A Model of Anticipation in Driving – Processing Pre-event Cues for Upcoming Conflicts

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ABSTRACT

The ability to anticipate future events in the traffic environment is an important competence in driving. This paper extends our prior work: 1) to show potential benefits resulting from anticipatory competence in driving, and 2) to collate characteristics of anticipatory competence from a theoretical point of view. The reviewed literature is foundational to our understanding of anticipation as a high-level cognitive competence, allowing for the prediction of future traffic situations on a tactical level. We conceptualize anticipation as relying on the identification of stereotypical traffic situations based on indicative cues, and stress that the impacts of this competence are dependent on the driver's individual goals. Thus, anticipation enables a number of potential benefits, such as safety and fuel-efficiency, but the realization of these potential benefits depends on the goals of the driver. Further, we argue that the superior anticipatory competence of experienced drivers observed in an earlier simulator study can be explained via their heightened ability both to identify indicative cues, and interpret those cues relative to similar, memorized situations. We then capture anticipatory driving in a model inspired by the classical theory of information processing to describe the various steps necessary to process indicative cues from the environment, anticipate a future traffic situation, and take appropriate action or achieve a state of cognitive readiness.

Author Keywords

Driver Behavior; Anticipation; Traffic Safety; Fuel Economy; Information Processing; Driving Experience; Human Factors.

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INTRODUCTION

Driving depends on a multitude of learned competencies, the most basic of which is the ability to control the vehicle. Drivers need to be able to correctly interpret information from their vehicle and the roadway, and use vehicle controls to safely navigate on the roadway. Handling a vehicle is, in this sense, a physical task requiring continuous, skilled input to steering wheel, brake and gas pedal to control the vehicle's lateral and longitudinal movements. Many technical solutions seek to aid in this task of vehicle control, from simple ideas like power steering, to complex aids like electronic stability control.

However, driving cannot be reduced to the physical control of the individual vehicle, but depends also on the correct interpretation of the surrounding traffic environment – traffic rules have to be applied, signage understood and most importantly, the actions of other traffic participants need to be taken into account. As such, driving also is a continuous, cognitively demanding sense-making task, and can be understood in terms of information processing. Information from the traffic environment enters the senses, is filtered and then consciously perceived. Working- and long-term memory are then used to interpret the information, and based on this interpretation, appropriate actions are selected and executed.

In this way, drivers interpret the sensory input from the traffic environment to enable appropriate action – a highly cognitive task. The continuous nature of this task is of crucial importance: Using a visual system that is optimized for speeds of less than 15 mph [22], piloting a car requires drivers to maintain correct understanding of their own position in the roadway and those of the traffic participants around them at many times this speed. The traffic situation can change very quickly; any given situation assessment can become meaningless in a matter of seconds if the driver fails to update it using the continuous sensory input from the environment. In this sense, a driver already perceives new sensory input in parallel to interpreting the input perceived moments ago, operating in a constant feedback loop. Driving requires our cognitive apparatus to constantly add to a given situational assessment, and it has to do so in real time, using as little processing time as possible.

This cognitive process, however, does not end with the continuous feedback loop between sensory perception and action, but also includes an important feed-forward component allowing drivers to estimate the near future. Based on the memory of how the traffic situation has evolved, the knowledge of similar situations from experience, and inductive reasoning, we also anticipate what is about to happen. Merely understanding the situation correctly and reacting may often be insufficient for safe driving – once a vehicle loses traction due to an ice patch, the chance to avoid an accident may be low. But understanding the situation prior, and being able to project ahead based on uneven road surface, low-temperature, and humid weather will allow a driver to anticipate a possible ice patch. In the best case, a cautious driver would likely act on this possibility, lowering speed adequately beforehand. However, even when the driver does not act right away, the knowledge about the potential danger will result in cognitive preparation.

This paper revisits and builds on prior work [25] undertaken to review research into anticipation in driving to date, as well as advances the characteristics and definition of anticipation we propose. It then summarizes the findings of an earlier experiment that sought both to identify anticipatory actions in driving, and investigate the role that driver experience plays in it [26]. A discussion of this experiment forms the basis of the model of anticipation in driving that we propose. We conclude with the overview of future research.

THE CURRENT STATE OF ANTICIPATION IN DRIVING RESEARCH

Benefits of Anticipatory Driving Competence

Driving research frequently alludes to the importance of actively anticipating what might happen next in the road environment. For instance, research focusing on eco-driving shows that the effective ways of evoking more fuel-efficient driver behaviour include the anticipation of traffic flow and of control signals more generally. [2]. The anticipation of upcoming needs for deceleration appears to be a critical factor for fuel-efficiency. A study comparing the natural stopping behaviour of truck drivers, characterized by late release of the accelerator and significant use of the brake pedal, to anticipatory behaviour facilitated by indicating optimal accelerator release times to the drivers found a potential reduction in fuel consumption by 9.5%, at the cost of less than 5% increase in travel time [29]. A comparable simulator study focusing on anticipation as a potential way of saving fuel investigated the use of an interface to indicate optimal freewheeling distances to drivers of a passenger car. Here, potential savings of up to 13% were found, at the cost of less than 3% increase in total travel time [1]. Research investigating the consistency of this effect across traffic situations with varying complexity also used an interface to aid the driver in the decision of when to brake or coast, and found a reduction in overall fuel consumption of about 10% [21]. While visual fixations on the interface were dependent on the complexity of the given traffic situation, reductions in fuel consumption stayed constant.

The safety impact of using interfaces to aid in the anticipation of situations requiring speed reductions has also been investigated. Driving simulator research using a dashboard display has shown that interfaces aiding in the anticipation of situations requiring deceleration facilitate earlier deceleration, resulting in an average reduction of maximum deceleration by over 2 m/s^2 [18]. Another study using colour coding to advise the driver to either coast, brake lightly, or brake strongly reported improved reaction times and deceleration profiles that were more linear over time than the baseline condition without the interface [13]. Improvements in both reaction times and steering kinematics have also been found in an experiment investigating the effects of response preparation on a lane-change task in a simulator setting. Valid primes for an upcoming lane change resulted in significantly shorter reaction times to initiate the lane change, and significantly shorter kinematic phases for the first point of reversal of steering wheel movement [10]. The positive impact of response priming (and in general of alerting the driver to potential conflicts) on reaction times has been supported by other studies in the real world; both with regard to passenger vehicles on a test track [6], and also motorcycle riders on a flat stretch of road [3].

Some have argued that anticipation has a role in hazard perception, defining hazard perception is relying on “ (…) the ability to anticipate traffic situations” [23, S. 407]. Jackson et al. argue that experienced drivers in particular can develop the competency of predicting future events from understanding their driving environment [12]. They describe hazard perception using Endsley’s [4] three level model of situation awareness – perception of the hazard is attributed to level 1, the formation of understanding of the traffic scene based on the cognitive processing of this perception is attributed to level 2, and the anticipation of potential future movements of this hazard based on perception and understanding can take place on level 3. The authors theorize that such anticipation “maximizes [available] decision-making time, which allows for safer driving” [12, p. 156].

Anticipation is connected to driving experience, and can be viewed as a competence learned from exposure to similar situations in the past. This rationale can also be found in research on driver training for hazard perception. Novice drivers are diagnosed to have more difficulty in predicting roadway risks before the risks become critical, which, in turn, is argued to contribute to their over-representation in fatal crash statistics [16]. Support for this explanation can be found in a simulator study which investigated potential differences in visual scanning behaviour of experienced and novice drivers when exposed to hazards in the roadway. Early cues prior to the conflict, or the so-called ‘foreshadowing elements’, indicated the hazards. Due to their poor visual scanning, novice drivers performed worse with respect to the perception of those hazards [8]. The tendency of experienced drivers to be better at early recognition of hazards has also been confirmed in a similar study which used video-recorded scenarios instead of simulator drives [12]. Videos were stopped just prior to hazard onset, and experienced drivers correctly anticipated more of the impending conflicts than novice drivers.

As has been shown in the research presented, anticipatory competence in driving has the potential to improve driver performance with respect to several goals, such as eco-driving, safety, and hazard perception. However, we hypothesize in Stahl et al. [3] that anticipation aids in the realization of a given driver's individual goals in general, and therefore should not be argued to exclusively benefit either safety, or eco-driving, or both. An aggressive driver could use anticipatory competence to make quick headway by anticipating the movements of surrounding traffic in such a way as to choose the quickest path. Quotes referring to the importance of anticipation in racing appear to substantiate this rationale. For example, Julian Simon, a professional motorcycle racer, for example, explains the process of braking into turns optimally and in such a fashion as to allow overtaking of fellow competitors with reference to anticipation: *"When you have linked turns, when you exit the corner fast or slow and get to the next one, that's when there's more possibility to pass the rider and where you have to understand what the other rider will do, or how you can pass him. You have to anticipate this braking and go faster in the first turn so in the next you can pass him."* Likewise, race car driver and two-time rally champion, Walter Roehrl, describes the necessity of anticipating his car's state in a 1985 interview: *"In principle, and with respect to the capabilities of this car, you are already too slow with your thinking. To drive this car, you need this particular precognition. Everything has to happen beforehand; if with this car you wait until an action is due to be done, then you're overdue. Everything has to happen intuitively and in advance (...) You have to anticipate beforehand, because if you wait until you can feel what is happening, it's already too late."*

Theoretical Considerations – What is Anticipation?

Theory-driven work about driver behaviour also makes reference to anticipation. As such, driving has been argued to be, largely, a highly automated, cognitive task governed by anticipatory brain mechanisms, which in turn rely on the identification of familiar stimuli in the roadway [28]. Only when unfamiliar and unpredictable stimuli appear are those anticipatory mechanisms interrupted and temporarily replaced by reactive acting. Onken makes a similar connection between anticipation and prior experience [15]. He does not go so far as to identify anticipatory processes as a baseline, normal operating principle for driving, but still distinguishes between familiar situations allowing for anticipation, and unfamiliar situations relying only on immediate analysis of the situation at hand. Onken argues that such unfamiliar situations require high-level knowledge-based behaviour from the driver, while familiar situations with anticipated outcomes can make use of more immediate, skill- and rule-based behaviours.

Tanida and Poeppel [28] argue for different temporal windows of anticipation, ranging from a strategic level that addresses the entire driving activity, to a synchronization level describing near-instantaneous actions of sensorimotor control. We, however, advocate a tighter definition of anticipation that is restricted to the tactical level. Understanding anticipation as a highly cognitive, learned competence to predict the trajectory of a complex system in the timeframe of a few seconds, we distinguish it from both the general planning character of anticipation for longer time-frames, as well as the automated, reflex-like character of sensorimotor actions. This restriction is not meant to exclude prediction of future system states with respect to other temporal horizons, but to suggest that anticipation, as a planned process to facilitate proactive driving styles with respect to the planning of manoeuvres, is most crucial on the tactical level. A similar rationale has been put forward in [24].

Anticipation has further been discussed theoretically with respect to its potential to improve safety through risk reduction. Fuller [7] refers to it in his behavioural analysis of the driving task, which led to the formation of a threat-avoidance model. Fuller theorizes that a given discriminative stimulus can potentially remain without an appropriate reaction from the driver. In this case, the stimulus may either prove to not be indicative of an upcoming conflict, or evolve into an aversive stimulus requiring action, such that failure to act appropriately would result in an accident. Alternatively, the initial stimulus may be answered directly by what Fuller labels an anticipatory avoidance response, thereby resulting in elimination of the potential danger before the actual conflict is established. Here, the "integration of features projected into the future" [7, p. 1147] is highlighted to be a desirable behavior with respect to safety.

References to anticipation can also be found in work attempting to model and control the behaviour of cars. Research into the design of an automated driving agent for the remote control of scale-model racing cars, for example, has successfully used anticipatory modeling [27]. The automation considers action based on the predicted, rather than the currently recorded state of the race car in its environment, therefore also presenting a potential solution for the transmission latency of control signals for remotely operated vehicles. Likewise, the successful modeling of traffic flow in general appears to depend on the inclusion of mechanisms accounting for drivers' anticipation of acceleration patterns of vehicles ahead [30].

With all these references to anticipation in driving it is surprising how little work has been undertaken to provide a systematic definition. Attempts at specifying the meaning of the term are frequently made by specifying the time horizon of anticipation. We have already argued briefly for the anticipatory horizon spanning the tactical level of driving, and this understanding is also supported by work estimating anticipation of drivers to reach approximately 2s into the future [17]. Anticipatory attention of drivers has also been characterized with respect to information processing as a "(…) working memory-based attention system, which influences driving quality, for instance, driving speed, safety margins, and driving confidence" [14, p. 180]. The authors here describe anticipation as a process of real-time information processing that is dependent on long-term memory.

In congruence with the research presented so far, we understand anticipation in driving as a cognitive competence of information processing that allows for timely predictions of future traffic situations, and therefore provides drivers with more time to position their vehicle in a favourable way. To provide an intensional definition of anticipatory driving competence, we have identified four requirements [25]:

1. Anticipation describes a high level, cognitive competence in driving.
2. Anticipation in driving depends on the identification of stereotypical traffic situations, and a given driver's experience in similar situations in the past.
3. With respect to a temporal horizon, anticipation takes place on the tactical level, impacting the planning of driving manoeuvres a few seconds before they become necessary.
4. Anticipation as a cognitive competence of information processing is largely part dependent on the early identification of cues for an upcoming event.

Based on these requirements, we have proposed a definition of anticipatory driving competence [25]: *Anticipatory driving is a high level cognitive competence that describes the identification of stereotypical traffic situations on a tactical level through the perception of characteristic cues, and thereby allows for the efficient positioning of a vehicle for probable, upcoming changes in traffic.*

INVESTIGATING ANTICIPATORY COMPETENCE IN DRIVING

Experimental Summary

The research discussed in section 2 of this paper provides valuable insight for the understanding of anticipation. It argues for the importance of predictive skills in the traffic environment and shows potential benefits that these skills have, in particular with respect to eco-driving and safety goals.

However, to our knowledge, practical investigations of anticipation have been restricted to well-defined scenarios in which the driver has to decelerate in the near future. They mostly study the effects of aids that help drivers identify the optimal moment in time for accelerator release to enable coasting, and alleviate the need for braking. This means that they do not investigate the anticipatory competence of human drivers, but rather the potential benefit of anticipatory interfaces for human drivers. The opportunity for anticipation is realized not by the driver, but by the automation behind the anticipatory interface; as such no conclusions can be made about 1) how drivers are able to anticipate future traffic situations, and 2) how the characteristics of the individual driver impact their competence to anticipate the traffic situations - and the potential conflicts within them - a few seconds ahead of their occurence.

For these reasons, we undertook a driving simulator experiment to identify when drivers naturally use anticipatory competence [26]. The experiment investigated participants' behaviour in five independent scenarios, all of which were stereotypical traffic scenarios that allowed for the anticipation of a conflict. The types of scenarios were limited in such a way that all of them were based on an anticipatory horizon on the tactical level (see section 2.2 of this paper), and on the anticipation of the behaviour of other traffic participants. The possible, early actions participants could take prior to the conflict event were not limited to deceleration, but included, for example, acceleration and overtaking, or lane changes. That is, the experiment was of an exploratory nature, and attempted to identify a wider range of anticipatory driving acts (according to the definition proposed), as opposed to just deceleration.

The Impact of Experience on Anticipatory Competence

Due to the significant role that driving experience plays in the successful interpretation of traffic situations, specifically with respect to hazard detection [11], [16], the experiment investigated the driving behaviour of three different experience groups, as described in table 1.

Experimental results confirmed the hypothesis that experienced drivers are more likely to exhibit anticipatory competence in their driving, and act accordingly. A statistical investigation showed that participants with high and medium experience acted prior to an event more often than participants with low experience (figure 1). There was only a marginal statistical effect between high and medium experience groups, with a trend of high experience participants displaying more pre-event actions.

Exp. level	Years of licensure	Last annual mileage (km/year)	n	Mean age (SD)
Low	≤ 2	< 10,000	10	19.3 (1.34)
Med.	≥ 10	< 10,000	10	32.6 (9.46)
High	≥ 10	> 50,000	10	29.8 (4.29)

Table 1: Grouping into three levels of driver experience (adopted from [3])

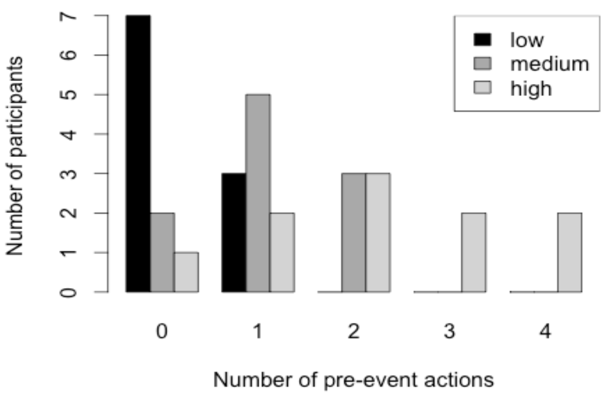

Figure 1: Number of participants displaying different numbers of pre-event actions (adopted from [3])

The ability to anticipate future states of surrounding traffic and act accordingly, just as the ability to understand the current situation and identify hazards, is dependent on driving experience. In this sense, anticipating future traffic situations appears to be a learned competence, depending in large part on prior exposure to similar situations, and the ability to access and compare the current situation to those potentially similar, memorized situations.

This view of sense-making in traffic as a top-down process of interpreting the sensory input from the environment relative to already existing mental models has been discussed in [11]. It is an idea in the constructivist tradition, where any learning can only take place as an iterative, comparative process between perceived information and existing constructs of the world. Constructs are the reference point for any interpretation of sensory information, and new information in turn continuously evolves our mental constructs. In this regard, facilitating anticipatory competence can be seen as a task of aiding in the development of a catalog of stereotypical traffic situations, their likely progression in the immediate future, and appropriate actions to position a vehicle efficiently in those situations. Research into the potential for benefits of driver training uses this approach [16], [5], [19].

ANTICIPATION AS AN ACT OF INFORMATION PROCESSING

Identifying and Interpreting Pre-event Cues

The role of experience in anticipatory competence, however, does not explain the process drivers use to identify particular traffic scenarios and anticipate their likely progression into the immediate future. Implicit to the definition of anticipation is the assumption that the identification of stereotypical traffic scenarios depends on characteristic sensory cues that are perceived and then analyzed and interpreted in working memory.

In the experiment described, the categorization of drivers into a "pre-event action" category depended exclusively on the evaluation of participants' simulator performance data. However, we also conducted post-experiment cognitive walkthroughs. Participants viewed their simulator drives in an animated, top view recording and reported on the cues they remembered. Comparing the answers of drivers with and without pre-event actions suggested clear differences in the number and kind of cues remembered. Drivers who took more pre-event actions gave more complete, causally connected accounts of how the situation evolved around the various cues. In the first scenario, they referred to the initial cue, namely a slow tractor, and consistently remembered the braking of several cars ahead, their brake lights, and the decreasing headways between them. Drivers who did not take pre-event actions in contrast, were often only able to remember that the brake lights of their immediate lead-car activated. Likewise, in the second scenario, non-anticipatory drivers often reported having been aware of an overtaking car only once it pulled beside them in the opposing lane. Anticipatory drivers, however, described the overtaking car as having tailgated them, were aware of intermittent lines on the road allowing for overtaking, and reported having been alerted to the overtaking manoeuvre because they saw the left signal of the overtaking car flash in the rear-view mirror.

Similar tendencies of anticipatory drivers to remember more cues, and connect them to a more precise, detailed account of the situation were found throughout all five scenarios. This qualitative observation in our experiment corroborates the importance of characteristic cues for anticipation. The crucial ability to compare the existing traffic situation with similar situations stored in long-term memory relies on the identification of such cues. This sense-making based on comparable situations in turn creates expectations with respect to what will happen next [11], and thereby also guides selective attention and the continued perception of the traffic environment.

From this perspective, another means of facilitating anticipatory competence in driving is the manipulation of the cues in the environment, and their perception by the driver. The best catalog of stereotypical traffic scenarios and their potential conflicts will go unused and fail to enable anticipation unless the current situation is interpreted correctly based on the available cues.

While, in general, cues may be mediated through all modalities, driving in particular is dominated by the perception of visual information, which has been argued to make up as much as 90% of the total information available to drivers [9]. Limiting the following discussion to visual cues for this reason, it can be argued that two mechanisms govern where visual fixation occurs [11]. One mechanism is the guidance of selective attention through the knowledge about the situation. An anticipatory driver realizing that the car ahead is about to brake will be in a state of cognitive preparation for this braking manoeuvre, and likely focus on that car and its brake lights. The other mechanism guiding visual fixation is one of recognition of change – fixations are attracted if the visual scene changes [11]. Phenomena like change blindness can take place when both of these principles are in conflict – because knowledge of a given situation has created expectancies, attention may be focused in such a way that unexpected changes in the visual scene are not recognized.

Part of the first mechanism depends on the comparative analysis of the current situation with memorized stereotypical situations (top-down), as the expectations developed from experience will guide attention. However, a bottom-up component of inductive reasoning likely works in parallel, and allows for logical analysis of a given situation. While an experienced driver may use similar, memorized situations as a shortcut to anticipate, an inexperienced driver may still develop the same understanding of the situation through a process of analyzing the available cues.

In this sense, physical properties of cues in the roadway, such as their salience, contrast, and onset will influence how strong a change in the visual scene is perceived by the driver. However, the semantic meaning of the particular cue will impact how attention is attributed to the environment, and how the particular situation at hand is interpreted. If we imagine a hypothetical scene in which another traffic participant merges in front of a driver in his travelling direction, then we can argue for some physical properties to influence how likely this driver is to pay attention. The contrast between the other traffic participant and the background, whether or not their lights are on, but also the size of the vehicle will play a role – a motorcycle without lights and with a color similar to the background will be less noticeable than a large truck, in bright red color and with its headlights on. However, the semantic meaning of the cue will impact expectancy as well – we can reason that the truck will take much more space to merge into the driver's lane, and also accelerate considerably slower than the quick, manoeuvrable motorcycle. Hence, the truck would make it much more probable that there will be a need to decelerate and provide space, while the motorcycle would produce a smaller expectancy for a conflict that requires braking.

A Model of Anticipation

Thus far, we have provided a definition of anticipation in driving, and investigated anticipation according to this definition in a simulator experiment. We also discussed two crucial principles behind anticipatory competence in driving. We explained 1) the importance of an existing, memorized catalog of appropriate reference situations for the purpose of comparative analysis in working memory, and 2) the importance of appropriate cues with respect to both the factors influencing cue perception, as well as the different semantic meanings of those cues.

Both of these principles match well with the effort in cognitive psychology to understand human thinking in terms of a general model of information processing. In [31], a general process is described in which any information from the environment is recognized through the senses, and then perceived in order to be interpreted. Based on this interpretation of the information, potential decisions and response actions are considered dependent not just on the perceived information, but also on analytical processes in working memory that are influenced by the attribution of available attention, and also on associated constructs from long-term memory.

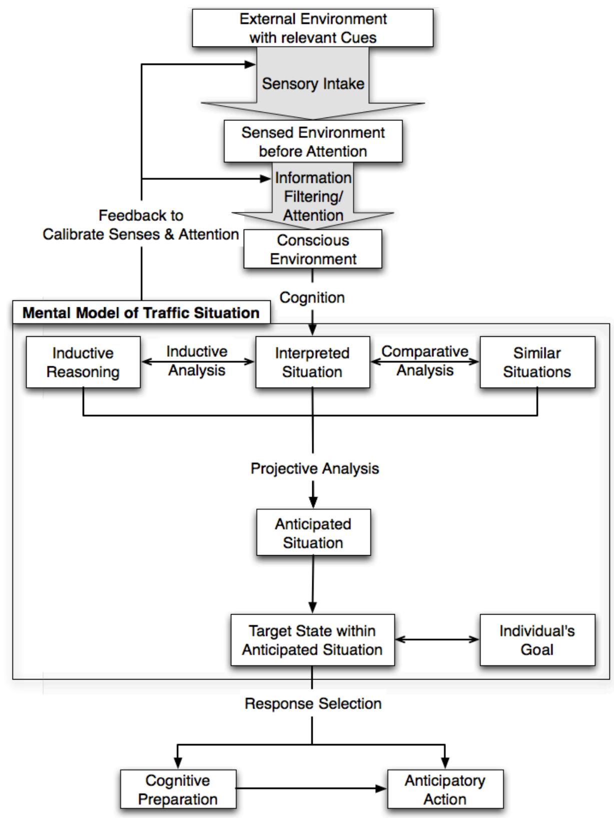

Figure 2: Model of Anticipation in Driving

Figure 2 displays our representation of anticipatory processes in driving, adopted from the general model of information processing. The starting point is the general (traffic) environment represented by the box at the top, which contains a wealth of information that can be sensed. Among this information are specific cues that are indicative of the particular traffic situation at hand. Some of these cues are internalized through the sensory apparatus, forming a "sensed environment" that represents the ecology. Before a "conscious environment", that is, an accessible representation of the traffic environment, is created, the current focus of attention filters this information. While the external environment therefore contains all relevant information, some information will be lost through the limitations of our sensory apparatus, as well as through cognitive filters – the progressively smaller boxes and arrows represent this reduction in information.

The more indicative cues reach the conscious environment, the better the chances that a given driver can correctly interpret the traffic situation at hand. This interpretation of the situation is further developed through two analytical processes; one based on inductive reasoning, the other based on the comparison of the situation at hand with similar situations in long term memory.

Experience can be argued to lead to a catalog of similar situations that is more detailed and more extensive. Consequently, for the experienced driver, the process of interpreting the situation at hand is guided heavily through the knowledge of comparable situations. Efficient and fast skill-based behaviour [20] takes over in this case. The novice driver in contrast may be unable to match the current situation to a fitting, memorized one due to an underdeveloped catalog of similar situations. The novice driver will instead rely more heavily on processes of inductive reasoning, such that more effortful processing will take place. He will still be able to interpret the current situation, but the accuracy of his interpretation will rely more on high level, knowledge-based behaviour [29].

Anticipation comes into play only after this development of an interpreted situation, and can be seen as a projection of this current situation into the future. Even more than the interpretation of the current situation, the establishment of the respective anticipated situation a few seconds ahead depends on the expectancies developed from the knowledge of similar situations, and from the inductive reasoning about this situation. In the case of the red truck merging onto the road one is travelling on, the experienced driver will likely be able to identify the need to provide space and decelerate due to his experience in similar situations. The inexperienced driver in contrast will need to interpret the semantic meaning of the perceived cues, access his construct of trucks, and based on attributions of characteristics to this truck-construct (i.e., slow, heavy, large, relatively inert) induce the likely consequence – the truck will need a lot of space to merge onto the road, and not be able to accelerate quickly.

As has already been pointed out, the practical consequences of anticipatory competence should not be limited to one particular benefit, such as safety or eco-driving. Rather, they depend on the way the specific driver uses them. This hypothesis has been supported by the findings of the aforementioned experiment, where the effects of pre-event actions on safety measures and fuel-efficiency were not generalizable. Hence, the driver will decide on a desirable future target state of her own vehicle within the anticipated situation only after she has considered her personal goals. Once this target state has been decided on, two possible responses can be selected: Either, the driver will carry out an immediate action that sets her in a favorable way with respect to this future target state, or she perceives no immediate need to act. In the latter case, she will have achieved a heightened sense of expectancy for the development of the traffic situation, and therefore be in a state of cognitive readiness, which may still lead to an anticipatory action, should it become necessary to achieve the desired target state.

The first three boxes in figure 2 represent perception: the translation of information from the environment to the reduced, conscious, and accessible representation of this environment that our cognitive apparatus can access. The rectangle around the following five boxes represents the processes forming a mental model of the situation. The relationship between perception and this mental model is not exclusively of a feed-forward nature. Perception feeds the cognitive apparatus with the necessary information from the environment, but the resulting mental model also calibrates a driver's senses (i.e., where to look) and attention (i.e., what information becomes conscious).

CONCLUSION & FUTURE WORK

In this paper, we have provided an account of the current state of research of anticipation in driving. We have reported benefits based on an updated body of research in comparison to prior work [25], [26]. References discussing anticipation from a theoretical perspective have been reported, and connected to our definition of anticipation. A prior simulator experiment designed to investigate this definition, and, more importantly, test the hypothesis that driving experience increases anticipatory competencies, was summarized and its main findings reported.

Based on the theoretical work leading to our definition of anticipation in driving, as well as the interpretation of the experimental findings, we have suggested the benefits of interpreting anticipation as an act of cognitive information processing. The information processing model of anticipation is the main contribution of this paper, and seeks to explain what processes are necessary for a driver to anticipate upcoming traffic situations.

We are planning to investigate specific aspects of this model empirically. As has been pointed out, anticipation relies on the recognition of indicative cues, and facilitating anticipation therefore becomes, in part, a task of maximizing the number of indicative cues that are accessible to the cognitive apparatus (i.e., the number of indicative cues in the conscious environment). To support this hypothesis, research can be undertaken to alter the physical properties of cues in a given scenario. With respect to the impact of experience on anticipatory competence in particular, two interesting questions are 1) how many indicative cues does an experienced driver require to be able to anticipate, and 2) can an increase in the number and salience of indicative cues aid also novice drivers to anticipate? Likewise, the potential effects of conflicting events attributed to the identified traffic scenario should be investigated. According to the model presented, an anticipatory driver should, upon identifying a situation based on the cues provided, exhibit anticipatory action even when a respective future conflict does not occur.

The semantic meaning of cues should also be investigated. Especially for inductive reasoning, the meaning of a particular cue and the respective mental construct it is referring to become crucial for the assumptions made about the situation. With respect to future interfaces that may aid in both the correct interpretation of a given traffic situation, as well as the anticipation of future states of traffic, the possibility of providing additional, artificial cues should also be investigated. A novice driver who does not possess a sufficient catalog of reference situations in long term memory may still be guided in the process of inductive reasoning through either the highlighting of important cues, or even succinct messages aiding in the interpretation of those cues.

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