehaene defines three distinct brain processing states when processing a stimuli: conscious, subliminal, and preconscious. During *conscious processing*, the stimuli provokes intense neural activations in the brain – users, or drivers, are actively aware of the stimuli and can verbally report it (e.g., important visual

information related to the primary task of driving such as the speed indicator or arrows for lane changes are actively perceived by the driver). During *subliminal processing*, the stimuli is perceived by the brain and the depth of neural activations it provokes depends on the task set, masking strength (in the case of visual stimuli, strength is the speed of the projection of the stimuli) and top-down attention (when top-down attention is present, the state is known as subliminal attended versus subliminal unattended when attention is absent). An example for subliminal auditory processing might be subtle sonic cues not consciously perceivable, but reflecting changes in driving speed, etc. It is important to note that subliminal processing is not independent of the driver's attention or working strategies. On the contrary, one cannot simply send invisible stimuli without consideration of task relevance and driver's willingness to comply as shown by numerous previous studies (see [7] for an overview). The last brain state, called *preconscious processing*, is a new state proposed by [6] mainly to account for the data regarding neurological disorders (blindsight and attentional blink paradigms). The application of this stage is irrelevant to driving and will not be discussed here. One final distinction regarding the term "subconscious". It is often interchangeably used with "subliminal", even if it is generally accepted that they have a different meaning in cognition science. We explicitly state to distinguish these two terms, relating "subconscious" to processes like thoughts, fears, deep trauma, etc. that take place in the human mind, and of which we are not totally aware nor fully understand yet. Subconscious is, for that reasons, not at all considered in the course of this work.

2.2.1 Example: Priming in the head-up display

We can imagine a head-up display (HUD) in a car permanently showing the current driving speed in large numerals in the field of view of the driver. The fact of realizing and reporting the car's speed value is enough to state that the driver consciously perceives this information (taxonomy-wise, we could say that the stimulus strength carries enough strength and has obviously attention: a driver would be able to quickly estimate speeds when asked without hesitation and be very close to the correct number).

On the other side, however, suppose that we additionally flash navigational information using simple arrows for indicating directions to turn very quickly to the HUD, e.g., for 30ms. We can say in this case state that the driver consciously perceives the driving speed, but not the subliminally added navigational information (a driver asked what information he/she can read off the HUD would never indicate the shortly flashed navigation information).

If evidence can be shown for an impact of visual priming on reasoning and behavior, and if a generally accepted separation threshold ($\approx 50ms$) can be indicated, this knowledge can be used for steering stimuli projected on the HUD accordingly, i.e. subliminally (flashing interval below the threshold) or consciously (display duration above the threshold). For other sensory channels, considered to be also alterable by information transferred subliminally, similar examples can be specified.

3 REVIEW OF RELATED WORK

The question if subliminal support through non-conscious processing actually works (in the automotive domain) is still open, most likely due to the fact that it is difficult to measure the effectiveness of subliminal interaction. Another crucial factor in the success of such studies is the method used for assessing whether the non-consciously experienced stimulus is indeed unconsciously perceived (as subjects cannot be directly asked whether or not they perceived a stimulus). In case of proven functionality stimuli presented subliminally can have a considerable influence to reduce cognitive load or distraction of a driver.

3.1 Visual Information Processing

Driving is known to be more or less a pure visual task, but there exist only few approaches for supporting the driver in dealing with the increasing amount of information in and around the car. [12] experimented with subliminal visual information on road safety hazards displayed in a driver's field of view and found out that response times tend to be shorter with subliminal support as compared to the baseline study without added information. With latest achievements in display technology, projecting information in the driver's field of view using a head-up display (HUD) could be indicating a promising alternative to the dashboard. Studies have substantiated that this interface causes only low impact on mental load and is preferred by users as compared to traditional in-car displays [13]. As the visual channel covers more than 80% of all the information in the car (Table 1), it should also be the number one choice for research on subliminal information presentation in the car –shown either in the HUD, the dashboard, or on other visual displays.

3.2 Auditory Driver Stimulation

Using audio signals to "inject" subliminal information is not a very common approach today. [14], for example, have investigated the potential impact of a car voice interface on a driver's performance and attitude, and came

to the conclusion that drivers who interacted with a voice matching their own emotional state drove better while communicating more as compared to drivers interacting with mismatched voices. Is this a proof that emotions derived from the voice carries subliminal information which influences driver behavior? We have no evidence, but for sure drivers use kind of “hidden” sound/noise sources in and around the car to infer the best time to switch gears (from tracked motor rpm) or to assess and adapt driving speed (from ambient noise). In qualification, it should be mentioned that sonic feedback can quickly become annoying (when disturbing other auditory activities) and that auditory output also interferes with driving capabilities to a certain degree. Past experience has also shown that drivers do not like to receive driving instructions from a voice command system [2] and that speech modalities in native or known languages have very high saliency. In conclusion, too much sound-based information (even if transferred subliminally) might distract the driver, particularly in situations where attention to the traffic should have top priority.

3.3 “Smell the Information”

Olfactory notification systems are still a problematic research area, however, we see high potential in its application, e. g., to display a mild scent of burning oil in the passenger compartment to warn the driver in case of motor defects or to systematically employ odors to calm down or refresh the driver to increase driving safety or avoid a driver to fall asleep. (Taxonomy-wise, this type of stimulus would fall under the mental processing state of subliminal unattended because of the absence of top-down attention and the weak strength of the stimulus.) Studies have confirmed that olfactory interfaces had a less disruptive effect on the primary task of vehicle operation as compared to visual or auditory stimuli and this can also be seen in concrete products on the market. Nissan, for example, presented a olfactory gratification system to enhance driving pleasure back in 2009 and Renault aims to “bring people health and well-being while on the road” by employing odors in the passenger compartment.

However, before broad application several issues need to be resolved. It is known that the perception of odors is subtle, imprecise, and that particular fragrances won’t work for everyone. Even more problematic is, that the emotional state of healthy subjects has a clear effect on olfaction and that a negative emotional state reduces olfactory sensitivity. Emotional states are likely to change quickly and uncontrolled during vehicle operation and the variation of the emotional state would directly affect olfactory sensitivity. Further issues limiting its application are the fact that olfactory interfaces normally saturates the entire space (passenger cabin) and the problem of olfactory adaptation.

3.4 Tactile Driver Feedback

(Vibro-)tactile notification systems are in production for several years (Citroen, Audi, BMW, etc. have been integrating warning systems based on vibrotactile notifications in pedals, seat or steering wheel since a couple of years), and the benefit of these systems is that tactile feedback can be transmitted very effective and with adding only little accessorially load on the cognitive channel. (Taxonomy-wise, this type of stimulus would fall under the mental processing state of subliminal attended because of the presence of top-down attention and the weak or subtle strength of the stimulus.) For subliminal support using the tactile modality, however, only little progress has been made so far. Virtual haptic feedback has been discussed, for example, in the research project IMMERSENCE (“[...] subjects did not recognize changes in the sensory cues, but behaved as if they did. This suggests that performance can be affected and possibly improved through subliminal cues by reducing the cognitive load, allowing the transfer of additional information otherwise impossible”). This result motivates to make an effort in employing the tactile channel also to improve driver-vehicle interaction. Research focusing on subliminal driver support using tactile signals is even more uncommon and unexplored to day, but our own studies on assessing the capability of subliminal tactile techniques in vehicular interfaces have shown its potential. Real driving experiments have proven that drivers tend to alter their driving behavior when receiving subliminal tactile stimuli as compared to the control group driving without artificial feedback [15]. The effect is discoverable in the measured quantity of carbon dioxide emissions in the two groups.

4 EXAMPLE: SUBLIMINAL VIBROTACTILE DRIVER NOTIFICATION

The research focus of subliminal support in the automotive domain does not occur without reason –it is one of the greatest challenges to assist the driver while maintaining “hands on the wheel” and “eyes on the road” mantras. One approach to achieve this is to reduce the complexity in the driver-vehicle interaction loop using subliminal techniques. We try to reach this goal by employing sensory modalities capable of providing additional implicit information without generating supplemental cognitive load. Subliminal techniques should not be employed to initiate concrete actions, but more to condition a driver to change its driving behavior automatically based on hidden indication or insinuation. Our experiment on CO_2 economic driving [15] was designed to reach this objective and

conducted according to the stimulus–response relation indicated in Fig. 1. (The reactions types specified on the output side, i.e., gear changing behavior or conservative accelerating are only exemplary; the effective behavioral change is fully in the control of the driver.)

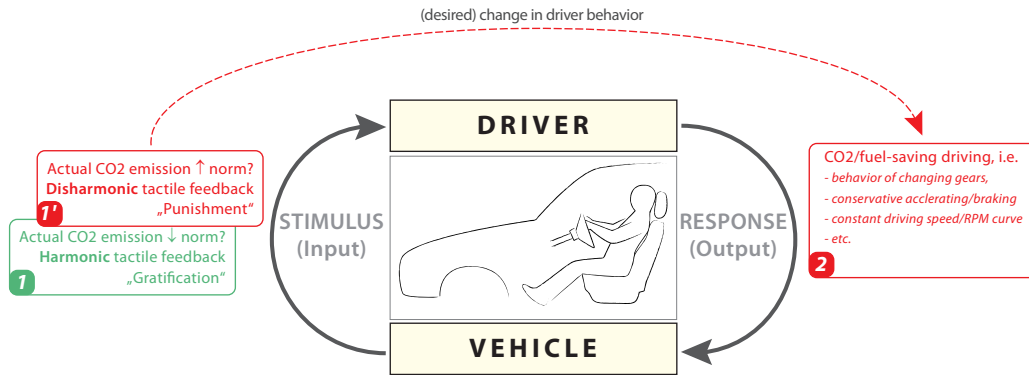


Fig. 1. Stimulus received (subliminally) at the driver and corresponding response.

Based on the taxonomy of non-conscious perception, we started our research with the vibrotactile channel because it presently exhibit the highest potential to provide evidence for subliminal support. The aim of such an interface is most-likely related to road safety, which could be easily achieved if part of the information currently transferred attentively can be in the future conveyed subliminally (driving would be much safer if the driver is less demanded). The vibrotactile channel is gradually finding its way as a feedback modality into the vehicle, but is still underemployed and mostly used for providing binary information only. Subliminal tactile systems can be integrated into any controls in the car as the somatic senses responsible for the perception of tactile stimuli operate all-over the body and at all times.

To test on the effect of subliminal support a multi-tactor system was integrated into different controls of our test vehicle (driver seat, safety belt, and steering wheel). Positive experience in the utilization of vibrotactile interfaces has been gained in earlier experiments on conscious driver stimulation with tactile patterns of different complexity.



Fig. 2. Different styles of vibrotactile displays (left: eight tactors embedded into the face of the steering wheel, much more tactors can be integrated into the backside; right: eight tactors in both safety belt and seating).

The on-the-road study conducted and presented in [15] showed that different tactile signals can be employed for notifying on ancillary driving related information in a subliminal way, which does not negatively affect road safety. In the example study, embedded tactile actuators (Fig. 2) notified the driver about his/her current level of carbon dioxide emission as compared to the mean value for the same section of the track. Initial results compiled from 464 kilometers driven have revealed that the application of assistive technology in the car to notify the driver in a subliminal style has the potential to reduce CO₂ emissions by about 8%.

Even higher potential is attributed to the (yet not tested) placement option “steering wheel” (Fig. 2). In addition to the aforementioned interface variants, this setting satisfies with two improvements, firstly that both hands could be fixed on the wheel all the time while driving, and secondly that fingers/hands offer a very low touch threshold and are highly sensitive to vibrations (Weinstein, 1968).

5 CONCLUSION

In this work we have introduced subliminal stimulation (or information transfer below aware perception) as a challenging research field to improve vehicle-to-driver notifications. The review of related work, the discussed approaches, as well as indicated concrete examples (e.g., subliminal driver-vehicle interaction [15]) have shown the potential to support drivers in their increasingly complex task of driving without further distraction. Evidenced assertions about the applicability of information delivered below the threshold of perception will be of great value

since it will open completely new ways to improve driving safety and convenience, and to hopefully reduce traffic accidents. With this overview we would like to invite researchers and policy makers to take part in a in-depth investigation of this timely, relevant and important field of research – we are confident that subliminally-driven interfaces might find their way as standard equipment in cars of the (near) future.

Appendix: Research questions

A promising approach to prevent cognitive overload in driver-vehicle interaction but also in human-computer interaction in general is to employ subliminal support through non-conscious perception; however, the question whether or not subliminal communication through non-conscious processing actually works remains unsolved. Recent empirical research suggests the assumption that subliminal interaction techniques improve human-computer interaction by reducing workload undertaken by sensory channels, but there are also other researchers that have found that subliminal perception does not, or even cannot, work. One possible reason for this controversy is that it is difficult to measure the effectiveness of subliminal interaction as one cannot ask subjects about the experienced stimuli as they do not know the process under their level of awareness. Even though experimental results show different performance with and without inattentively perceived information, it is hard to make sure whether the difference can be attributed to subliminal perception or not.

Questions that might be of interest to be discussed in a broad audience are:

- How to reduce “risk” in interfaces?
- How do measure the effect of subliminal driver support if he/she did not consciously attend to it?
- Influence of characteristics such as age, gender, intelligence, abilities/disabilities?
- Differences in the sensitivity of individuals to subliminal effects?
- Impact of subliminal information to further information submitted explicitly?
- Socio-technical issues (acceptance, aversion, repulsion, ethics)?
- Impact of subliminally delivered information on the perceived workload?

REFERENCES

- [1] Christopher J.D. Patten. *Cognitive Workload and the Driver: Understanding the Effects of Cognitive Workload on Driving from an Human Information Processing Perspective*. PhD thesis, Dept. of Psychology, Stockholm University, Sweden, 2007.
- [2] Gerhard Mauter and Sabine Katzki. The Application of Operational Haptics in Automotive Engineering. Business Briefing: Global Automotive Manufacturing & Technology 2003 pp. 78–80, Team for Operational Haptics, Audi AG, 2003.
- [3] Tor Norretranders. *Spüre die Welt*. Rowohlt, 1997. ISBN: 978-3499602511.
- [4] S. Lehl and B. Fischer. The basic parameters of human information processing: Their role in the determination of intelligence. *Personality and Individual Differences*, 9(5):883–896, 1988.
- [5] Andreas Riener. *Sensor-Actuator Supported Implicit Interaction in Driver Assistance Systems*. Vieweg+Teubner Research, Wiesbaden, Germany, 1st (January 14, 2010) edition, January 2010. ISBN-13: 978-3-8348-0963-6.
- [6] Stanislas Dehaene, Jean-Pierre Changeux, Lionel Naccache, Jérôme Sackur, and Claire Sergent. Conscious, preconscious, and subliminal processing: a testable taxonomy. *TRENDS in Cognitive Sciences*, 10(5):204–211, May 2006.
- [7] Sid Kouider and Stanislas Dehaene. Levels of processing during non-conscious perception: a critical review of visual masking. *Philosophical transactions of the royal society B*, 362:857–875, April 2007.
- [8] D. Holender. Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: a survey and appraisal. *Behavioral Brain Science*, 9:1–23, 1986.
- [9] A.D. Greenwald, S.C. Draine, and R.L. Abrams. Three cognitive markers of unconscious semantic activation. *Science*, 273:1699–1702, 1996.
- [10] S. Dehaene, L. Naccache, G. Le Clec’H, E. Koechlin, M. Mueller, G. Dehaene-Lambertz, P.F. van de Moortele, and D. Le Bihan. Imaging unconscious semantic priming. *Nature*, 395:597–600, 1998.
- [11] Richard W. DeVaul, Alex Pentland, and Vicka R. Corey. The Memory Glasses: Subliminal vs.Overt Memory Support with Imperfect Information. In *Proceedings of ISWC’03*, Los Alamitos, CA, 2003. IEEE.
- [12] Hiroshi Takahashi. *A Study on a Method to Call Drivers’ Attention to Hazard*. Springer-Verlag, Berlin, Heidelberg, 2009.
- [13] G. Weinberg, B. Harsham, and Z. Medenica. Evaluating the Usability of a Head-Up Display for Selection from Choice Lists in Cars. In *Proceedings of AutomotiveUI’ 2011*, Salzburg, Austria, 2011.
- [14] Clifford Nass, Ing-Marie Jonsson, Helen Harris, Ben Reaves, Jack Endo, Scott Brave, and Leila Takayama. Improving automotive safety by pairing driver emotion and car voice emotion. In ACM, editor, *CHI 2005 — Late Breaking Results: Short Papers*, April 2005.
- [15] Andreas Riener, Alois Ferscha, Peter Frech, Michael Hackl, and Marius Kaltenberger. Subliminal vibro-tactile based notification of CO2 economy while driving. In *Proceedings of AutomotiveUI’ 2010*, page 10, Pittsburgh, Pennsylvania, November 11-12, 2010. ACM.