Information injection below conscious awareness: Potential of sensory channels

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ABSTRACT

Vehicle drivers are nowadays responsible for a large number of driving related and side activities in parallel. This results in more and more attention required for their observation and operation, and distracts from the primary task of driving. To cope with the rising demand, explicit and attentive interaction is increasingly replaced by implicit means of notification. The problem, however, is that the trend of rising information, supported by context- and activity-aware assistance systems, is still ongoing and implicit methods for information delivery hit their limits. To avoid occurrence of cognitive overload, new solutions are required to deal with the bunch of concurrent information. Subliminal interaction techniques are considered a promising approach to deliver information or warning signals to the driver without causing any supplementary workload.

By starting with a review of related work on subliminal feedback, we try to identify potential fields of application of subliminal methods in the car domain. Identified solutions are discussed and recommendations are given of how to apply a specific technique while driving. We see great potential in this timely, relevant and important field of research and are quite confident that subliminal messaging will find its way into the automotive domain in the near future.

Categories and Subject Descriptors

H [**Information Systems**]: H.5 Information Interfaces and Presentation—*H.5.2 User Interfaces*; H [**Information Systems**]: H.1 Models and Principles—*H.1.2 User-Machine Systems*

Keywords

Subliminal support; Relaxed driver-vehicle interaction; Cognitive load; Human attention; Workload reduction.

1. INFORMATION OVERLOAD AND IMPACT ON DRIVING PERFORMANCE

Recent studies have shown that vehicle accidents are to more than ninety percent caused by driver error [18] and that reasons include (beside others such as drivers' that tailgate, suddenly change lanes or overestimate their driving skills) distraction due to cognitive overload [33] or reduced situation awareness when driving with high workload levels [30, p. 59f.]. While driver assistance systems on the market covers only traditional driver errors, solutions covering cognitive resource issues are still missing, but are badly needed to guarantee safe vehicle operation in future, and to adhere to plans established on national and global levels to reduce traffic accidents. (For example, the EU is targeting reduced road traffic deaths by 50% by 2020 and adopting "Vision Zero" for 2050 [19].)

The main problem is, from our point of view, threefold:

1. **Information** the driver is exposed to is **steadily rising**. This problem is tightened up as multimodal feedback or implicit vehicle operation also hit their limits, resulting in an ever increasing level of attention required by the driver for observation and operation of the car,
2. All these information is available concurrently and the **level of importance** of a certain information item is in general **not discoverable**, challenging the driver even more,
3. Cognitive abilities of a driver as well as its attention capacity are limited resources [13].

We see possible solutions in (i) the application of novel forms of interaction to discharge the information channels mainly responsible for driving and driving related tasks and (ii) the supplementary use of information exchanged below the level of active awareness, i. e., transferred in a subliminal style without adding load on the cognitive channel.

The term "subliminal" as used in this work is grounded in neuroscience, where the notion that subliminal stimuli (etymologically *below the threshold* or *outside conscious awareness*) could influence cognition is well established (e. g., taxonomy of Dehaene [7]). Subliminal perception "*is inferred when a stimulus is demonstrated to be invisible while still influencing [..] actions*" [17].

In this work, we keep focus on (ii) and on the ideas and the body of work in the cognitive science, and try to identify the potential of the diverse sensory channels available in the car with respect to successful application for information processing below the threshold of consciousness.

1.1 Cognitive Overload

Beside the Cognitive Load Theory (CLT) [35], the Multiple Resource Theory (MRT) [39], the mechanisms of the working memory, and others have been used to describe and interpret the occurrence of cognitive overload (i. e., a situation where task difficulty exceeds available resources). In case of road traffic, the performance of the driver gets worse and worse and driving behavior degenerates accompanied by declined road safety.

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While in multitask situations different tasks can use or share different attention resources, in case of driving the performed tasks mostly rely on the same resource (vision). In using a single resource channel, tasks may interfere with each other and affect task performance in both tasks due to "cognitive overload". A typical example related to driving would be the interruption of the primary task (*driving*) by side activities (e. g., *dashboard inspection*, *radio/navigation system operation*) [13].

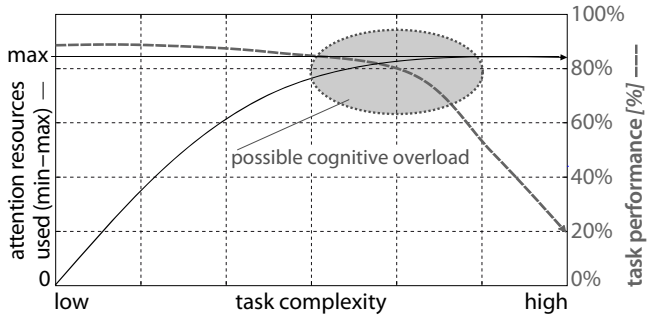

Figure 1: Attention resources versus task performance (adapted from [30, p. 57]). The gray region indicates an area with possible appearance of cognitive overload (task performance starts to decrease).

To avoid cognitive overload its appearance needs to be detected in advance. Implicit methods to determine the level of cognitive load includes for example the measurement of physiological indicators such as eye or brain activity, heart rate/heart rate variability or respiration. However, interpretation of metered values is not an easy task as (i) humans have only limited amount of attention available at any given time (according to the MRT of attention), (ii) the capacity available by a driver is not constant while driving [10], and (iii) it would be –in the end– almost impossible to determine the exact point where cognitive overload starts to occur (indicated as the gray area in Figure 1). A explanation for the latter issue might be the observation that a driver tends to alter his/her task management, e. g., by decreasing the speed when engaged in side activities [41, p. 338], or by excluding or omitting certain elements.

1.1.1 Subliminal Techniques - A Solution?

Subliminal techniques are considered a encouraging approach to provide the driver with driving related information without dissipating available attention resources. The notion that stimuli presented outside conscious awareness could influence cognition is not new. Peirce and Jastrow reported in 1884 that people could perceive small differences in pressure to the skin without conscious awareness of different sensations and it is well know that certain subliminal cues can facilitate certain behaviors. For example, store chains sprays fragrances with a subtle influence outside their stores to attract customers, background music in shopping malls is said to increase sales by subliminally stimulating shoppers, and millions of people buy subliminal audiotapes to help them lose weight or increase their assertiveness [34]. The underlying concept of these examples is subliminal persuasion (c. f., Fogg [12]). The idea is to "inject" information into the human mind below active awareness, thus transferring supplementary information in a subliminal style without adding load on the cognitive channel.

We want to pick up on these ideas and put them into an automotive context to improve driver-vehicle interaction. The main benefit of this approach would be the reception of additional, essential driving relevant information even in the case where (almost) no capacity is left for information transmission in a traditional way.

1.1.2 Information Processing Constraints

Due to information processing limitations (see Table 1) inherent to our physical system (c. f., Figure 1) we may not be able to perceive the entirety of the emerging information; however, what seems more unsettling is that we may not even be able to experience all that we perceive [29]. What we have observed in earlier studies (c. f., [31, pp. 138]) is, that race car drivers (or other highly experienced drivers) are likely to be better equipped to process information for optimum performance using a minimum of cognitive resources compared to "normal", untrained drivers.

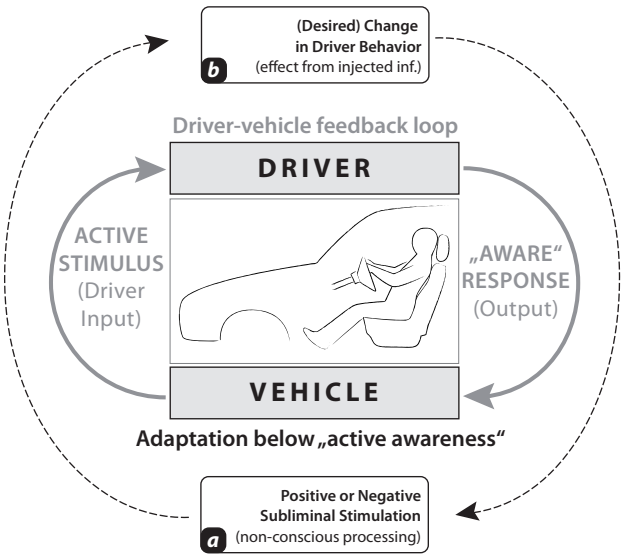

Figure 2: Stimulus received (subliminally) at the driver and corresponding response.

Many psychological experiments have attempted to prove the existence of unconscious perceptual processes by demonstrating that stimuli are perceived when subjects are not consciously aware of the stimuli [23, p. 6]. The most crucial factor in the success of such studies is the method used for assessing that the non consciously experienced stimulus is indeed unconsciously perceived. A facility to distinguish between consciously and non consciously perceived information has been demonstrated in several experiments focusing on the type of reaction. Studies found that consciously perceived stimuli allow subjects to follow instructions, whereas unconsciously perceived stimuli lead to much more automatic reactions [6] [20]. Furthermore, it was particularized that conscious perception of a stimulus is constrained by context but that unconscious perception of the same stimulus leads to automatic reactions that are relatively unconstrained by context. Merikle and Daneman [23] have reviewed the history of unconscious perception from a psychological point of view and summarized the current status of experimental research in this area of investigation. They concluded that as "*[..] unconscious perception has been shown to have a firm empirical basis, future experimental*

studies can concentrate on exploring other characteristics of unconscious perception". (As one future challenge they specified to establish whether or not individuals differ in their sensitivity to the effects of unconsciously perceived information – an issue actually investigated in our own studies.)

For application in the car, subliminal information presentation should not be employed to initiate concrete instructions or commands, but more to pique a driver to change his/her driving behavior automatically based on its intuition. Therefore, we propose to use a stimulus–response relation similar to that shown in Figure 2. The effective behavioral change at the driver as result from the injected information should be left in the control of the driver.

2. CAPACITY OF SENSORY CHANNELS

The human sensory system includes visual, auditory, haptic, olfactory, gustatory, and other channels. In the course of this work, the sensory system is understood as simplified model of aggregated independent channels, exciting only associated receptors. The truth, however, is, that human sensory processing is affected by various sorts of cross-channel interactions [26].

According to Table 1 the human senses can handle more than 11 million bits/second. Interesting is, that the number of bits processed *consciously* is much lower – reaching a maximum of about 50 bits per second [27]. The exact number of bits which can be processed explicitly (or consciously) actually depends on the task and goes down to 45 bits (reading silently), 40 bits (spoken speech), 30 bits (reading aloud), or 12 bits (calculating in the head) [14, p. 82] and tactile information is processed at 2–56 bits/s. Compared to our total capacity these numbers are very small, showing that the information processed consciously only deals with a very small percentage of all incoming information – all the rest is processed without awareness, or subconsciously, and further motivates its application in workload sensitive scenarios.

2.1 Subliminal Techniques in the Field

The question if subliminal persuasion (while driving) actually works is still a unexplored field of research which carries –on evidenced effects– much potential to reduce a driver's cognitive load or distraction while operating the car. This assumption follows the result of cognitive and social psychologists, who have learnt that stimuli presented subliminally can have a considerable influence over a variety of cognitive processes and possibly even on behavior [24]. In the following, a brief review of its potential is given systematically for each feasible modality, and further supplemented by recommendations for its application in the car domain.

2.1.1 Visual Information Presentation

In 1957, Vicary reported increases in sales after flashing words subliminally onto the screen at a movie theater, years later he withdrew the statement and reinformed that this has only been a marketing joke and that he never flashed anything on the movie screen. Tests using visual subliminal messages to demonstrate that subliminal persuasion could be feasible have increased in recent time. It has been shown that visual subliminal messages do have an effect on a viewer's color choice and that those containing words can be more effective than that containing colors, [1] found higher relationship between visual subliminal stimulation with the word "Coke" and test persons' ratings of thirst compared to test persons stimulated with non-drinking related words.

Much potential, but also danger, is attributed to subliminal visual persuasion. For example, television broadcast agencies all over the world have special clauses in their advertising rules quoting that "*advertising must not use subliminal techniques*" (TV5Monde, France) or "*avoid broadcasting any advertising material that makes use of any subliminal technique or device [..]*" (Canadian Association of Broadcasters).

Car domain: Although driving is more or less a pure visual task there exist only few approaches for supporting the driver in the increasing amount of information on dashboard and/or road. [36] experimented with subliminal visual information on road safety hazards displayed in a driver's field of view and found out that drivers' response times tend to be shorter with subliminal support compared to the baseline study without added information.

Recommendation: Studies, e. g., [3], have shown that information presentation in drivers' field of view (i. e., by projecting the information into the windshield using a head-up display (HUD)) is a viable alternative to information shown in the dashboard. Excellent perspectives for the visual modality as channel for subliminal persuasion makes it the number one choice for research on subliminal information presentation in the car, using either HUD's, the dashboard or other display regions. In the following we motivate the use of subliminal messaging on example of the head-up display, similar examples can be given for the *other channels* of the human sensory systems. First, we claim that a driver is *consciously perceiving* a stimuli if he/she is fully aware about the stimulus and, in addition, is able to identify or indicate it. Thinking of a common head-up display in a car permanently showing the driving speed in large numerals in the FOV of the driver, the fact of detecting the speed value is enough to state that the driver consciously perceives this information. On the other side, however, mention that we additionally flash navigation information using simple arrows for indicating direction very quickly to the HUD (e. g. for $20ms$ or less), then we can state in this case that the driver consciously perceives the driving speed, but not the navigational information. The reason for this is the existence of a threshold of visual stimuli to be perceived consciously. Del Cul *et al.* [8] reported about experiments causing a visual stimulus to cross the threshold to consciousness. When a flashed stimulus ("target") is followed by a second stimulus ("mask"), subjects fail to perceive the first unless the target-mask interval exceeds a certain threshold duration; below this threshold the stimulus remains non visible. The discovered threshold, which is in the region of $50ms$, can now be used for steering stimuli projected on the HUD to be perceived subliminally (flashing interval below the threshold) or consciously (above the threshold).

Beside the display duration, characteristics of the shown information like color, contrast, transparency, or size are other relevant criteria influencing perceptibility, and have to be analyzed separately. Moreover, it has to be taken under consideration that subliminal priming can also cause emotional reactions at the recipient, leading to unexpected driver behavior [9].

2.1.2 Auditory Driver Stimulation

Subliminal persuasion is attributed to show effects employing music. Messages embedded in songs are supposed to be evident when the music is played backwards (when played normally critics claim that the messages are heard sublim-

Channel	Information capacity			Advantages	Disadvantages
	bit/s	%	perceptual	-	-
Visual	$1x10^7$	80-90%	30-45bits/s.	fast, private	visibility problems, cognitive overload (while driving)
Auditory	$1x10^6$	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
Vibro-tactile	$4-5x10^3$	$< 10\%$	2-56bits/s.	new modality, non-disturbing, private, whole-body perception	learning required, intuitive mapping activity $\rightarrow$ tactogram required (subjective?)
Olfactory	20	$\ll 1\%$	?	sedative/relexant influence, driver vitalization shown	problem of odor generation, subjective interpretation, saturates entire space slow alteration

Table 1: Capabilities of different sensory modalities (summarized from [22], [4] [11], [27]).

inally). Belief in the ("backmasking") effect is so strong that, for example, Arkansas and California have passed bills demanding that records and tapes with backmasking have warning labels and Texas and the Canadian parliament have funded investigation of backmasking [34]. Moreover, millions of people buy subliminal audiotapes to help them self and background music in stores is said to increase sales. Wilson [40] argued that advertisers embed the word sex in their advertising copy to obtain enhanced recall and recognition through implicit sexual association, Vokey *et al.* [38] tested the same hypothesis with different experiments, however, found no evidence for the claim.

Car domain: The possible impact of subliminal auditory stimulation on drivers has not been studied extensive to day, but some ideas have already been discussed. Nass *et al.* [25] have addressed the potential of the impact of emotions on drivers' performance to determine how user emotion and the emotions of a car voice interface interact to influence drivers performance and attitudes. They found out that drivers who interacted with a voice matching their own emotional state drove better while communicating more compared to drivers interacting with mismatched voices. These results are quite relevant for the considerations made in this work as there is evidence that emotions derived from the voice (of a navigation system) carries subliminal information influencing a driver's performance. Furthermore, drivers definitely use some kind of subliminal source of noise in and around the car as input for vehicle operation. The sound of the engine (motor rpm) is tracked to determine when to switch gears and ambient noise is used to infer and adapt driving speed.

Recommendation: Considering the aforementioned findings at least some potential can be attributed to the use of the auditory channel for transmission of subliminal information the driver is used to adapt to, e. g., delivering loud wind noise to force the driver to throttle. Contrary to that, perception of changes on the audio channel is supposed to be sophisticated as several sound sources appear simultaneously (environmental noise, motor sound, car stereo, cell phone conversation, etc.) while a person can only differentiate between a low number of them (and is unclear what the impact on added auditory information perceived subliminally is (on consciously perceived information)?). There is support that sound based feedback quickly becomes annoying when disturbing from other auditory activities and that auditory output also interferes to a certain degree with driving capabilities. Past experience has also shown that drivers do not like to receive driving instructions from a voice command system at all. These issues might distract a driver's attention from traffic, particularly in situations where attention to the traffic should have top priority.

2.1.3 Tactile Driver Feedback

Numerous research studies using classical vibro-tactile interfaces have recently been published to overcome some of the shortcomings associated with the use of visual and auditory interfaces [31, p. 62]. For subliminal persuasion using the tactile modality, however, only little research efforts have been presented so far. One is the phenomenon of subliminal perception in virtual haptic feedback discussed in Deliverable D2.2.2 of the EU-FP6 research project IMMERSENCE. They reported that "*[..] subjects were not aware of texture roughness change below a threshold limit, yet the normal force they applied, changed. They didn't 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 is a promising basis for the research discussed in this work, however, not directly comparable to the setting proposed.

Car domain: Simple tactile notification systems are in production for several years (e. g., in lane departure warning systems of Citroen and BMW or in Audi's collision warning system). The common benefit of these systems is that vibro-tactile feedback can be transmitted to the driving person very effective and with adding only little accessorily load on the cognitive channel compared to the utilization of visual or auditory feedback [37]. Continental has utilized this finding in the Accelerator Force Feedback Pedal (AFFP) system to overcome the issue of getting too less attention in high-workload conditions [2]. The active pedal is used as a driver-alert system by overlaying a subtle counterforce, e. g. on obstacles in the vehicle's path, to the pedal. A study demonstrated that the AFFP system provided an intuitive, easily understood link with the driver that could be acted on without adding to stress levels.

Recommendation: The tactile channel is still underemployed in driver-vehicle interaction and research focusing on subliminal driver persuasion using tactile signals is even more uncommon and unexplored to day. Nevertheless, our own studies assessing the capability of subliminal information transfer using tactile interfaces in vehicles [32] or in office situations [21] have shown its potential, provoking to further develop its application. In post-experimental questionnaires some of the test participants stated that they "did not notice vibrations at all" [32]. This can be taken as proof

for tactile information perceived subliminally – as, in fact, they showed a changed steering behavior on tactile feedback compared to the second group effectively receiving no tactile stimuli at all.

When designing subliminally operating vibro-tactile interfaces two factors have to be considered. First, the vibratory threshold as function of the presented frequency and second, the minimum separation at which two stimuli are perceptible as separate ("two-point touch threshold").

2.1.4 Olfactory Information

Olfactory technology is becoming increasingly a standard interior of commercial locations and public places and is also gaining increased importance in HCI, even if it is still a simple form of perfuming rooms and flavoring goods. Olfactory perception takes an exceptional position in processing of sensory stimuli – there is no way to avoid smelling odors or filtering olfactory information. The olfactory channel offers high potential for transmitting warning or danger messages and it has been evidenced that odors can have positive and negative effects on the performance of cognitively based tasks. On the other side, however, the interpretation of odors is subjective and related to individual emotions [5, p. 322] – the positive applicability of subliminal stimulation stands in stark contrast to the reported failings, making it even harder to give a clear statement on its real potential.

Car domain: Olfactory notification systems have only be used rarely in the car to date. Nissan, for example, presented at the 2009 Tokyo motor show a olfactory gratification system to enhance driving pleasure and Renault and Biotherm have presented in the same year the zero emission spa concept car "ZOE". We see high potential in "displaying" scent of burning oil in the passenger compartment to warn the driver in case of a motor defect or on detected trail of oil, or to systematically employ odors to calm down or refresh the driver in order to increase driving safety or avoid a driver to fall asleep. The odor of jasmine or lavender, for example, elicits sedative or relaxant effects and peppermint seems to be the most popular fragrance to revitalize a tired person [16, p. 30]. Further studies have found out that the olfactory channel was less effective, had a less disruptive effect on a driver's primary task compared to visual or auditory stimuli, and has the potential to improve vehicle steering.

Recommendation: The utilization of olfactory interfaces (not only in the car context) is somewhat problematic as it still remains, most likely due to its subtle and imprecise perception, a developing research branch and particular fragrances won't "work" for everyone. Even more important, it has been revealed that the emotional state of healthy subjects has a clear effect on olfaction – a negative emotional state reduces olfactory sensitivity. As emotional states are likely to change quickly and uncontrolled during vehicle operation, e. g. in congested situations or on vehicles cutting in, a changing (degrading) emotional state would directly affect (reduce) olfactory sensitivity. A further problem of smell interfaces restricting its field of application is the fact that they either saturate the entire space (passenger cabin) or requests the user to wear a mask (would, illicitly, limit the field of view of the driver). Solutions to this problem have recently been proposed with prototypical devices providing scents to a restricted space only [28]. Another problem is olfactory adaptation; to cope with this, [15] found out that a driver could continuously detect scents over a long time when using pulsed ejection instead of scent delivery without interrupt. Summarizing, the broad application of the olfactory channel for subliminal persuasion has to be anticipated in the present day due to the manifold restrictions and lot of open issues.

3. CONCLUSION

Our research focus on subliminal persuasion in the automotive domain does not occur without reason – it is a challenging field of research to reduce the complexity in driver-vehicle interaction. We try to reach this by employing sensory modalities capable of providing additional information to the driver without generating supplementary cognitive load. The review of related work and the discussed approaches have shown the potential to support drivers in their increasingly complex task of driving without further distraction. Subliminal persuasion could be, for example, understood as stimuli that might be *visual* images transmitted so quick that they are perceived only subliminally, *sound* inaudible to the conscious mind but interpretable to the subconscious mind, *vibration* patterns not consciously sensible but noticeable in a subliminal way, or *fragrances* sprayed with such a weak strengths that affected persons are not conscious of the aroma.

With the starting point given in this work we would like to initiate active discussion and in-depth investigation of this timely, relevant and important field of research. We are quite confident that subliminal persuasion will find its way into cars in the near future.

3.1 Future work

Previously we have tested the potential of subliminally delivered/perceived vibrotactile stimuli during driving to reduce CO_2 emission, and now we are in the preparatory stage of extending the approach to the visual and olfactory channel as well. For example, we are planning studies with subliminal images flashed in a head up display to change the driving behavior or a targeted dispersion of different scents in the passenger compartment (e. g., lavender, peppermint, lemon) to change a driver's state of mood.

The higher purpose of experimentation is to find answers for general questions such as (i) what are characteristics of subliminally delivered information?, (ii) does information delivered in a subliminal way really affect cognitive load or perceived workload?, (iii) is this type of technology socially acceptable?, (iv) how much –if at all– depends the perception of subliminal information on individual differences?, and (v) how could subliminal driver support be employed to improve road safety?

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