Defining, Investigating and Supporting Anticipatory Driving

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A Systematic Investigation of the Competence to Predict Traffic

by

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Abstract

Driving research shows safety and economic benefits of anticipatory competence. While the literature recognizes the notion of anticipation, it has not yet operationalized the construct. This dissertation addresses this gap by presenting a systematic investigation of anticipation in driving. It starts by defining anticipation as a competence relying on the conscious perception of visual cues and their cognitive processing. Two driving simulator studies then investigate the ability of novice and experienced drivers to anticipate conflicts in stereotypical scenarios.

The first experiment shows the feasibility of identifying anticipation through the surrogate measure of pre-event actions relative to a conflict event, and confirms the hypothesis that experienced drivers exhibit these actions more often. This experiment supports an information-processing model of anticipation. The model suggests two crucial steps for the facilitation of anticipatory competence: (1) the conscious perception of appropriate cues that serve as indicators for the traffic scenario, and (2) efficient cognitive processing of those cues for a correct situational assessment.

The second experiment investigates the effect of two interfaces designed to aid these steps. The attentional interface aids only the perception of cues and is hypothesized to yield larger benefits for experienced drivers who do not struggle with the interpretation of traffic. The interpretational interface supports both steps and is hypothesized to improve particularly novice drivers' competence in interpreting traffic. Contrary to these hypotheses, results show similar improvements in anticipation for both interfaces across all participants, although fewer and shorter glances towards the attentional interface suggest that it is preferable from the perspective of driver distraction.

This dissertation extends the formerly vague concept of anticipation by defining and operationalizing it as a construct, identifying anticipatory actions, demonstrating that driver experience predicts anticipatory competence, and suggesting aids to support anticipation. These advances promote anticipation as a viable construct for future driver behaviour research.

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1.1 The Technology-driven Approach to Traffic Safety

Technological advancements have changed cars significantly throughout the last century and safety in particular has been a major driver for continuous change. Hence, numerous safety features are taken for granted in today's automobiles: Cars have been sold with three-point seat belts since their invention in the late 1950s (Matinu & Ploechl, 2014), they come equipped with head rests, and current car bodies are built to absorb energy during crashes while maintaining safe cabin space for passengers. Although the airbag was already invented in 1951 (Matinu & Ploechl, 2014), it was not until the 1990s that it became a standard feature in most production cars. All of the above are examples of passive safety features; they have improved crash safety significantly, but do not aid in the prevention of crashes.

Active safety systems, that is, systems that help avoid crashes, have also improved significantly. Anti-lock braking systems ensured that cars remained maneuverable while braking, and have been found to reduce especially run-off-road crashes (by 35%), as well as multiple vehicle crashes (by 18%) (Burton, Delaney, Newstead, Logan, & Fildes, 2004). More recently, electronic stability control systems detect decreasing traction and actively brake individual wheels to prevent over- and understeering. Studies estimate that such systems reduce fatal single-vehicle crashes by up to 50% (Ferguson, 2007). Active safety systems in recent days have made advancements that blur the lines between manual and autonomous driving. With the advent of adaptive cruise control (ACC) systems, longitudinal control of the vehicle is not regulated by the driver anymore, and lateral control can be taken over in modern vehicles by lane keeping systems. Mercedes now offers cars that drive autonomously during specified traffic conditions (such as stop and go traffic) (Levin, 2013).

However, what appears striking about all of these technological advancements is that they either seek to protect the driver when a crash is already happening, or seek to take away control from the driver. And while the development towards automation and autonomous driving is bound to continue, it does not come without risks and disadvantages. A very influential paper (Bainbridge, 1983) discusses pitfalls of automation and highlights the potential dangers of excluding operators from the active control of a given system, and instead expecting them to (1) monitor the automated system, and (2) take over in specific cases not suitable for automatic control. Humans are notoriously bad at monitoring tasks, and the advantages of automation come with the trade-off of skill degradation (Lee, 2006). Skill degradation in turn often leads to inferior performance in the case of manual take over. Operator understanding of such impactful systems also has to be ensured. For example, a study investigating users' knowledge of their vehicle's ACC system came to the conclusion that a significant number of drivers is unaware of ACC limitations that could create potentially dangerous situations (Dickie & Boyle, 2009).

Another limitation of both active and passive safety systems is that neither focuses on improving driver competence. But as long as autonomous vehicles have not taken over our roads to 100%, the driver and his or her competency are crucial elements in traffic. Crash statistics support this view by estimating that 57% of all crashes are solely, and 90% at least partially, due to human error (Treat et al., 1977). Further, research has concluded that these human errors are predominantly due to errors with respect to the perception of traffic and visual scanning (Sabey & Taylor, 1980). The known overrepresentation of novice drivers in crash statistics in particular has been attributed to novices' failure to correctly interpret the roadway and its upcoming risks (Pollatsek, Narayanaan, Pradhan, & Fisher, 2006).

All of this speaks for the argument that the human operator and his timely, correct interpretation of the traffic environment are important factors in road safety. The general perspective I took for the work presented in this dissertation is therefore one not focusing on the car and its capabilities, but instead on the driver. The goal was not to automate and replace human operators, but to support and facilitate their competencies when piloting a car.

1.2 Driver Competencies: Anticipation vs. Reaction

Prior to my research into driver behaviour, my understanding of traffic crashes was dominated by the notion of drivers who had "reacted too late". I still vividly remember the discussions after a family member was involved in a traffic accident, and from my perspective as a Human Factors engineer nearly 20 years later, I can now identify numerous elements characteristic of crashes. The person involved in the crash was rushing to get to work on the morning of the accident, and the time of day was just past dawn. She was approaching a T-intersection from the Northeast on a minor road, and about to make a left turn to continue travelling Southeast on a major road, the general direction where the sun must have been located at that time of day. While she was making the left turn, her car was hit by another vehicle which was travelling the major road northbound. I clearly remember how shocked my family member was after the crash – she swore she had simply not seen the car on the major road and kept insisting how she might have been able to avoid the crash if only she had ‘reacted’ earlier. Today, I would wonder about classic Human Factors issues in such a crash: Given the time of day and the directionality of the intersection, was the sun behind the car she collided with at the time of the collision, and may she have been blinded by it as a result? Did her rushing to work impact her willingness to take risk? Were there any objects obstructing her view, and how early on could she have seen the car? Back then however, discussions of the crash focused on how she had braked too late, and the strategy to avoid similar situations in the future was as simple as ‘reacting earlier’.

Driving altogether appears to be a task in which quick reactions are very much favored and expected. Especially with respect to accident investigations in forensic human factors, the question of whether a driver could have reacted in time to avoid a crash is frequently raised. Many different, context-dependent guidelines for perception-reaction time have been discussed, and summaries of studies investigating perception-reaction time in general argue for driver expectancy to result in variations of reaction times between 0.7s (high expectancy) and 1.5s (surprise events) (Green, 2010).

An example for a driver who was seemingly very fast with his reactions in traffic was my father. An experienced driver with close to 100,000 km annual mileage as a regional manager, I remember numerous instances when I sat in the passenger seat of his car and would be thrown into my seatbelt before I could even understand the reason for his braking. When travelling on the autobahn, he seemed to be able to travel more freely – where other drivers needed to brake frequently due to slower vehicles in their lane, my father seemed to consistently choose the lane that was free. Over time, I noticed several characteristics of his driving that deviated from other drivers I observed. When it was raining or snowing my father fell back further, and in general adjusted his speeds down more than I was used to from other people. His position in the lane, and his choice of following distance varied based on the situation: He tried to avoid following large SUVs or transporters on the autobahn, and if he found himself behind one would fall back further and keep to the very left edge of the lane. His headway distance also seemed to change much more relative to speed and weather. While he consistently tended to choose higher speeds, he also followed at much greater distances. The contrast became glaringly apparent when a friend from university changed from a relatively weak to a powerful car – while I generally felt safe in his car, he was suddenly following other traffic participants much too closely when travelling the Autobahn at speeds greater than 150km/h.

While I do think my father's reaction times in traffic are appropriate, the much more impactful aspect of his driving was his focus on understanding and acting according to the traffic situation such that he could position himself in a beneficial way for what was about to happen. While this understanding also enabled him to react quickly in numerous conflicts, he more often avoided conflicts altogether. I learned that his choice of lane on the Autobahn was determined much more by his anticipating the movement of slower right lane traffic – if he suspected a slower car might switch into his lane, he would merge one lane further left himself, or speed up or slow down to avoid conflict. He explained that he avoided following larger vehicles because they obstructed his view of the traffic ahead, so that he would not be able to anticipate anymore what was about to happen.

When I finally got my own license, I learned how to operate a vehicle in driving school. My driving instructors taught me all relevant traffic rules in my home country of Germany, and after I had passed a successful theoretical test, proceeded to have me practice on the road. Surprisingly to me, none of the anticipatory driving that I had gotten used to from observing experienced drivers was taught. I knew speed limits, traffic rules, who had right of way, and how to operate a vehicle because of driving school. But I understood what to look out for and how to read traffic because of having developed an understanding of other peoples' behaviour in traffic and being able to anticipate their actions to some extent. Wayne Gretzky, a Canadian hockey player summarizes the concept well in the context of his sport: "A good hockey player plays where the puck is. A great hockey player plays where the puck is going to be." (Forbes, 2013).

1.3 Benefits of Anticipation

The usefulness of anticipation appears clear: with an earlier understanding about the developments in traffic, the time horizon for action increases. And even the driver who anticipates the future traffic state but chooses to remain passive rather than acting on it will develop an expectancy that, as has been briefly described above, could improve his reaction time. If on the highway I am surprised by a car in the right lane merging into my lane and cutting me off, all I can do is react and apply the brake as quickly as possible. If however I have been aware of this car closing in on another traffic participant in its own lane, and have therefore concluded it likely for it to change lanes even before it signals or moves into my lane, I have more time and more options. I can decide to act right away, and for example release the accelerator to allow for more room, or move one lane further left myself. Even if I decide not to act yet, I will likely monitor the car and expect its lane change and therefore be able to apply brake pressure earlier than a driver who is taken by surprise. In this sense, one clear benefit of anticipation should be traffic safety.

In the same scenario however, I frequently observed drivers who anticipated a car in the right lane to merge into their lane to accelerate, trying to pass the car in the right lane before it would make the lane change. While I would argue this behaviour to still be safer than the non-anticipatory reaction of a driver who is suddenly being cut off by another traffic participant, anticipation also appears to allow for more aggressive driving. Quotes referring to the importance of anticipation in racing appear to substantiate this rationale. For example, Julian Simon, a professional motorcycle racer, 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*." ("Moto2^{TM} - Braking and tyre use in Grand Prix racing - YouTube," 2013).

Likewise, race car driver and two-time rally champion, Walter Roehrl, describes the necessity of anticipation to handle his race car. Rally cars had made a huge leap in engine power under group B regulations and had therefore pushed drivers' skills to their limits (Davenport & Klein, 2012). Roehrl states in a 1985 interview (translation by author): "*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*." ("Audi Quattro S1 Doku-Die Legende des Rallyesports kehrt zurück - YouTube," 2014)

Anticipation can also be beneficial to fuel consumption. While many techniques for what has been termed ‘hypermiling’ focus on proper car maintenance and minimizing the engine’s fuel consumption, actively minimizing brake usage by anticipating traffic is also emphasized. Hypermiler.co.uk, for instance, states among its five top hypermiling driving tips: “Anticipate the road ahead. By driving ‘reactively’ you effectively hand control over your fuel consumption (and safety) to other drivers. Look well ahead so you’re aware of what you’re driving into and can anticipate changes before they occur.” (“Hypermiling Techniques,” 2011). An account of hypermiling (Gaffney, 2007) describes the ways in which Wayne Gerdes realizes fuel economies of up to 110 mpg, among others through anticipating traffic light phases and the actions of other traffic participants.

1.4 Structure and Research Goals

My research focuses on the investigation of anticipation in driving and is subdivided into three major phases:

The first phase is investigative in nature and reflected in chapter 2; it contains a literature review and assesses the status quo of driver behaviour research with respect to anticipation. It seeks to support the aforementioned benefits of safety and eco-driving with findings from a number of studies. It also refers to several studies discussing anticipation in a more theoretical light. The goal of Chapter 2 is to show the importance of anticipation as a concept for driver behaviour, while also demonstrating the research gap: Anticipation has, as of yet, not been investigated in a systematic manner, and even a working definition of the term is lacking. Chapter 2 concludes with the identification of crucial aspects of anticipation in driving, and based on those provides a definition of the term.

The second research phase builds on the theoretical work and had two distinct goals, namely to (1) show that drivers’ use of anticipatory competence can be determined by means of identifying the point in time they act relative to each scenario, and (2) investigate whether anticipatory competence profits from driver experience. Especially research in the context of hazard perception has attributed a higher sensitivity to potential risks in traffic to trained drivers (Fisher, Pradhan, Pollatsek, & Knodler, Jr., 2007), thereby also suggesting a heightened ability to anticipate. Chapter 3 therefore summarizes empirical research that addresses these two goals: In the context of a simulator experiment we investigated the behaviour of 30 participants with three different levels of driver experience in five distinct scenarios. These scenarios were designed specifically to indicate an upcoming conflict through visual cues, such that participants had the opportunity to demonstrate adequate action prior to the conflicting event if they correctly anticipated.

The third and final phase of my research finally investigates potential ways of facilitating anticipation. It aims at understanding how drivers use visual cues to interpret the traffic situation at hand. With these goals in mind we designed two different interface types; the attentional interface aimed at supporting drivers' anticipatory competence by highlighting the most relevant cue only, while the interpretational interface highlighted several relevant cues and also suggested potential consequences of those cues. The interfaces were investigated in a second driving simulator experiment with 48 participants in three distinct driving scenarios. Eye-tracking was used in this experiment to investigate glances towards the interface and towards the relevant visual cues in the scenarios that indicated upcoming conflict events.

Chapter 2
Theoretical Considerations on Anticipation in Driving

2.1 Anticipation in the Literature

2.1.1 Safety

With respect to safety, changes in braking behaviour have been investigated when the need for deceleration is being indicated to the driver through anticipatory aids in multiple studies. 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 (Popiv, Rommerskirchen, Bengler, Duschl, & Rakic, 2010). Another study using colour coding to advise the driver to either coast, brake lightly, or brake strongly reported improved reaction times and more linear, even profiles for the reduction of speed over time than in the baseline condition without the interface (Laquai, Chowanetz, & Rigoll, 2011).

By preparing the driver for the likely development of a traffic situation in the future, anticipation can be argued to result in a state of cognitive readiness. It is plausible to assume that this cognitive readiness would result in faster reaction times as expectancy appears to have a significant impact on reaction times in driving (Green, 2010). Response preparation is a similar process, in which expectancy is heightened through appropriate primes, thus preparing the human operator for a specific action. It is however relatively detached from the context of a specific situation and does not attempt to aid an operator in interpreting a specific situation, but instead seeks to elicit a more automated response. Still, like response preparation, anticipation can be argued to result in a reduction of surprise.

Positive effects of response preparation on driver safety have been shown. Specifically, improvements in both reaction times and steering kinematics have 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 (Hofmann & Rinkenauer, 2013). The positive impact of response priming (and in general of alerting the driver to potential conflicts) on reaction times has been supported by other on-road studies; both with regard to passenger vehicles on a test track (Fitch, Blanco, Morgan, & Wharton, 2010) and also motorcycle riders on a flat stretch of road (Davoodi, Hamid, Pazhouhanfar, & Muttart, 2012).

Some have argued that anticipation has a role in hazard perception, defining hazard perception as relying on “ the ability to anticipate traffic situations” (Sagberg & Bjornskau, 2006, p. 407). Jackson et al. (2009) argue that experienced drivers in particular can develop the competency of predicting future events from understanding their driving environment. They describe hazard perception using Endsley’s (1995b) three level model of situation awareness (SA) – 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” (Jackson et al., 2009, 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 (Pollatsek et al., 2006). Support for this explanation can be found in a simulator study that investigated potential differences in visual scanning behaviour of experienced and novice drivers when exposed to hazards in the roadway (Garay-Vega & Fisher, 2005). 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. 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 (Jackson et al., 2009). Videos were stopped just prior to hazard onset, and experienced drivers correctly anticipated more of the impending conflicts than novice drivers.

Finally, defensive driving is a practice frequently advocated for in post-licensure driving courses, and attempts to teach elements of anticipation and hazard perception with the goal of enhancing road safety (Lund & Williams, 1974). A variety of studies comparing pre- and post-training crash involvement however conclude that training for defensive driving does not improve safety (Christie, 2001; Hill & Jamieson, 1978; Planek, Schupack, & Fowler, 1974). The OECD propose that this unexpected lack of safety improvement is due to behavioral adaption, such that drivers with additional driver training adopt higher confidence and drive more aggressively (OECD, 2001). It appears that increased skill alone is insufficient for safety improvements, but that individual goals have to be taken into account: Superior skill can be used for a variety of goals, and safety is not necessarily one of them. This rationale will be argued in the following sections for how anticipation is used.

2.1.2 Eco-Driving

The relevance for anticipation in eco-driving has already been mentioned in the earlier reference to hypermilers. Here, anticipation is being described as a necessary strategy to predict the development of surrounding traffic such that the car can travel with as little interruption as possible. Not surprisingly then, research 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 (Barkenbus, 2010).

The anticipation of upcoming needs for deceleration in particular appears to be a critical factor for fuel-efficiency. As a consequence, interfaces alerting drivers to the appropriate point in time to release the accelerator to maximize coasting prior to a stop are not only studied with respect to their potential to increase safety, but also to maximize 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 found a potential reduction in fuel consumption of 9.5%, at the cost of less than 5% increase in travel time (Thisjen, Hofman, & Ham, 2014). A comparable simulator study focusing on anticipation as a potential way of saving fuel investigated the use of an interface to indicate optimal freewheeling (coasting) 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 (Baer, Kohlhaas, Zoellner, & Scholl, 2011). 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% (Rommerskirchen, Helmbrecht, & Bengler, 2013). While visual fixations on the interface were dependent on the complexity of the given traffic situation, reductions in fuel consumption stayed constant.

On a more general level, possible ways to improve fuel-efficiency through changes in driver behaviour have also been investigated with interfaces that suggest the optimal gear to the driver (Van der Voort & Maarseven, 1999). Reductions of up to 16% in fuel consumption were realized this way, and appear to be in line with estimations that through changes in driver behaviour alone, reductions of about 10% are possible (Messier, Hirsch, Quimper, & Beaupérin, 2010). It is noteworthy that all studies reported in this chapter appear to look at specific situations instead of attempting an assessment of the potential for fuel reduction based on the sum of possible changes in driver behaviour. The numbers reported by hypermilers, who report average fuel savings in the range of 50%, appear to speak to the true potential here (Gaffney, 2007).

2.1.3 Theory-Driven References to 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 (Tanida & Poeppel, 2006). 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 (1993). He does not go so far as to identify anticipatory processes as a baseline operating principle for driving, but maintains the distinction 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, referring to Rasmussen’s classification of operator competencies (Rasmussen, 1983).

Tanida and Poeppel (2006) 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 maneuvers, is most crucial on the tactical level. A similar rationale has been put forward by Schoemig et al. (2011).

Anticipation has further been discussed theoretically with respect to its potential to improve safety through risk reduction. Fuller (1984) 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 a crash. 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” (Fuller, 1984, p. 1147) is highlighted to be a desirable behaviour 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 (Tanev, Joachimczak, Hemmi, & Shimohara, 2005). 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 (Treiber & Kesting, 2007).

Finally, it should be noted again that anticipation in driving is akin to level three situation awareness in Endsley’s model (Endsley, 1995b). Situation awareness (SA) in driving on a general level has been discussed in a variety of research, as has been summarized in Salmon et al. (2011). Gugerty discusses SA at a relatively high level with respect to its role for attention allocation in driving (2011), and uses SA to investigate the ability to recall correct locations of other traffic participants (1997). Ma and Kaber (2007) discuss SA specifically with respect to navigation while using aids of different reliability levels. Discussions of SA in driving can also be found in research focusing on whether and when drivers engage in secondary tasks; anticipation of the attentional demands of the primary driving task in the near future is argued to be a deciding factor (Schoemig & Metz, 2013; Schoemig et al., 2011). While SA is an excellent framework for the descriptive study of anticipation, it is not a particularly useful tool for the formative operationalization of anticipation in driving. The identification of anticipation as a concept akin to the third level of SA does not aid in the development of interface aids, and framing this research in the SA perspective would have suggested the use of query-based methods such as SAGAT (Endsley, 1995a), which would rely on drivers' interpretation of their own performance, as opposed to discussing anticipation based on their actions.

With all the references to anticipation in driving presented in this section, 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 (Popiv, Rakic, Bengler, & Bubb, 2009). 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" (Lundqvist & Roennberg, 2001, p. 180). The authors here describe anticipation as a process of real-time information processing that is dependent on long-term memory.

2.2 Theoretical Considerations

2.2.1 Challenges

At first glance, anticipation in driving appears to be a relatively straightforward concept. An anticipatory driver would identify cues that indicate a potential conflict in advance. She would consequently be able to act to avoid conflict. However, it is surprisingly difficult to distinguish driver reactions to events from actions taken before the event. To explain the challenges, consider the scenario illustrated in Figure 1.

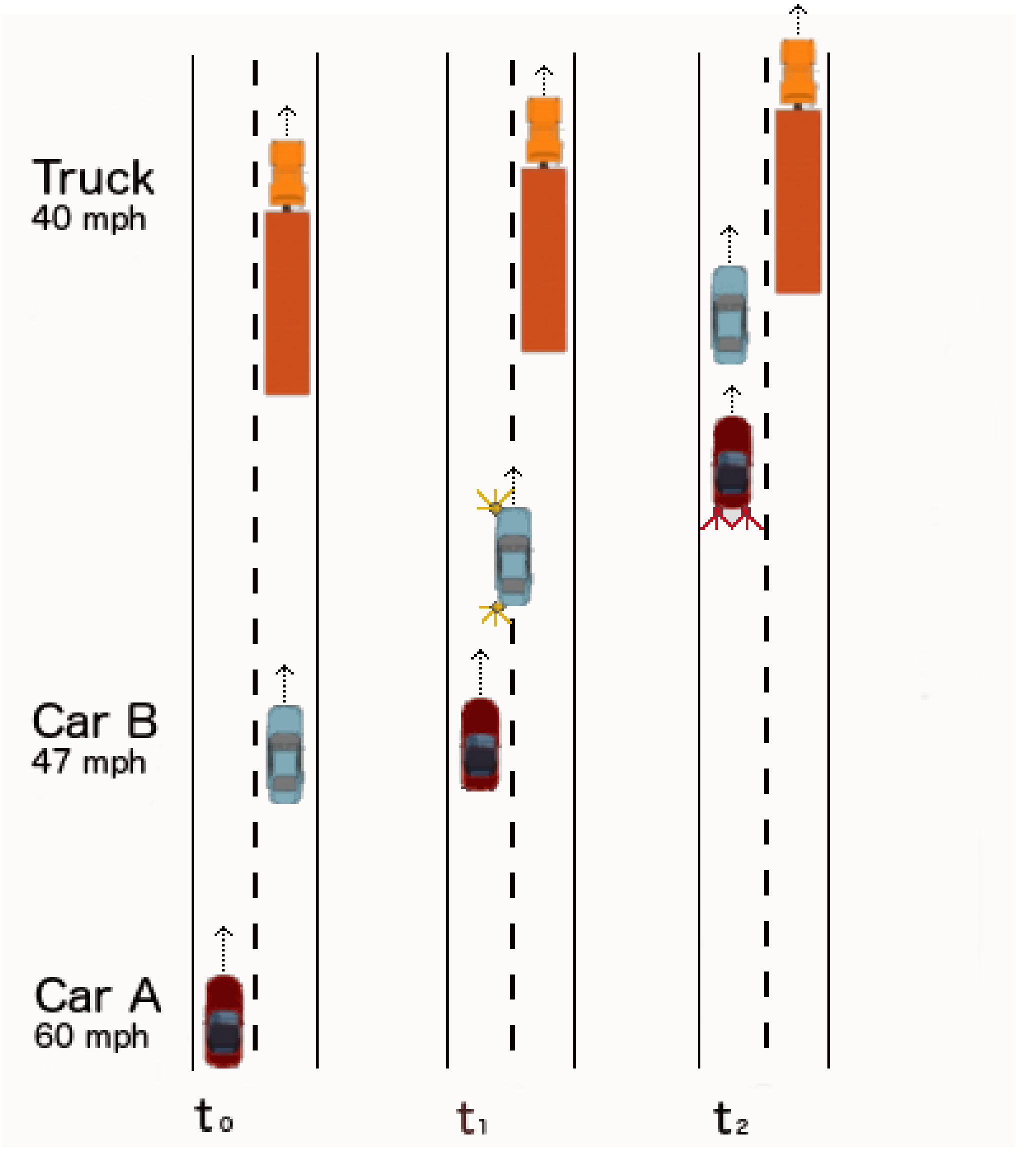

Figure 2: Anticipatory Scenario - A potential headway conflict for the driver, caused by the lane change of a leading car that attempts to overtake a truck in its own lane

Here, the travelling direction of all vehicles is from the bottom towards the top of the graphic, and we consider the perspective of the dark red car, car A, which is in the left lane and travelling at the highest speed. At time $\mathbf{t_0}$, the light blue car, car B, is travelling in the right lane, ahead of car A and at a slightly lower speed. The slowest vehicle is an orange truck travelling in the right lane, ahead of both cars. In this scenario, a potential conflict may occur if car B were to change lanes to overtake the truck. This conflict is visualized at time $\mathbf{t_1}$; car B is signaling left and in the process of pulling into the left lane, thereby cutting off car A. Depending on the speed difference and the distance between the two cars, car A would have to brake to avoid a collision, as visualized at time $\mathbf{t}_2$

The driver of car A might anticipate car B changing lanes and may therefore take action to avoid potential conflict. A defensive anticipatory driver would be likely to release the gas pedal, whereas an aggressive anticipatory driver may accelerate to pass car B before it changes lanes. In both cases, an anticipatory action is taken – the driver of car A predicts what might happen in the future and reacts with an anticipatory avoidance response appropriate to the driver's goal. With slight variations of the scenario, however, the determination of whether or not anticipatory competence is present becomes significantly more complex. Potential challenges include:

- The *non-reactive, anticipatory driver* – There is a possibility for a driver to anticipate the potential conflict, but to consciously decide against taking action. While such a driver may still be considered under the "anticipatory" label (or a sub-category of such), the decision against taking action would make it difficult to distinguish this driver from a non-anticipatory one.
- The *timing of the anticipatory action* – At what point in time does an action cease to be anticipatory, and instead become a reaction? To be recognized as an anticipatory action, does action have to be taken before the car B signals a lane change or before it initiates one?
- The *reactivity in anticipation* – Even the anticipation of events can be described as a reaction to specific cues. An anticipatory driver could be considered to be reacting not to the event itself, but to subtle cues heralding the event. For example, an increase in the acceleration of car B with respect to the acceleration of the truck ahead might be considered an event to which the driver reacts.

2.2.2 Towards a Definition of Anticipatory Driving Competence

The examples in the previous section lay out the challenges in defining anticipation in driving. However, when working towards a theoretical basis for anticipatory driving competence there are also aspects that can be clearly identified. The four aspects below should not be viewed as the only correct approach for an investigation of anticipation in driving. They however do explain and justify the approach pursued in the context of this dissertation.

1. Anticipation in driving needs to describe a high level competence of cognitive reasoning that facilitates driver goals. Anticipation will increase the useful time and space in which the driver can act, but it will not determine specific actions. The driver will select a behaviour to

achieve his goal depending on his personal situation and characteristics. Consequently, a race car driver may use anticipatory competence to select maneuvers to overtake the driver ahead, while a freight trucker would likely position his truck to minimize braking or acceleration. In both cases, the competence to anticipate the traffic situation a few seconds ahead aids the drivers in achieving their particular goal – two very different behaviours, but both the result of anticipation. Following this rationale, the extent to which anticipation will help achieve short travelling times, improved safety, or fuel efficiency will vary not just because one driver may be able to act early due to anticipation while another only reacts to highly salient events, but also because drivers may have different motivations and goals. Therefore, anticipation in driving can be described as a competence of cognitive reasoning that, based on the conscious processing of specific cues in the environment, allows the projection of future traffic states. This reasoning process is then followed up with observable, goal-directed behaviour that may vary from driver to driver.

2. Anticipation requires stereotypical situations as a basis. It is not clairvoyance, but requires the recognition of cues that are indicative of distinct traffic configurations and predictive of upcoming conflicts. Anticipation therefore does not require the computation of an infinite number of potential scenarios, but the recognition of stereotypical traffic situations that have a high likelihood of resulting in similar events from one time to another (Rasmussen, 1986).
3. With respect to levels of driver behaviour – strategic, tactical, and operational (Lee & Strayer, 2004; Michon, 1985) – anticipation has to take place on a tactical level. Anticipation allows for the recognition of events a couple of seconds ahead. The further ahead the event to be anticipated, the more potential alternatives and the more cognitive processing is required. While the strategic level allows for general planning of driving, it does not allow for anticipation of specific events due to near endless possibilities. In contrast, sudden events do not leave enough time for the perception and cognitive processing of complex cues indicative of upcoming scenarios. Thus, on the operational level, a driver can only be described as reactive.
4. Anticipation in driving has to describe the competence of correctly interpreting cues for upcoming events, as opposed to a competence to recognize particular events. The difference between reactionary and anticipatory action (the third challenge identified earlier) has to be found in the semiotic status of the observed information. If it is a highly salient, well-defined symbol for a conflict, such as the signals or brake lights of another car, then a driver is

> merely reacting. Little cognitive effort is necessary here. If, however, the driver picks up on relatively subtle, potentially ambiguous cues, such as changes in headway distance between other traffic participants, and connects several of these cues together, then he is going beyond reaction to a well-defined symbol. Experience and significant cognitive processing are necessary to make sense of these combined cues – the driver is anticipating.

Building on these requirements, we propose the following definition of anticipation in driving: *Anticipation in driving is a manifestation of 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*.

2.2.3 Towards a Taxonomy for Foreseeable Situations

As suggested in our working definition, anticipatory driving involves the identification of stereotypical traffic situations. An understanding of such situations can help researchers investigate to what extent anticipation is utilized by drivers and to which effects, as well as develop ways to facilitate it. Facilitation could be in the form of interfaces helping drivers recognize such stererotypical situations and suggesting appropriate actions. To this end, a taxonomy can help us to systematically identify these stereotypical situations. Guided by the comprehensive task analysis of driving conducted by McKnight and Adams (1970), we can categorize these situations based on the type of cues that trigger the driver to recognize the situation. These cues are categorized into three types, depending on whether they reflect the natural environment, the road environment, or actions of other traffic participants:

<u>Natural Environment:</u> Drivers can anticipate upcoming changes in traffic based on changes in the natural environment. For example, lighting conditions can change suddenly due to weather or natural vegetation, often resulting in changes to a driver’s sight distance. Being conscious of such upcoming phenomena, for example, when approaching a foggy road section or a shady forest road, and adjusting speed accordingly would constitute anticipatory driving. Many other examples, such as changes in vehicle behaviour due to rain or snow on roads, or due to the consequences of changes in temperature and road surface friction would fall under this category.

Road Environment/Infrastructure: Drivers can also anticipate changes in traffic based on changes in infrastructure. For example, an anticipatory driver entering a city may alter behaviour by being aware of the added risks of reduced visual fields and increasing number of other traffic participants. Many other events can be anticipated based on changes in road infrastructure, such as railroad crossings, road surface, and tight curves in specific locales such as highway ramps. For this category, the desirable actions are often regulated through signage.

Other Traffic Participants: This category deals with the interaction between the driver and the other traffic participants. In the widest sense, animals and even autonomous vehicles can be included here. Due to the difficulty in predicting the actions of other humans, including drivers, pedestrians, and bicyclists, this category likely involves the most complex and interesting situations.

It is important to note that these categories are not mutually exclusive, and anticipatory scenarios can be characterized by cues from several categories. A strip of fog-covered road, for example, has very different implications depending on the amount and kind of other traffic participants present. If such a road is located on a crowded highway, the potential that a driver would need to adjust his driving (or react to a change in the traffic ahead, in case he fails to anticipate) is much higher than if it is located on a straight, empty road section. Furthermore, the categories here are not meant to represent an exhaustive taxonomy – they are merely the highest-level categories for a preliminary taxonomy. Further research is needed to expand this taxonomy and identify useful subcategories.

For the purpose of this dissertation, only scenarios in which the actions of other traffic participants could be anticipated were investigated. Further, in terms of the kinds of traffic participants, this research is focusing exclusively on other vehicles on the road. Other interactions of high relevance, for example those between vehicles and pedestrians or vehicles and bicyclists, were not taken into account. The reason for this choice was twofold: Vehicle-to-vehicle interactions, and particularly scenarios prone to rear-end collisions were particularly interesting due the high proportion of these types of crashes in accident statistics (Wang, Knipling, & Blincoe, 1999). Further, since all experiments were conducted in a driving simulator, limitations with respect to a realistic representation of the natural and road environment, as well as a lack of flexibility when designing interactions between vehicles and pedestrians/bicyclists spoke in favor of focusing only on interactions between multiple vehicles. With respect to vehicle interactions, the scenario development tool used in this research allowed for a high degree of individualization, such that we were able to develop realistic scenarios focusing on the interaction of several vehicles on the road.

2.2.4 Describing Anticipatory Competence as a Goal-Driven Task in Stereotypical Situations

The importance of stereotypical situations for the concept of anticipation in driving as proposed in this dissertation has been discussed. Anticipation is being understood as a driver competence focusing on the timely and efficient identification of a given traffic situation, and the evaluation of this situation based on experience. A cognitive computation of potential developments in traffic without any reference to knowledge about similar situations is argued to be inefficient given the nature of the driving task in a real-time, constantly changing environment, mainly because it would take too much time. It is for this reason that Control Task Analysis (ConTA) was chosen to model these stereotypical situations, a tool that Vicente has argued to identify requirements in similar situations. It is somewhat ironic that he chooses to refer to anticipation when characterizing the purpose of ConTA: “Although an analysis of control tasks does not identify the support required to deal with unanticipated events, it does allow us to identify the requirements associated with known, recurring classes of situations.” (Vicente, 1999, p. 181). Hence, the decision ladder, a tool going back to Rasmussen’s work (Rasmussen, Pejtersen, & Goodstein, 1994) that Vicente exploits for the purpose of ConTA, appeared to be a suitable choice to model the stereotypical traffic situations investigated in this research, as well as the goal-driven driver behaviour of skilled drivers within these situations.

Figure 2 depicts the Decision Ladder for the scenario presented in Figure 1. It describes how an anticipatory driver would likely navigate the task. Whereas a usual task analysis centers on the current system state, for the purpose of anticipatory driving we are concerned with a future system state – so with respect to the scenario explained in Figure 1, the system state of the Decision Ladder is the future state after the lane change of the blue car.

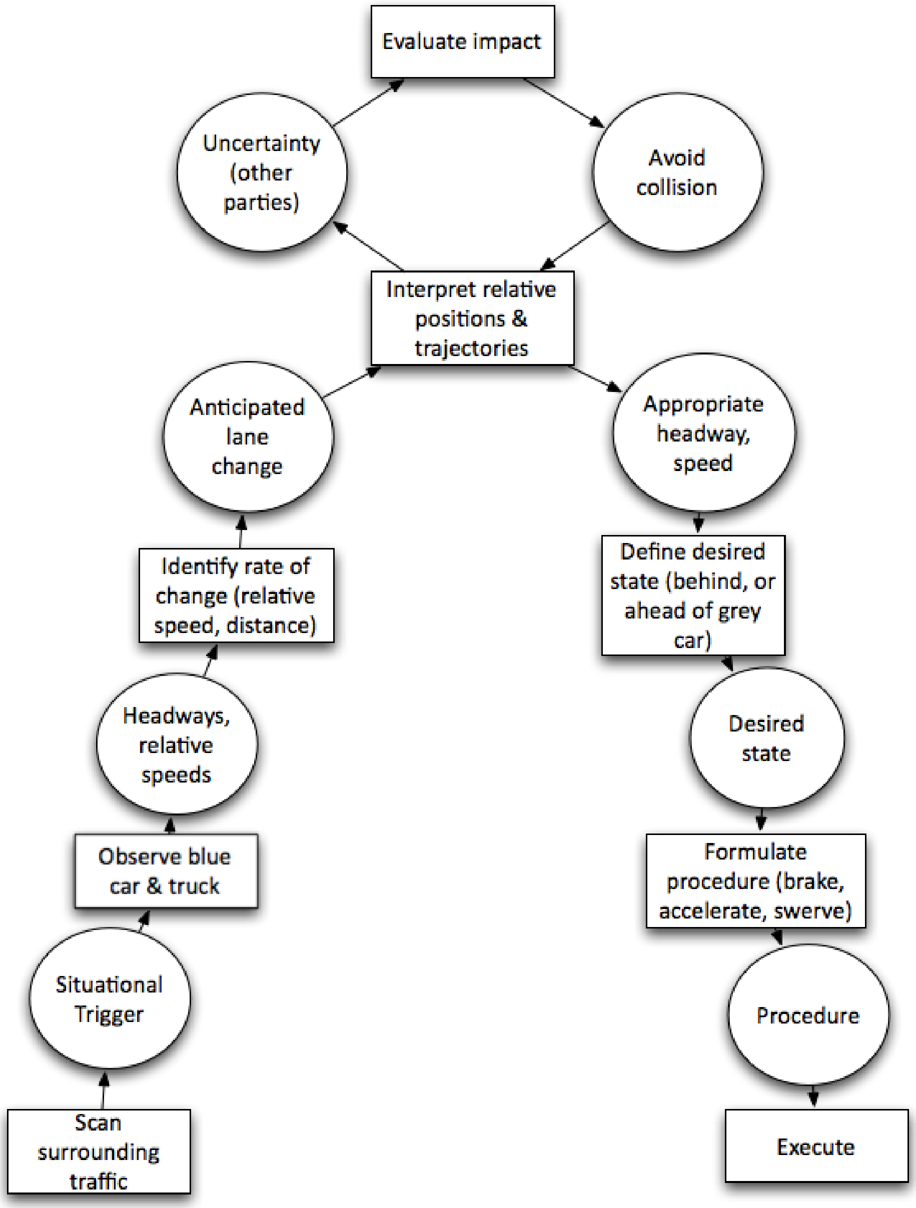

Figure 3: Decision Ladder for the scenario described in Figure 1

On the left side, we see the perception and analysis of the situation: from being alerted to the situation by specific triggers and then observing the appropriate traffic participants, to anticipating the probable future traffic state. The right side then describes the decision making process and execution of an appropriate action. It is interesting to note that the distinction between competence and behaviour is again helpful. The cognitive competence of anticipating the correct future system state is situated entirely on the left side of the Decision Ladder, whereas the behaviour, as characterized by the establishment of an appropriate goal and subsequent implementation of appropriate action, is found on the right side.

2.2.5 Shortcuts of Anticipatory Driving

Decision Ladders uncover potential “shunts” and “leaps” that can be used by drivers to jump from one part of the ladder to another (Vicente, 1999). The goal of an aid designed to facilitate anticipatory driving should be to enable such shortcuts, optimally from the earliest stage of scanning the traffic environment directly to the appropriate action. One way to achieve this goal is by identifying the shortcuts used by anticipatory drivers and the cues triggering use of these shortcuts.

Looking at the Decision Ladder from this perspective, we can interpret the path up the left side of the ladder as one requiring ever-rising cognitive resources and time. Due to inexperience, novice drivers would have to go all the way up the ladder sequentially, and logically deduce the upcoming traffic situation, having to expand considerable amounts of cognitive resources, which are also largely claimed by basic vehicle control and the continued monitoring of the current traffic situation. In contrast, experienced drivers would be more skilled at vehicle control and monitoring, and therefore be able to spare more cognitive resources for anticipation. Furthermore, they would have prior experience with similar situations. This familiarity of a comparable situation would allow the experienced drivers to anticipate the traffic situation much earlier and execute appropriate action earlier as well.

Using Worker Competency Analysis (Vicente, 1999), we could describe the way novice drivers arrive at an appropriate action through knowledge-based behaviour, and the way experienced drivers arrive at the same action through skill-based behaviour (Rasmussen, 1983). For the purpose of enabling anticipatory driving, knowledge-based behaviour is not likely the preferred mode of cognitive processing. We instead advocate for the use of skill-based behaviour. Interfaces that aid experienced drivers to trigger an intuitive, experience-based shortcut across the bottom of the Decision Ladder appear promising. Once we understand which time-space cues in the environment enable the skilled anticipatory driver to act in near-automated fashion to avoid upcoming conflict, we can then work on augmented representations of the environment that highlight these exact cues for other experienced drivers.

However, expecting a novice driver to use skill-based behaviour appears highly unrealistic. A potential solution may be rule-based behaviour, the final element in Rasmussen's taxonomy (Rasmussen, 1983). Here, the process of arriving at a specific action is neither the cognitive, logical reasoning of knowledge-based behaviour, and nor the intrinsic, near automatic triggering of those actions through skill. Instead, these drivers can be aided to ground their actions in pre-defined situational conditions. For example, if a specific traffic situation A is observed, then it will (most likely) lead to particular situation 2 in which action IV is desirable.

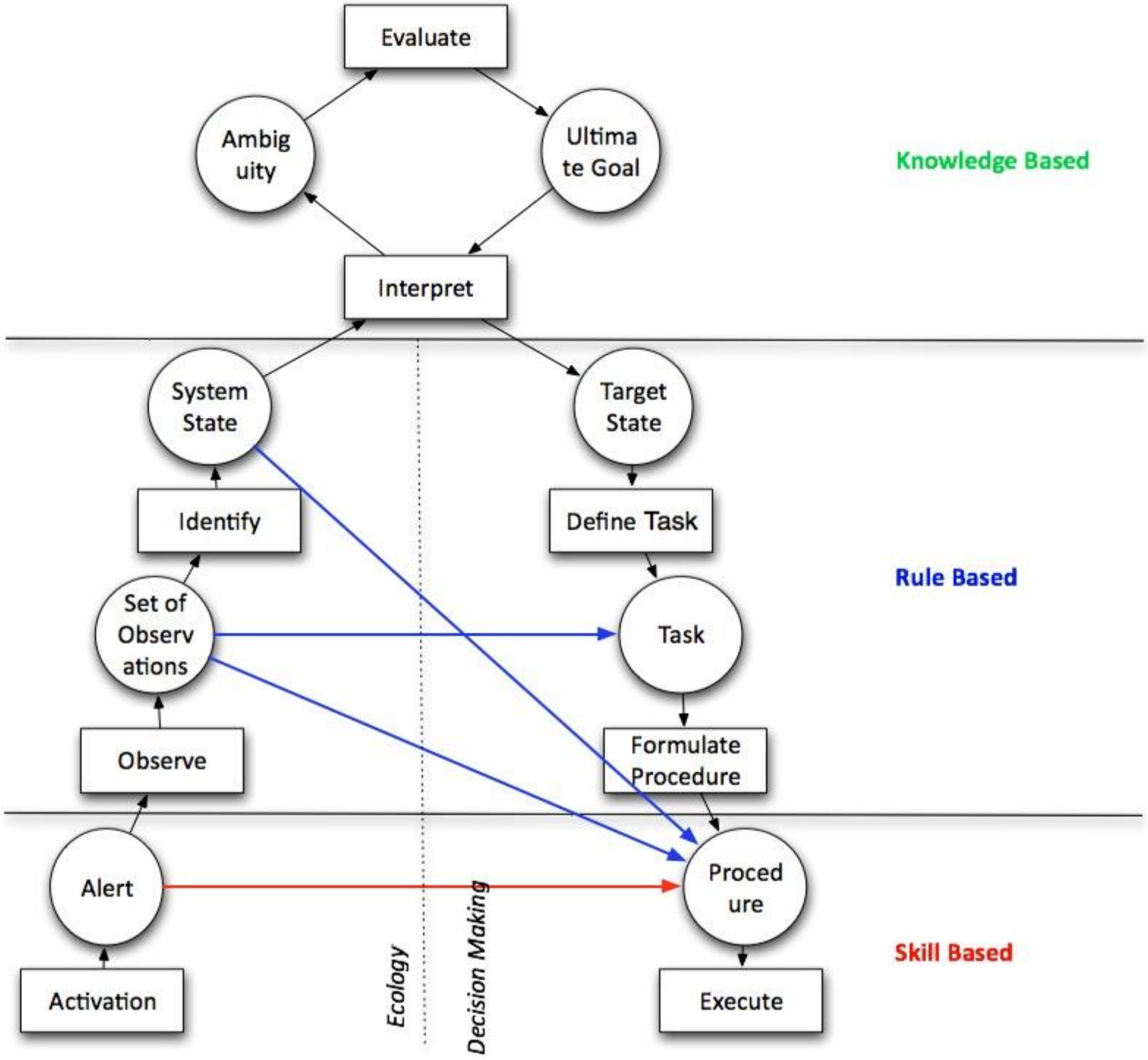

Figure 4: Decision ladder highlighting the potential for skill- and rule-based shortcuts

To sum up, we suggest that anticipatory driving could be facilitated by enabling shortcuts through the Decision Ladder. These shortcuts can be described in terms of skill- and rule-based behaviours. Consequently, an interface should support skill- and rule based leaps through the Decision Ladder (Vicente & Rasmussen, 1992). Figure 3 depicts a task-independent Decision Ladder with possible shortcuts highlighted, inspired by existing work on the theory of interface design (Bennett & Flach, 2011). As illustrated, shortcuts on the skill-based level should be expected to jump across the very bottom of the Decision Ladder, while shortcuts on the rule-based level are likely to happen in the middle. Finally, resource-intensive knowledge-based reasoning would be situated towards the top of the ladder.

2.3 Chapter Summary

The purpose of this chapter was to (1) review the existing literature with respect to research on anticipation in driving, and to (2) build a theoretical foundation for the systematic study of the phenomenon of anticipation in driving. Existing literature supports potential benefits of anticipatory driving for safety, hazard perception, and eco-driving. For safety, anticipatory aids have been shown to facilitate earlier deceleration prior to conflicts and better reaction times in combination with improved, more linear deceleration profiles. Response priming for specific driving tasks has been studied as well, and proven to have positive impacts both in simulator studies as well as in on-road research. Hazard perception has been connected to anticipation and described as “the ability to anticipate traffic situations” (Sagberg, Stein, & Inger-Anne, 1997, p. 407). This ability has been argued to support safety by maximizing available decision-making time. In eco-driving, the anticipation of upcoming braking events suggests a potential for fuel savings of approximately 10%, both in driving simulators and on the road.

Building on these findings from existing literature, requirements for anticipation in driving have been defined and used to determine a definition of the term. This definition stressed the cognitive nature of anticipation as a competence that relies on the sensory perception of visual cues in the traffic environment and then interprets the meaning of those cues relative to stereotypical situations. We have also discussed how the stereotypical situations for anticipation can be subdivided into different categories, depending on whether the goal is to anticipate developments in the natural environment, in the road environment, or the actions of other traffic participants.

As has been discussed, the research in this dissertation focuses on the latter and does not investigate anticipation with respect to the natural- or road environment.

Finally, we have discussed how task analysis can aid in the analysis of stereotypical situations: Decision ladders allow for the modeling of anticipation as a task from the perspective of the driver. The left side of the ladders will usually represent the situational assessment based on the cues perceived, while the right side represents the determination of appropriate action based on that assessment, and in accordance with the driver's individual goals. Shunts and leaps leading from the left side to the right then represent the ability of a skilled driver to use skill-based behaviour to quickly act on specific cues, as opposed to a more knowledge-based, sequential progression through all individual steps of the ladder.

Chapter 3

Experimental Apparatus and Scenario Development

3.1 Apparatus

3.1.1 Driving Simulator

The research for both experiments conducted for this Ph.D. was a PC-based, quarter-cab MiniSim research driving simulator developed by the University of Iowa's National Advanced Driving Simulator (NADS). The setup used in the experiments is depicted in Figure 4, and uses three 42" plasma TVs to create one combined display spanning a 130° horizontal and 24° vertical field of view at a 48" viewing distance. An additional 19" screen integrated into the dash displays speedometer and revolution meter, changing to a representation of the dash of the particular car chosen for the simulation. Of the cars available for driving in the simulation, the BMW 3 series was chosen – the simulation of driving dynamics changed depending on the particular car, and a choice was made based on which one appeared most realistic in driving behaviour. The simulator uses an authentic Chevrolet steering wheel, column gear selector, pedals, and vehicle seat. Stereo sound of the vehicle and its surroundings is produced through two speakers in the front; a third speaker mounted below the driver seat simulates roadway vibrations. The simulator collects a large number of driver performance measures, as well as measures reflecting the participant's interaction with other dynamic option (such as time-to-collision, for example). All data are logged at a frequency of 60 Hz. The simulator is also equipped with a four-channel video capture system. Our experiments used three of these channels' cameras to capture participants' pedal positions, a frontal view of them driving, and a rear view capturing the participant and the simulator screen. The fourth channel is used to record a variety of simulator outputs (such as frame number and simulation time) for analysis purposes.

3.1.2 Eye-Tracking System

For the second experiment, a FaceLAB 5 eye-tracking system from Seeing Machines was used. The system uses two cameras to capture the participant's face from two angles. The cameras were mounted on the dash of the driving simulator (see Figure 4), and generate data on eye movements, head position, head orientation, eyelid aperture, and pupil size at a frequency of 60 Hz. The system is able to track gazes at ±45° on the horizontal axis and at ±22° on the vertical axis, and typical accuracy of gaze direction measurement is between 0.5° and 1°. To increase the reliability of the system, we used an infrared emitter also mounted on the dashboard and facing the participant, and set the cameras to record in the infrared spectrum. All data generated from the eye tracking system were automatically linked with the driving simulator through the FaceLAB software package. EyeWorks, another software tool, was incorporated into the system and served to overlay a visual, synchronized indicator for participants' gaze location over the simulated environment (of just the center screen) in the driving simulator. The resulting video that showed gaze location as the participant is driving was recorded at 30 Hz.

Figure 5: NADS MiniSim driving simulator with FaceLab eye-tracking system and Microsoft Surface

3.1.3 Interface Display

The anticipatory interfaces in the second experiment were presented through a Microsoft Surface Pro 2. The Surface was mounted to the right of the dashboard and did not obstruct the view to the other simulator screens (Figure 4). The visible screen size of the display was 10.6”, and it displayed interfaces that were edited in GIMP on a 1366x768px canvas to ensure a good quality representation on the Surface. A custom program developed in JavaScript synchronized the Surface with the driving simulator, and ensured that the interfaces were displayed at the exact same location in the simulated scenario across different trials.

3.2 Stereotypical Traffic Scenarios

The development of adequate driving scenarios was a major challenge for the work in this dissertation. Because anticipation as a competence has been argued to rely on the identification of stereotypical scenarios, this research relied heavily on participants perceiving the simulations as realistic, and behaving in them as naturally as possible. In particular, a significant challenge was the determination of adequate visual cues within the scenarios. Giving away too many highly salient cues ran the danger of making it too easy for participants to understand the situation, whereas a very subtle scenario could result in nearly no one being able to anticipate.

Scenarios were therefore designed with situational realism as the highest priority, and numerous discussions with experienced drivers were taken as a reference point. Frequent trial studies throughout the development of the scenarios also generated a multitude of feedback, such that the resulting five scenarios used in the experiment were perceived as very realistic from the viewpoint of their situational dynamics, and behaviour of the vehicles involved.

As already mentioned, scenarios involved interactions between various traffic participants. No inner-city driving was simulated, and environmental conditions were held constant, without any adverse weather, and without night-time driving.

The five scenarios are described below. Note that Figures 5-9 represent the order in which the vehicles were setup, but not necessarily road properties (the first scenario, for example, was always situated on a curve so the tractor could be seen). Decision ladders for all scenarios are attached in Appendix A.

1. Chain-braking due to a slow tractor: The participant (P) was asked to follow a chain of five vehicles travelling at 40 mph (speed was displayed in imperial units throughout our experiments due to simulator specifications) into a curve on a two-lane rural road. Due to a tractor (T) travelling at 20 mph, initially 300 m ahead of the first car (at an approximate visual angle, VA, of 0.72° calculated based on the distance of participant to the screen and the object size on the screen), the vehicles started to brake consecutively (1st car when within 70 m of the tractor and at a deceleration of 1 m/s^2, 2nd car when within 21 m of the 1st car at 2 m/s^2, 3rd car when within 24 m of the 2nd car at 2.5 m/s^2, 4th car when within 21 m of the 3rd car at 2.5 m/s^2, and the last car when within 37 m of the 4th car at 2.5 m/s^2), requiring the participant to reduce speed as well. Anticipatory cues were the appearance of the slow tractor in the visual scene (visibility of the tractor was ensured through the curvature mentioned above), and then the braking of each consecutive vehicle in the chain. All vehicles had to slow down from 40 mph to 20 mph, so that aside from their brake lights, the visible deceleration and diminishing headway distances between them were further cues. The defined event in this scenario was the braking of the vehicle directly ahead of the participant. If the participant had not acted on any of the cues until this point, she had to act at now to avoid collision.

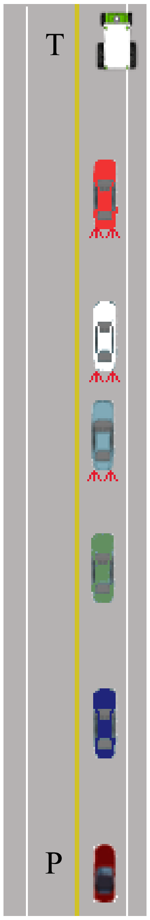

Figure 6: Visual schematic of Scenario 1 with tractor (T) and participant (P)

2. Vehicle behind cutting in-front: After scenario 1, the participant (P) kept on following the chain of five vehicles. Upon reaching a long straight on the two-lane rural road, the vehicles accelerated consecutively from 30 to 50 mph at a rate of 0.25 m/s^2. A vehicle (V) directly behind the participant signaled for 3 s, pulled into the opposing lane, and accelerated to 125% of the participant's speed to overtake the participant's vehicle. Due to an oncoming vehicle (O) in the opposing lane, the overtaking vehicle cut in front of the participant vehicle abruptly, after having used its right signal for 2 s and while decelerating to

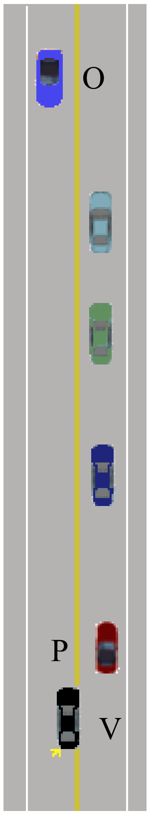

Figure 7: Visual schematic of Scenario 2 with opposing vehicle (O), overtaking vehicle (V) and participant (P)

40 mph at a rate of 5 m/s^2. In this scenario, the event was marked by the overtaking vehicle putting its right signal on. Anticipatory cues were the vehicle signaling left and pulling out of the lane, which were observable to the participant in the rear and side view mirrors. A second cue hinting at a potentially abrupt overtake was the vehicle approaching from the opposing lane. While the mere switch into the opposing lane does not necessarily indicate the intention to merge back in front of the participant's vehicle (the overtaking driver could potentially overtake several vehicles), the oncoming traffic necessitated a merge back and the onset of the right signal conveyed the intention to do so. The event for this scenario was the overtaking vehicle's right signal, indicating the intention to merge back into the right lane.

3. Stranded truck on highway shoulder: Before this scenario, the participant (P) merged onto a four-lane divided highway following a stream of vehicles (which maintained 55 mph) in the rightmost lane. A stranded truck (T) on the highway shoulder, as well as two police cars (O) parked on the shoulder behind the truck (without flashing lights, due to simulator limitations) were visible from a distance of 500 m (VA ~ 0.48° calculated based on the distance of participant to the screen and the object size on the screen). Upon approaching the vehicles on the shoulder, the vehicles in front of the participant started merging left (all of them using their signals for 2 s before starting lateral movement) to safely pass the vehicles on the shoulder, thereby resulting in a chain of braking events on both the left and right lanes. Deceleration rates were not specified by the investigator, but were left to the simulator's artificial intelligence with the goal of maintaining a time to collision of 6 s between all vehicles. The cues were the stranded truck and police cars, the consecutive merging of vehicles into the left lane, as well as the brake lights and decreasing speeds of vehicles ahead. Similar to scenario 1, we defined the event based on the behaviour of the vehicle immediately in front of the participant vehicle. Due to the complexity of this scenario, two events were identified: 1) the braking of

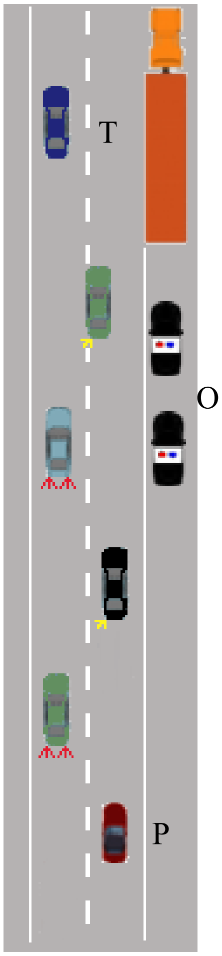

Figure 8: Visual schematic of Scenario 3 with stranded truck (T), police cars (O) and participant (P)

the lead vehicle in response to the slowing speeds of the vehicles ahead, and 2) the left signal onset of the lead vehicle indicating a merge to the left lane. This allowed for the extraction of two potentially anticipatory actions. For example, a driver changing lanes before either of these events would exhibit an anticipatory action, whereas pedal release had to take place before event 1 to indicate an anticipatory action.

4. *Merging onto a highway:* The participant (P) followed a lead vehicle (L) (going at 50 mph) onto a highway ramp. The lead vehicle failed to signal when going onto the ramp, decelerated to a relatively low speed (to 30 mph at 1.5 m/s^2) at the beginning of the ramp, and then varied speed, switching between acceleration (to 40 mph at $1 m/s^2$) and deceleration without braking (to 35 mph at $1 m/s^2$). Upon approaching the acceleration lane on the highway, the lead vehicle finally accelerated to 45 mph at 1 m/s^2, only to abort the merge in the middle of the acceleration lane and brake to 20 mph at a rate of 5 m/s^2 to let a chain of semi-trailer trucks (T) on the highway pass before merging. The event was defined as the braking of the lead vehicle in the acceleration lane. Pre-event cues were the lack of signaling and erratic behaviour of the lead vehicle, as well as the visibly busy highway.

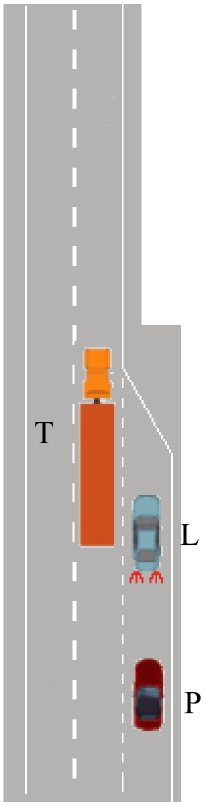

Figure 9: Visual schematic of Scenario 4 with truck (T), lead vehicle (L) and participant (P)

5. *Slow moving traffic on the highway:* This scenario appeared in the introduction and is visualized in Fig. 1. The participant (P) was driving on a four-lane divided highway with no lead vehicle ahead (and thus was instructed to maintain 60 mph). The participant then approached two vehicles in the right lane – one vehicle (V) directly ahead and traveling at 80% of the participant's speed (first visible at VA ~ 0.24°), and a semi-trailer truck (T) ahead of this vehicle traveling at 66% of the participant's speed (first visible at VA ~ 0.48°). Once the distance to the vehicle ahead fell below 122 m, the speed of the truck was set to 40 mph, and the speed of the vehicle ahead was set to 47 mph. Thus, the lead vehicle was approaching the truck as the participant approached both vehicles. The lead vehicle signaled for 2 s and then pulled out into the left lane (accelerating to 50 mph at a rate of 2 m/s^2) to overtake the truck as soon as the participant vehicle was within 76 m of the leadvehicle. We defined the event as the signaling of the lead vehicle, which was followed by the lead vehicle overtaking the

truck. The anticipatory cue was the diminishing headway between the car and the truck. The diminishing headway between the vehicle and the truck had to necessarily result in the lead vehicle either decelerating or changing lanes. The left-turn signal indicated the intention to change lanes.

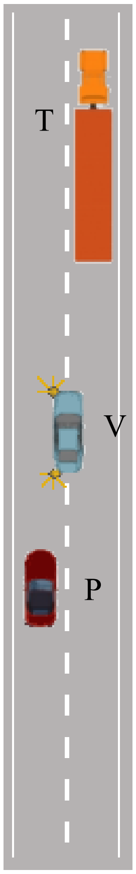

Figure 10: Visual schematic of Scenario 5 with slow truck (T), vehicle (V) and participant (P)

Chapter 4

Experiment I: Identifying Anticipation and the Role of Driver Experience

4.1 Introduction

Section 2.2.2 laid a theoretical foundation for anticipation, defining it as a driver competence that allows for the recognition of stereotypical situations based on the perception of relevant visual cues. Based on the knowledge of these stereotypical situations, the development of a situation in traffic can then be anticipated, and adequate goals formulated.

The next logical step in the course of this Ph.D. research was to develop a means of identifying anticipatory actions. Since anticipation as per definition is the manifestation of a cognitive competence, we cannot directly measure it. We either have to rely on drivers to report their driving behaviour and identify the use of anticipation themselves, or we need to identify the outcome of cognitive anticipation – an observable action in the form of a control input to the vehicle.

The research in this dissertation mainly pursues the approach of identifying observable actions that directly result from anticipation. The challenges to this approach have been discussed in section 2.2.1: First, we need to unambiguously decide whether an action taken is reactive, or anticipatory in nature. This is directly connected to the question of how we operationalize anticipation – how does a reaction to a conflict differ from a reaction to a cue for that conflict? Also, how do we deal with the possibility of drivers correctly anticipating an upcoming conflict situation, but choosing consciously to not act on that knowledge? In this case, there would not be any action to observe. And finally, what about coincidental actions in the correct moment that are not based in anticipation?

The following chapter reports on the first experiment, which was designed to investigate the feasibility of identifying anticipatory competence through the actions that result from it. It therefore describes the method used to identify anticipation, and reports on the distribution of anticipatory vs. non-anticipatory drivers within our sample of participants.

Section 2.1 in particular discussed the superior performance of experienced drivers in contexts where the interpretation of the current traffic situation plays a role, such as hazard perception. These advantages of driver experience suggest also a heightened skill at identifying relevant cues and using them to effectively assess traffic, as well as predict its development into the future. Consequently, one of our hypotheses was that experienced drivers would outperform novices also with respect to anticipatory competence. To investigate this hypothesis, we consciously investigated the driving behaviour of participants with different amounts of driving experience, ranging from novice drivers to very experienced drivers.

To summarize, the experiment described in this chapter pursued two research goals:

1. To identify anticipatory competence in a simulator setting through the surrogate measure of pre-event actions in conflict situations, and
2. To investigate the hypothesis that driver experience increases the number of pre-event actions.

4.2 Methods

4.2.1 Experimental Design

Driver experience, a between subjects variable, was the only independent variable in this experiment. Three levels of driver experience were defined (see Table 1) based on years of licensure (years a valid driver's license had been held) and mileage (distance driven within the previous 12-months), similar to Holland, Geraghty, and Shah (2010), who measured experience based on number of months since licensure and number of hours driven per week. Drivers who fell into the category of high mileage and short licensure were excluded from the experiment due to the infrequent occurrence of such people in the general population. Further, the thresholds used to separate the groups were intentionally set far apart (e.g., ≤ 2 years vs. ≥ 10 years of licensure) to recruit drivers with distinct differences in experience level. Our hypothesis was that drivers who had been licensed for longer periods of time (medium and high levels) would exhibit anticipatory actions at a higher rate than novice drivers. Further, among the drivers who had been licenced for a longer period (≥ 10 years), we hypothesized that those with higher annual mileage would exhibit more anticipatory actions than low mileage drivers. Thus, we recruited participants such that a large difference in annual mileage was evident between the medium and high experience groups (i.e., < 10,000 vs. > 50,000 km/year). Each participant experienced the five driving scenarios introduced in Chapter 3, which were designed to allow for anticipation of an upcoming event. The scenarios were presented in the same order for all participants, as we did not intend to compare the scenarios but rather the experience groups to each other.

Scenarios were designed such that if participants followed the speed limits, there would be 35 sec in scenario 1, 20 sec in scenario 2, 25 sec in scenario 3, 40 seconds in scenario 4, and finally 50 seconds in scenario 5 from the visibility of the first cue to the event respectively. The investigator reminded participants of the speed limit if they deviated from the speed limit by more than 10 mph. Hence, a participant consistently deviating from the speed limit by just under 10 mph could have deviated by approximately 10 sec in the longest scenario.

Table 1: Three levels of driver experience investigated in Experiment 1

Experience level	Years of licensure	Distance driven within past 12-months (km/year)	n	Mean age (SD)
Low	≤ 2	< 10,000	10	19.3 (1.34)
Medium	≥ 10	< 10,000	10	32.6 (9.46)
High	≥ 10	> 50,000	10	29.8 (4.29)

4.2.2 Participants

Thirty participants completed the experiment. All participants held at least a valid G2-level driver license in the province of Ontario, had driven a passenger vehicle with an automatic transmission, and reported using only their right foot to operate the accelerator and brake pedals. Of these 30 participants, ten were novice drivers with two years of licensure or less who reported driving less than 10,000 km/year; ten were mid-experience drivers with ten or more years of licensure who reported driving less than 10,000 km/year; and ten were highly experienced drivers with ten or more years of licensure who reported driving more than 50,000 km/year. The mean ages and standard deviations (SD) for these three groups are provided in Table 1. An analysis of variance followed by posthoc t-tests showed that novice drivers were significantly younger than the medium ($t(27)= -4.92$, $p<.0001$) and high experience groups ($t(27)= -3.88$, $p=.0006$). There was no age difference between the medium and high experience groups ($p>.05$). Overall, nine participants were female (mean age 25 years) and 21 participants were male (mean age 28 years). An independent t-test revealed that age was not statistically different between the two genders (p>.05). The female participants were fairly evenly distributed across the three experience categories (4 in low, 3 in medium, and 2 in high).

Participants were recruited from the student body of the University of Toronto, as well as through calls for participation on advertisement websites, social media, and networking services. They filled out an online screening questionnaire (Appendix B) 1)) to determine their experience category. Further, they were screened for their profession and were limited to non-commercial drivers of passenger vehicles; groups with special driver training, such as cab drivers and law enforcement were excluded, as were commercial drivers of trucks and buses. The participants were also screened for simulator sickness (Kennedy, Lane, Berbaum, & Lilienthal, 1993). Participants were compensated C$20 for their participation in the study. The study took approximately 1.5 hours.

4.2.3 Procedure

Participants were first verbally briefed on the experiment by the investigator. The general intent to study driving behaviour was stated and the low risk of simulator sickness was mentioned. Participants were then instructed to read the more detailed informed consent form (Appendix C) 1)) and were given the opportunity to ask any questions not answered therein. Participants were not informed about the experimental focus on anticipation until after they completed the driving scenarios. Instead, the objective to study natural driving behaviour was highlighted, and participants were instructed to drive as naturally as possible. Specifically, they were told to not treat the simulator like a game, and to not drive in a safer or more law-abiding way than they would on the road. The investigator allowed the participants to adjust the steering wheel, backrest, and seat positions to their liking, and explained the controls of the simulator. Participants read another document (Appendix C) 2)) with detailed instructions for the scenarios, and the investigator then engaged them in a short conversation to ensure understanding of the two default behaviours: to maintain 60 mph on the highways when possible, and to not overtake when a lead vehicle was present.

Participants then had the opportunity to familiarize themselves with the simulator and train for the above default behaviours in two practice runs. The first run gave them an opportunity to drive on a rural road below 40 mph and follow a lead vehicle, while the second run involved a highway merge as well as practice at maintaining a highway speed of approximately 60 mph.

Participants were informed that 60 mph equates to approximately 100 km/h, and care was taken to ensure that they were aware of all speed indications being in mph. The practice sessions took approximately 10 min in total and ended when the participant and the experimenter were both content with the performance achieved. An optional five minute pause was then followed by the two experimental drives of approximately 10 min each. The final part of the experiment was a review session in which the investigator replayed the two experimental runs to the participant in a top-down view from the recorded data stream, and guided the participant through a questionnaire. The intention was to get subjective feedback regarding the extent to which cues for the events were recognized and correctly interpreted. The top-down view was chosen over a first person playback to enable the participant to not just recollect based on a limited viewing angle, but also interpret their recollected perception relative to the development of the scenarios as a whole. We further collected data on perceived mental effort using a 0-150 scale as suggested by Zijlstra (1993), and assessed risk using the 1-10 riskiness scale used by Tsimhoni (2003). Appendix B) 2) contains the entire questionnaire used after the experiment. These measures were collected for additional, exploratory analysis; there were no specific hypotheses connecting perceived mental effort or situational risk to anticipatory competence.

4.3 Results

4.3.1 Pre-event and Post-event Actions

The data analyzed consisted of 30 responses each for the first four scenarios and 26 responses for the fifth scenario. Data for the last scenario were lost in two cases due to technical difficulties with the simulator, and in two cases due to participants dropping significantly below the prescribed speed, resulting in a failed scenario. All data were reduced and coded by the author, who was not blind to the experimental conditions. Care was taken, however, to code all simulator data before the experimental conditions (i.e., driver experience) were added.

For each scenario, participants were grouped into two categories: one in which the participant clearly acted prior to the event, and one in which no clear pre-event action could be identified. We assume that if a participant acted between pre-event cues and the event itself, then she was anticipating the upcoming event and displayed anticipatory driving competence.[1]

Since all scenarios resulted in decreased headway distances between the participant and the driver ahead, deceleration (either by release of the accelerator or depression of the brake pedal) was considered as a potential action that could be taken by the participant. Furthermore, for scenario 3 (stranded truck on highway shoulder), a lane change into the left lane was also considered to be a potential action. In fact, it was the appropriate action to take. In scenario 5 (slow moving traffic on the highway), acceleration and overtaking of the lead vehicle before it changed lanes to the left was considered to be an appropriate alternative action to deceleration.

Table 2 presents the number of participants grouped into pre-event and post-event action categories for each scenario. A further discussion of these specific actions is provided later in this section. With the exception of scenario 3, which provided two distinct events, the percentage of pre-event actions appear to be comparable across scenarios.

Table 2: Distribution of pre- and post-event actions across scenarios in Experiment 1

Scenario	# of participants acting pre-event	# of participants acting post-event	Total
1: Chain braking due to slow tractor	5	25	30
2: Vehicle behind cutting in-front	5	25	30
3: Stranded truck on highway shoulder	13	17	30
4: Merging onto a highway	6	24	30
5: Slow moving traffic on the highway	7	19	26

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[1] Participant actions were coded consistently across scenarios; e.g., the threshold brake pedal force used to define a braking action was the same for all scenarios. We were, however, sensitive to the possibility of actions being taken not as a response to pre-event cues, but for other reasons (such as regulation of headway), and therefore looked at the speed-, braking-, acceleration-, and headway profiles of participants prior to judging them as having taken pre-event actions. Multiple sources of data were used in addition to automated coding, and particularly the data of pre-event responders were cross-checked with the videos of their drives to ensure they were indeed acting on the pre-event cues. There were very few cases in which the coding algorithm incorrectly identified a participant as having a pre-event action (i.e., coincidental release of the accelerator pedal) and in which an anticipatory action was missed (i.e., the accelerator pedal would be gradually eased off, but not pass the threshold value until the event happened), but those cases were manually corrected.

To investigate the hypothesis that experienced drivers would have higher anticipatory competencies, we compared the number of pre-event actions taken by each driver across the three experience levels (low, medium, high) (Figure 10). A driver could exhibit between zero and five pre-event actions (one per scenario). No participant exhibited pre-event actions for all events. A cumulative logit model was built on these data to assess the relation of experience and number of pre-event actions. Because the number of participants with three or more pre-event actions was relatively low, we used only three categories – no, one, and two or more pre-event actions. The model was fitted using PROC GENMOD in SAS 9.1, with the specifications of cumulative logit link function and multinomial distribution. Overall, experience had a significant effect ($\chi^2(2)=11.90$, $p=.003$). Participants with high experience acted prior to an event more often than participants with low experience ($\chi^2(1)=11.79$, $p=.0006$), as did participants with medium experience ($\chi^2(1)=5.47$, $p=.02$). There was only a marginal effect between high and medium experience groups, with a trend of high experience participants displaying more pre-event actions ($\chi^2(1)=2.89$, $p=.09$). The effects of gender proved to be non-significant.

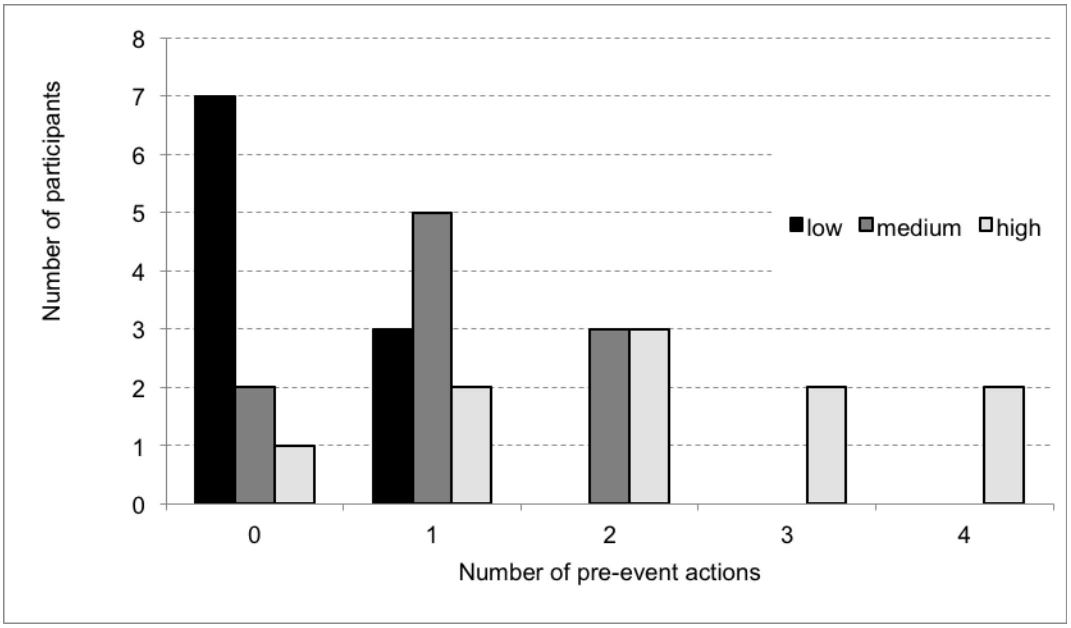

Figure 11: Number of participants who displayed different numbers of pre-event actions (maximum possible was 5) in Experiment 1 broken down by driver experience

The following sections report the differences in overall outcome measures between the two groups of drivers (pre-event and post-event responders) for each scenario. The first measure of interest was the minimum time to collision (min TTC, as calculated based on gap distance and relative speed) recorded throughout a scenario. The second was the difference between two headway time values: maximum headway time recorded from the first cue presentation to the event minus the headway time when the event occurred. A positive difference indicated a participant closing in on the lead vehicle. The higher the difference, the more loss of headway time had taken place. We expected safety-conscious pre-event responders to have small positive differences, or even negative differences due to having increased headway time in response to a correctly interpreted cue, and likewise demonstrate higher min TTC values. On the other hand, we have discussed before that anticipation will likely aid in the realization of drivers' individual goals, and therefore not have a generalizable safety impact. For example, drivers could use anticipation to drive in a fuel-efficient manner, braking as little as possible and accepting dangerously low headways. We were therefore uncertain with respect to the overall impact of pre-event actions on the two safety measures analyzed here.

Scenario 1– Chain-braking due to slow tractor:

Five participants released the accelerator pedal before the event, i.e., the lead vehicle braking onset. Three of these five participants also braked before the event. The remaining 25 participants released the accelerator and started to brake only after the event. For the pre-event responders, the mean headway time difference was -1.88 s (SD=1.95) and the mean min TTC was 10.1 s (SD=2.90) (Figure 11). For the post-event responders, the mean headway time difference was -1.34 s (SD=3.69 s) and the mean min TTC was 7.4 s (SD=2.90). Overall, there was no significant difference between the two groups for headway time difference (p>.05). Min TTC was marginally significant (t(28)= -1.89, p=.07). Although we expected to see positive headway differences in general, the majority of responses were negative. This unexpected finding might be due to participants responding to an upcoming curve in the driving environment.

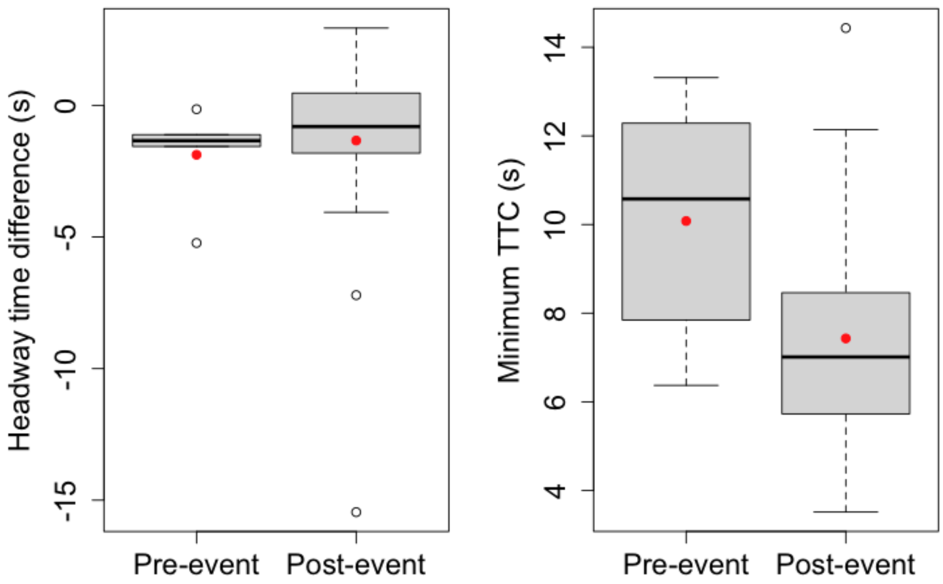

Figure 12: Headway time difference and min TTC for Scenario 1 in Experiment 1 (in this and all following boxplots we present minimum, first quartile, median, third quartile, and maximum, as well as potential outliers indicated with hollow circles and means indicated with solid circles)

Scenario 2 – Vehicle behind cutting in-front:

Five participants released the accelerator before the overtaking vehicle signaled its merge back into their lane. Of those releasing the accelerator pre-event, one participant also braked pre-event, three braked post-event, and one did not brake at all.

The remaining 25 participants did not show clear pre-event actions. One of these participants remained entirely passive throughout the scenario, and did not release the accelerator or brake even when the overtaking vehicle merged back into his lane, leading to a minimum TTC value of 2.9 s. Four participants released the accelerator after the vehicle signaled but did not brake, and 21 released the accelerator and also started to brake.

Since the lead car changed mid-scenario due to the overtaking manoeuver, headway time difference could not be calculated as presented earlier. For this scenario only, we focused on headway time to the lead vehicle at the time of the event, expecting that anticipatory drivers would have noticed the overtaking vehicle and increased their headway in response. It should be pointed out that while in all other scenarios small headway time differences are desirable, here a large headway time is desirable. For the pre-event responders, the mean headway time at the event was 2.16 s (SD=1.11) and the mean min TTC was 9.02 s (SD=2.73) (Figure 12). For the post-event responders, the mean headway time was 1.35 s (SD=0.73) and the mean min TTC was 11.8 s (SD=9.27). Four min TTC values were excluded from analysis, two from pre-event and two from post-event groups, due to the values being extremely large compared to the rest of the observations (>100 s). The difference in headway time was significant (t(28) = -2.06, p=.046) whereas the difference in min TTC was not significant (p >.05).

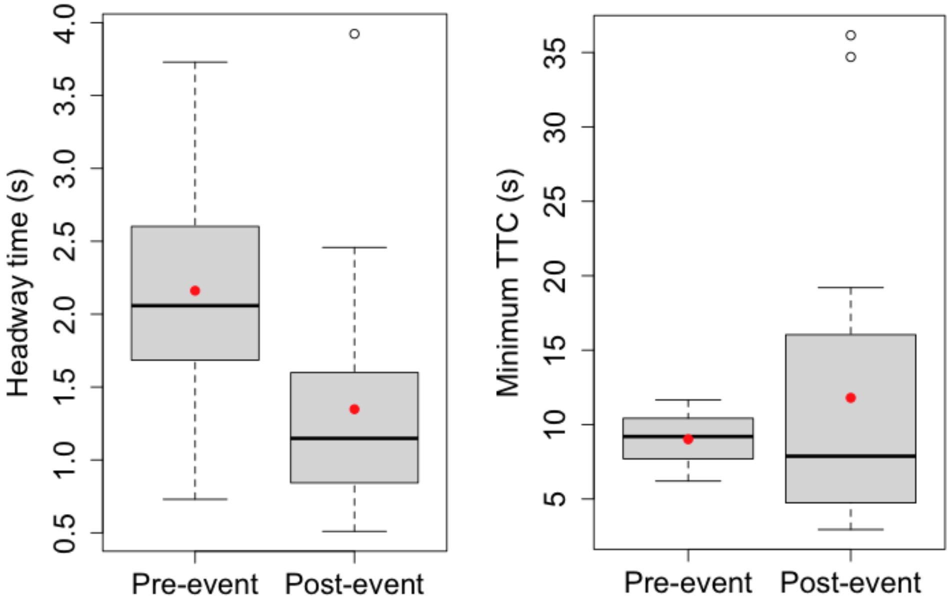

Figure 13: Headway time and min TTC for Scenario 2 in Experiment 1

Scenario 3 – Stranded truck on highway shoulder:

Thirteen participants displayed pre-event actions: six released the accelerator before the vehicle directly in front braked (due to the lane change of the first car in the right lane), seven changed lanes before the vehicle directly in front did so, and two exhibited both actions. The remaining seventeen participants did not act before the first vehicle merged left, and only released the accelerator after the convoy of cars including the vehicle directly in front had started braking. In this group, five participants did not change lanes at all throughout the scenario and 12 merged left only after the vehicle directly in front did so. For the pre-event responders, the mean headway time difference was 0.17 s (SD=0.17) and the mean min TTC was 9.8 s (SD=4.2) (Figure 13). For the post-event responders, the mean headway time difference was 0.35 s (SD=0.31) and the mean min TTC was 10.8 s (SD=6.5). The effect for headway time difference was significant (t(25.9) = 2.06, p=.049). No significant difference was found for min TTC (p>.05).

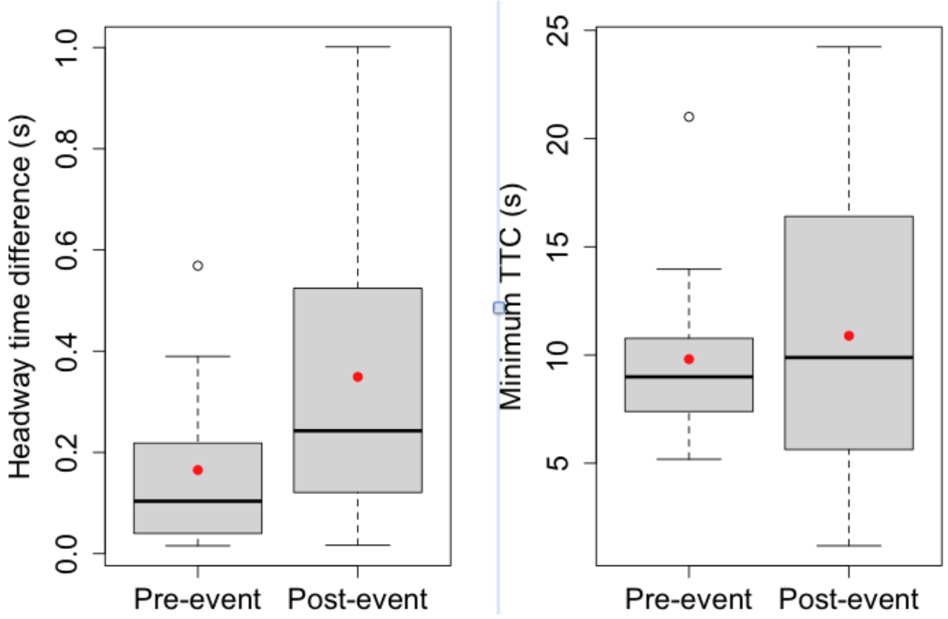

Figure 14: Headway time difference and min TTC for Scenario 3 in Experiment 1

Scenario 4 – Merging onto a highway:

Six participants released the accelerator before the lead vehicle started to brake in the acceleration lane (i.e., pre-event). Three of these participants also braked pre-event. The remaining 24 participants did not display pre-event actions; 22 released the accelerator only after the lead vehicle started braking and two did not release the accelerator at all. Among the post-event responders who released the accelerator pedal, eight did not use the brake. For the pre-event responders, the mean headway time difference was 1.64 s (SD=2.0) and the mean min TTC was 7.19 s (SD=5.64) (Figure 14). For the post-event responders, the mean headway time difference was -1.37 s (SD=5.03) and the mean min TTC was 6.09 s (SD=3.2). No significant effects were found for headway time difference (p>.05) or min TTC (p>.05).

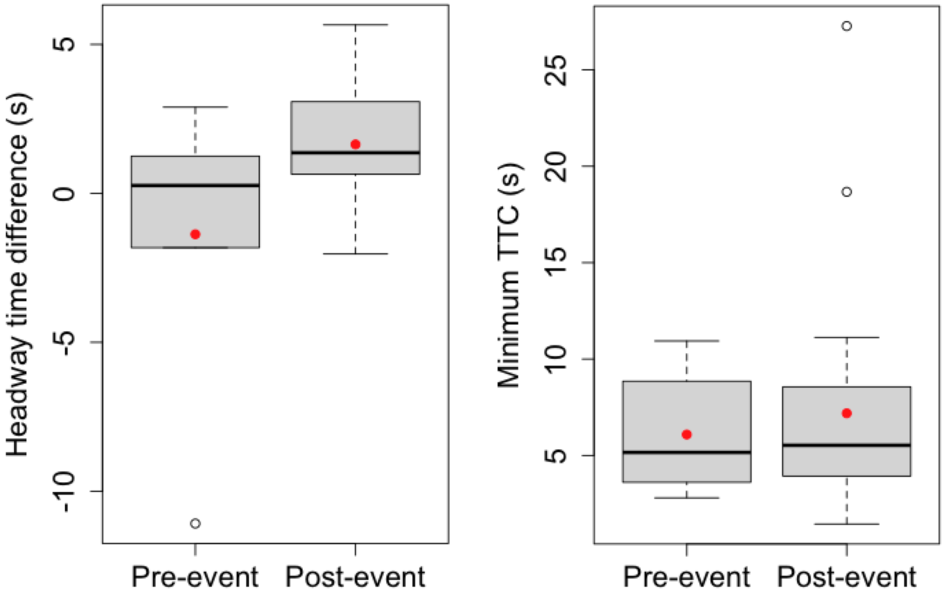

Figure 15: Headway time and min TTC for Scenario 4 in Experiment 1

Scenario 5 – Slow moving traffic on the highway:

Seven participants displayed pre-event actions. One participant released the accelerator prior to the vehicle ahead signaling its lane change and six participants took the opposite approach of accelerating. These six never had to release the accelerator or brake pedals within this scenario because they had already passed or were in the process of passing the other vehicle as it was signaling. The remaining 19 participants approached the vehicle and truck at approximately 60 mph, four of these were travelling in the left lane of the otherwise empty highway, and 15 were travelling in the right lane and switched to the left upon approaching the vehicles. These participants maintained a fairly constant speed until they braked after the vehicle ahead started signaling left. Given that a majority of pre-event responders accelerated past this vehicle, headway time difference and min TTC are not appropriate measures for this scenario.

Figure 15 summarizes pre-event actions, grouped by driver experience, across the five scenarios. In particular, it presents the percentage of participants within each experience group who acted pre-event during a scenario. A statistical analysis was not conducted due to the low number of pre-event actions observed for certain scenarios. However, the statistically significant effect of experience reported previously at the aggregate level appears to be supported at the individual scenario level. In a given scenario, the percentage of pre-event responders in the high and medium experience groups tended to be larger than in the low experience group.

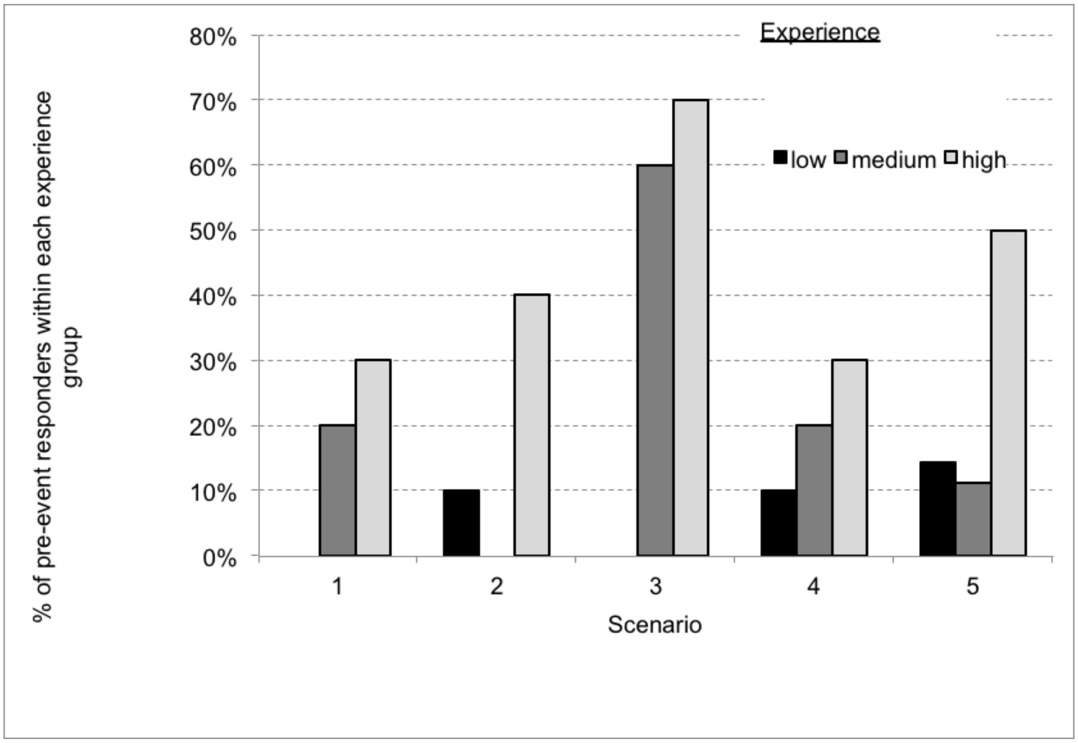

Figure 16: Percentage of participants within each experience group who acted pre-event during a scenario in Experiment 1

4.3.2 Subjective Responses

At the end of the experiment, participants reviewed their two experimental runs and responded to a series of questionnaires[2]. First, participants were asked if they had anticipated the event in each scenario and taken pre-emptive action. In 30 of the 38 cases (79%) where a participant actually had taken a pre-event action, participants responded yes. In 73 of the 112 cases where a participant had not taken a pre-event action, participants also responded yes (65%).

Participants were asked to rate their levels of surprise for the events on a seven-point Likert scale (ranging from “not at all” to “very much”). Their responses were averaged across the five scenarios. These averages were then compared among three participant groups: those who had 0 pre-event actions, those who had 1 pre-event action, and those who had 2 or more pre-event actions. The mean surprise ratings appeared to decrease with increasing number of pre-event

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[2] It should be noted that due to participants experiencing the scenarios in the same order, there is a potential for their memory of earlier scenarios having been less accurate.

actions taken (Table 3); however, there were no statistical differences among the three groups (p>.05).

Table 3: Subjective responses in Experiment 1

Subjective measure	Mean response (SD)		
	0 pre-event actions taken	1 pre-event action taken	≥ 2 pre-event actions taken
Surprise (1 to 7)	3.94 (0.78)	3.62 (1.47)	2.74 (1.39)
Perceived risk (1 to 10)	4.36 (1.18)	4.46 (1.16)	3.76 (1.55)
Mental effort (0 to 150)	40.6 (13.1)	46.1 (14.2)	34.8 (21.3)

For each scenario, participants indicated their perceived risk on a 10-point scale and their perceived mental effort on a continuous scale from 0 to 150 (Table 3). There were no significant differences between the three groups of participants for either of these measures (p>.05).

4.4 Discussion

4.4.1 Identifying Anticipatory Actions

The approach chosen to distinguishing between anticipation and reaction in this work relied on the use of specified events in stereotypical scenarios, and the use of cues leading up to these events. From a temporal perspective, actions that participants took had to take place either pre-event, or post-event, thereby indicating anticipatory and reactional behaviour, respectively. The subjective feedback provided by participants with pre-event actions, which consistently referred to the cues provided, further strengthens the understanding of anticipation as a competence of interpreting cues to identify stereotypical scenarios, and thereby future events.

Altogether, the percentage of participants who took pre-event actions was relatively low, particularly so for some of the scenarios. A potential reason is that the use of anticipation might be a relatively difficult task for most drivers and this difficulty is mediated by the specifics of the situation (i.e., driving in a simulated environment with particular instruction that may be opposed to their natural driving behaviour). The generally low number of pre-event actions recorded is in line with research investigating driver behaviour at lane drops on highways, which found that 50% of participants only signalled a lane change once the gore became visible (as opposed to reacting to earlier signage of the impending lane drop) (McGee, Moore, Knapp, & Sanders, 1978). In both contexts, i.e., the study of lane drops as well as the study of general anticipation, the relatively low number of early avoidance actions may also be attributable to a driver anticipating correctly, but choosing not to act prior to the event. Such a driver might instead only prepare for quick reaction and pay heightened attention to possible cues. Such a phenomenon would also help explain the high number of participants who considered themselves as having taken pre-emptive actions without their simulator data supporting those claims. The non-reactive, anticipatory driver was discussed as the first challenge in Chapter 2. For this reason, the definition of anticipation we proposed captures both anticipation with an appropriate pre-event action, as well as anticipation that is limited to mental preparation without an observable pre-event action. This passive type of anticipation does not result in a measurable control input to the vehicle prior to the event, and can therefore not be identified with this approach. A potential approach of identifying even passive anticipation could be to incorporate eye tracking data and the investigation of reaction times of post-event responders. Compared to a non-anticipatory driver, we would expect the non-reactive, anticipatory driver to visually fixate on cues relevant to an upcoming event longer and more frequently, and be able to react faster once the event occurs.

4.4.2 The Relation between Experience and Anticipatory Competence

The experiment showed that experienced drivers are more likely to take pre-event actions. This result supports our initial hypothesis and also confirms the effects of experience reported in other experiments that investigated drivers' abilities to correctly interpret traffic situations (Fisher et al., 2002; Jackson et al., 2009; Pollatsek et al., 2006). Due to novice drivers in this study being significantly younger than more experienced drivers, as is the case in the general population, the effect of experience may also be attributed partially to age differences. In order to unambiguously determine the influence of age, years of licensure, and annual mileage, a future experiment should test different combinations of these factors. However, even though there was no age difference between medium and high experience groups, there still was a marginal difference observed in their likelihood to exhibit pre-event responses. As is also evident in Figure 10, we observed counts of three and four pre-event actions per person only in the group of highly experienced drivers (two with three, and two more with four actions), while no driver with medium experience reached more than two pre-event actions. Due to the limited count frequency, however, we only accounted for participants with zero, one, and two or more pre-event actions in the cumulative logit model, which was therefore not sensitive to this difference between medium and high experience groups. A repetition of this study with a higher number of subjects is therefore advisable, and may support the difference between medium and high experience groups.

Experienced drivers showcased a heightened competence for the identification of cues for upcoming events, as well as for their correct interpretation. This was indicated by their higher number of pre-event actions, but became even more apparent throughout the post-experiment review sessions. When asked to recollect the behaviour of cars prior to an event, the majority of novice drivers only remembered the event itself (i.e., the brake lights of a lead car). Experienced drivers in contrast frequently pointed out multiple pre-event cues, and often gave detailed explanations for how they interpreted them.

While this study showed positive effects of high mileage driving and longer years of licensure on anticipation, it can also be expected that the reduced perceptual and cognitive abilities characteristic of advanced age will eventually negate the positive effects of experience. Future research should investigate whether and when increasing age results in worsening of anticipatory competence. The ages of our drivers in general were relatively young. A larger study, with a wider range of age groups in addition to years of licensure and annual mileage, should be undertaken. Further, when defining experience, our study focused only on annual mileage in the last year. The question of whether and to what extent the mileage driven in earlier years impacts anticipatory competence remains open.

4.4.3 Safety Impact

The temporal gains of pre-event, anticipatory actions present a potential for improved safety – a driver recognizing changes in traffic early will always have more time and space to take appropriate action. However, improved safety is not necessarily a consequence of anticipation because the individual driver decides to what end she uses this competence. For example, for the last scenario in our experiment, the majority of pre-event responders executed the more aggressive overtaking manoeuver, as opposed to deceleration. Similarly, the comparisons of headway time differences and minimum TTC in scenarios 1-4 showed that, while there is a general tendency of pre-event responders to be safer, these differences were not always significant. These findings support the understanding of anticipation as a high-level cognitive competence aiding drivers in their particular driving goals. Anticipation does not connect to one specific goal or behaviour universally.

4.5 Chapter Summary

The first experiment sought to show that acts of anticipatory driving can be identified in a simulator study. Because anticipation in itself is a cognitive competence, we monitored the surrogate measure of time of action relative to a defined event within the given scenario. Actions taken prior to this event were considered an indicator of anticipation, while actions taken after the event were not. This approach proved successful, and pre-event actions were clearly identified. Limitations apply with respect to post-event actions, however: Since the actual anticipation is entirely cognitive in nature and can therefore not be measured directly, a driver may correctly anticipate the development of the traffic situation, but consciously choose to not act on it. Therefore, post-event actions do not necessarily indicate failed anticipation.

The number of pre-event actions was relatively low; only approximately 25% of our participants showed pre-event actions. As hypothesized, this distribution was not equal across experience groups, and especially novice drivers had significant difficulty. Out of ten novices, none showed more than one out of five possible pre-event actions. This distribution improved with experience, such that in the high experience group up to four out of five possible scenarios were met with adequate pre-event actions.

There was some indication that anticipatory driving has positive effects on safety-relevant measures; however no consistent statistically significant findings with respect to TTC and headway time could be established. Since the specific use of anticipation and the resulting, increased pool of actions are subject to the individual driver's goals, this finding is in line with our expectations.

Chapter 5
The Process of Anticipating the Development of Traffic

5.1 Introduction

Driver experience predicts anticipatory competence, as the first experiment has shown. However, the findings from the experiment do not shed light on 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, analyzed and finally interpreted in working memory.

In the first experiment, the categorization of drivers into a "pre-event action" category depended exclusively on the evaluation of participants' simulator performance data. However, post-experiment cognitive walkthroughs revealed differences in the ways that anticipatory and non-anticipatory drivers described the scenarios, and particularly the visual cues they had perceived within those scenarios.

This chapter describes further theoretical considerations on anticipation in driving, this time focusing on the practical processing of relevant cues in the traffic environment. It seeks to model the process that takes an anticipatory driver from the perception of those cues to correctly anticipating the development of the situation. Understanding how this process differs between an experienced, anticipatory driver and a novice, reactive driver is the first step in finding strategies to facilitate anticipation.

5.2 Anticipation as an Act of Information Processing

5.2.1 Identifying and Interpreting Pre-event Cues

A significant part of our understanding of the practical mechanisms behind successful anticipation stemmed from the data collected from the post-experiment cognitive walkthroughs in our first simulator study. 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 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 (Hole, 2007), and thereby also guides selective attention and the continued perception of the traffic environment.

From this perspective, a 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 cues may be mediated through all modalities, driving 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 (Hills, 1980). Limiting the following discussion to visual cues for this reason, it can be argued that two mechanisms govern where visual fixation occurs (Hole, 2007). 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 second mechanism guiding visual fixation is recognition of change – fixations are attracted if the visual scene changes (Hole, 2007). Phenomena like change blindness (Simons & Levin, 1997) 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.

5.2.2 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 (Wickens & Hollands, 2000), a general process is described in which 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 16 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.

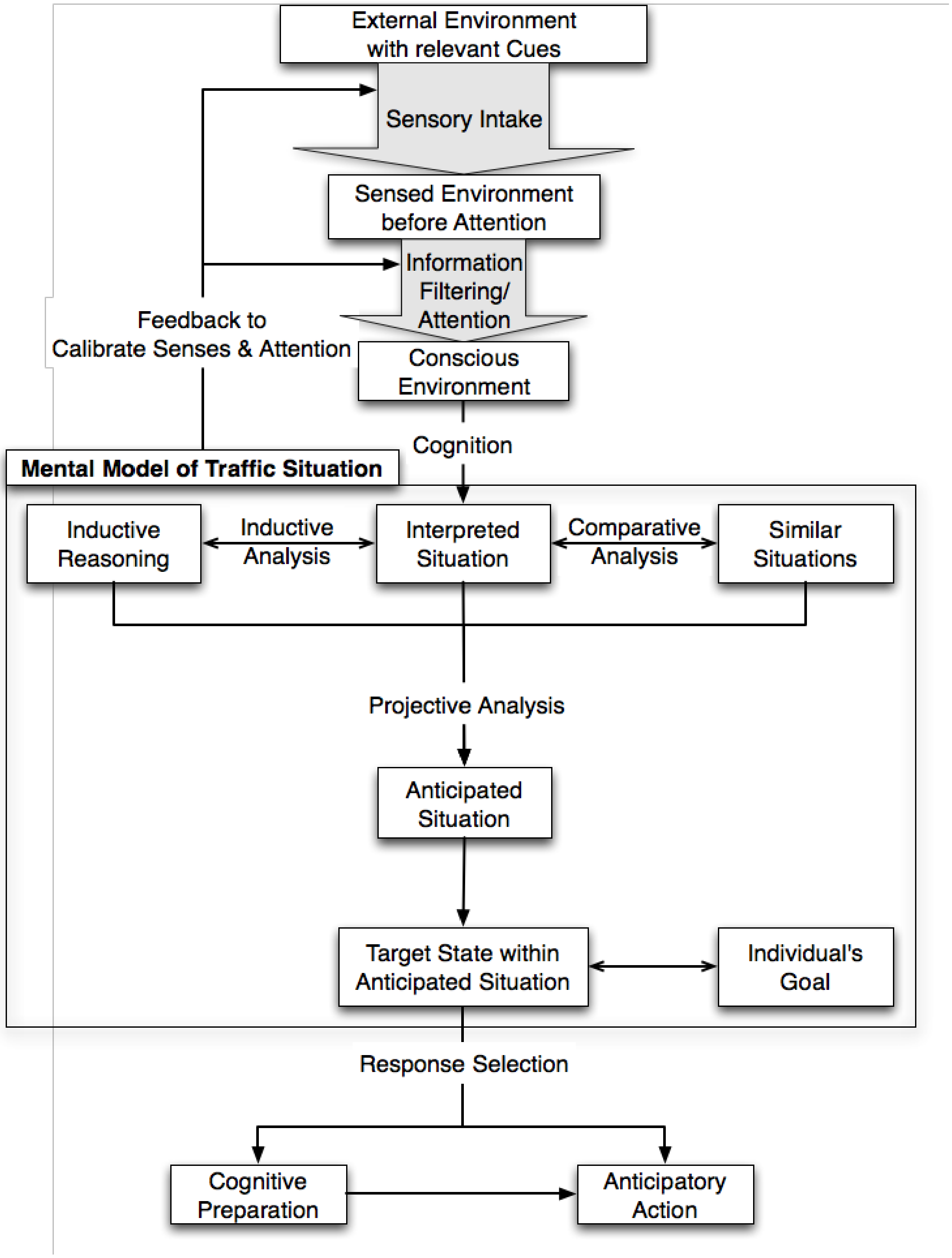

Figure 17: Model of anticipation in driving

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 (Rasmussen, 1983) 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 (Thisjen et al., 2014).

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 consistent throughout the scenarios. 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 positions her in a favourable 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 16 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).

5.3 Chapter Summary

This chapter described an extension of the theory of anticipatory driving that was proposed in Chapter 2. While it proved feasible to identify anticipatory competence based on determining the point in time when drivers act relative to conflict events, experiment 1 also confirmed the suspicion that some drivers consciously choose to not act, even though they successfully anticipate the developments in traffic. The significant differences in number of pre-event actions exhibited between novice and experienced drivers, as indicative of their different anticipatory competencies, further motivated a discussion on how anticipation in driving happens and how it can be operationalized. To this end, the present chapter attempted to model the process of anticipation from an information processing perspective, theorizing how appropriate visual cues are perceived in the environment, cognitively interpreted, and then lead to anticipatory actions. The model in Figure16 explains the difference in anticipatory proficiency between novices and experts through the use of two different strategies: Novices are more likely to require effortful inductive analysis of the perceived cues, while experts can fall back on efficient, comparative analysis between perceived cues on past situations.

The information processing model of anticipation proposed in this chapter seeks to explain what processes are necessary for a driver to anticipate upcoming traffic situations. The next logical step with respect to the research in this Ph.D. was to empirically investigate specific aspects of the model. 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. Going back to the example in Figure 1 for example, whether or not the conflicting car signals its lane change before it pulls out in front of the participant should have an impact. In this sense, cues could be altered in several ways, including number of cues, salience, and semantic meaning. 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. This approach of providing an additional, artificial cue for drivers was most interesting for a) its potential to translate directly into appropriate interface interventions to facilitate anticipatory driving competence, and b) the possibility of altering both the perception of cues by calibrating attention appropriately, as well as the cognitive interpretation of those cues by suggesting meaning. Chapter 6 therefore describes a second experiment that evaluated the benefit of two interface designs representing this rationale.

Chapter 6
Experiment II: Investigating the Perception of Cues to Facilitate Anticipatory Driving

6.1 Introduction

Up to this point, we have reviewed the role of anticipation in existing driving research, discussed the theory of anticipation in driving, and defined anticipatory driving as "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". We have also reported on the results of a first driving simulator study that investigated anticipation in several simulator scenarios, and found indication that experienced drivers were able to anticipate more consistently than novice drivers by comparing the frequency with which they took pre-event actions.

However, we have hypothesized only about the process of a driver anticipating the development of the traffic situation (as has been discussed in section 5.5.2). This chapter describes an experiment that investigated the processing of the visual cues that form the foundation of the information processing model of anticipation. The role of those cues for anticipation was the focus for the two research goals of the experiment:

1) We sought to create an aid that would facilitate anticipatory competence. Hence, this chapter describes the design of two interface interventions, both of which are based on the theoretical considerations derived from the model of anticipation: One interface highlights relevant visual cues, with the goal of ensuring appropriate attention, while the other interface highlights cues and also suggests meaning for those cues. The rationale and design of both interface types is described in section 6.2.

2) We sought to further investigate the perception of visual cues by assessing glance patterns. The analysis of eye glances focused on the perception of cues in the traffic environment on one hand, and on glance behaviour towards the interface interventions on the other. Section 6.3 therefore connects prior research on the characteristics of skilled glance patterns in driving to the topic of anticipation.

6.2 Aiding Anticipation

6.2.1 The Bases for Anticipation: Perception and Interpretation

The superior anticipatory competence of experienced drivers was expected given our hypothesis that experienced drivers possess heightened skills for the timely, accurate interpretation of the local traffic situation. It was also in line with prior research in hazard perception, where experienced drivers exhibited superior visual scanning patterns (Garay-Vega & Fisher, 2005) and early recognition of hazards (Jackson et al., 2009). We have argued in chapter 2 that anticipation in driving is rooted in the identification of stereotypical situations in traffic. In this sense, both anticipation and hazard perception rely on skilled perception and correct interpretation of the surrounding traffic situation. These mechanisms are largely learned competencies, and therefore are impacted positively by experience and repeated exposure to similar situations, as well as the abilities to access and compare the current situation to similar situations stored in memory.

The mechanism by which experience benefits anticipation should therefore be viewed as a top-down process in which existing mental models and knowledge from relevant past experiences guide attention and the interpretation of sensory input from the traffic environment. This view of top-down processing in traffic has also been discussed by Hole (2007) and is an idea in the constructivist tradition, where learning takes place as an iterative, comparative process between perceived information and existing constructs of the world. Constructs are the reference point for interpretation of sensory information, and new information in turn continuously updates and changes our mental constructs.

In this regard, facilitating anticipatory competence can be seen as a matter 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. In post-experiment cognitive walkthroughs following our first experiment, experienced drivers who exhibited timely, anticipatory actions frequently referred to past experiences when explaining the perceived traffic scenario and their actions within it. They also presented more complete accounts of the particular scenarios they had driven through, remembering more cues, connecting them causally, and drawing conclusions from those observations.

Experience can be argued to lead to a catalog of stereotypical situations that is more detailed and more extensive. Consequently, for the experienced driver, the process of interpreting the situation at hand is heavily guided through the knowledge of similar situations. Efficient and fast skill-based behaviour (Rasmussen, 1983) 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 stereotypical situations. The novice driver will instead rely more heavily on processes of inductive reasoning, such that more effortful processing will take place. He may still be able to interpret the current situation, but the accuracy of his interpretation will depend more on high level, knowledge-based behaviour.

These theoretical considerations suggest two crucial steps for anticipation in driving, namely 1) the conscious perception of appropriate cues that serve as indicators for the traffic scenario at hand, and 2) efficient cognitive processing that leads to a quick and correct interpretation of these cues. Experienced drivers' superior performance with respect to anticipation can be argued to result from heightened skill in both. Their driving altogether has become a more automated procedure, such that more cognitive resources are available to monitor the environment for cues. Even more so, frequent exposure to a multitude of stereotypical traffic situations will result in knowledge of appropriate cues indicating those situations, such that the monitoring of surrounding traffic will become a more targeted process than for a novice driver

6.2.2 Attentional and Interpretation Interfaces

While we cannot substitute for the heightened competencies of an experienced driver, we can attempt to mitigate lack of experience by highlighting relevant cues, and aiding the correct interpretation of these cues. Even for an experienced driver, highlighting appropriate cues may hold promise, since cues missed due to distraction can result in incomplete or incorrect situation assessments.

Different types of interfaces aiding anticipation have been proposed in prior driving research. Toennis et al. (2007) discussed the use of a head-up display that provides a visualization of the stopping distance to the driver. Laquai et al. (2011) proposed and investigated the use of color-coded LED arrays to help drivers modulate their brake pedal control in response to other vehicles. With a particular focus on improving fuel consumption, prior research has investigated interfaces that suggest the optimal gear to the driver (Van der Voort & Maarseven, 1999), and present optimal coasting distances to minimize braking (Baer et al., 2011; Rommerskirchen et al., 2013). All of these examples aim to directly support vehicle control when the system is anticipating in place of the driver. Further, none of these interfaces support the anticipation of potential conflicts resulting from actions that might be taken by other traffic participants.

To help drivers anticipate traffic situations, we propose that the drivers can be aided in the identification and interpretation of relevant cues. Driver training is one potential means of teaching drivers these competencies. Research on a PC-based risk awareness training using recorded, real-world traffic scenarios, for example, has reported positive effects on participants' performance in a subsequent simulator experiment (Fisher et al., 2002). With respect to anticipation, training can be expected to contribute to the development of a store of stereotypical situations to facilitate comparative analysis.

In contrast to the offline driver training to facilitate anticipation, we seek to aid drivers with the interpretation of traffic situations, and anticipation of possible conflicts as they are driving. A real-time in-vehicle design solution could aid the driver directly when anticipation is needed, as opposed to requiring time outside of the car to develop an adequate store of stereotypical situations. To this end, we propose two different in-vehicle interface types to support the two proposed stages of anticipation: attentional and interpretational.

The *attentional* interface type focuses on calibrating attention by highlighting the most relevant cue for the understanding of the situation at hand in an attempt to ensure that drivers attend to them. This interface would therefore specifically aid in the first anticipatory task of perception, without explicitly supporting the cognitive sense-making process to interpret the meaning of the perceived cues.

The *interpretational* interface type also seeks to calibrate attention, but in addition aids the driver in interpreting the meaning of the cues that it highlights. It would therefore be designed to guide the cognitive sense-making by suggesting possible consequences of the perceived cues, and hence support both the first anticipatory stage of perception and the second stage of cognitive processing.

The design of the six interfaces (three attentional and three interpretational) used within this experiment is described in more detail in section 6.4.4.The driving simulator experiment described in this chapter was conducted to evaluate these two types of interfaces. Our main hypothesis was that actively calibrating driver attention with appropriate interfaces would result in earlier actions on upcoming conflicts, and therefore result in more anticipatory driving behaviour. We have reasoned that experienced drivers will be more competent with the correct interpretation of a given traffic situation due to the benefits of their larger catalog of stereotypical situations. Facilitating anticipatory competence for experienced drivers should therefore focus on calibrating their attention such that they attend to the relevant cues, and less on aiding in the interpretation of those cues. Novice drivers in contrast may not possess a suitable store of reference situations, such that aiding anticipatory competence should focus on both attention allocation to relevant cues and the interpretation of those cues. This rationale led us to expect novice drivers to perform better with an attentional interface than without, and better with an interpretational interface than with an attentional one, whereas experienced drivers were expected to generally anticipate more often when using either display, without the interpretational aid resulting in added benefits.

6.3 Eye Glance Patterns in Driver Behaviour

6.3.1 The Visual Nature of Driving

Driving is a highly visual task, requiring constant monitoring of the vehicle's relative position to the roadway. The majority of information about other traffic participants, traffic infrastructure and traffic regulations is also communicated through the visual channel – signage and traffic lights, as well as the perception of in-vehicle interfaces rely on a driver's vision. Visual information is estimated to make up about 90% of the total information available to drivers (Hills, 1980). Not surprisingly then, poor visual scanning and errors with respect to the perception of the traffic environment have been reported among major causes of crashes (Sabey & Taylor, 1980). Given the importance of correct visual perception of the roadway, the need for the investigation of drivers' glance patterns is evident, and has become a major aspect of driver behaviour research.

It is also well known that young, novice drivers are overrepresented in crash statistics. After initial considerations of social factors, such as risk-seeking behaviour, drug abuse or nighttime driving were ruled out as major contributors, visual search and the correct interpretation of the roadway have been argued to be the deciding factors. Research has proposed that novice drivers' failure to correctly interpret the roadway and its upcoming risks (Pollatsek et al., 2006) contributes to their heightened crash risk. This failure has been argued to stem from general lack of experience, but also from failures in visual search. Research into crash statistics has shown visual search to be consistently among the top contributors, ranking as third most frequent reason (after lack of attention and wrong choice of speed) in a study conducted on police accident reports from the states of California and Maryland (McKnight & McKnight, 2003), and even as the leading cause for crashes in another study (Treat et al., 1977).

6.3.2 Differences in Visual Scanning Between Experienced and Novice Drivers

These rationales from forensic investigations of crashes are supported by research investigating visual scanning patterns of novice drivers relative to experienced drivers. One of the first studies on eye movements in traffic concluded that novice drivers' visual acquisition process was lacking skill, based on establishing that their fixations were covering a relatively small area, were mostly directly in front of the vehicle, and covered a significantly smaller horizontal range than those of experienced drivers (Mourant & Rockwell, 1972). Another study compared the visual scanning patterns of novice and experienced drivers each on three different road types, and concluded that experienced drivers varied the range of their horizontal visual scanning patterns to accommodate differing complexities in roadways, while novice drivers scanning patterns remained relatively constant and inflexible (Crundall & Underwood, 1998).

While not directly investigating differences with respect to visual scanning patterns, Pradhan et al. (2005) reported superior visual scanning for older participants in a study which investigated effects of age, a factor that usually correlates with experience. They investigated the performance of 24 novice, young, and older drivers each across 16 risky scenarios in a driving simulator, analyzing whether or not participants fixated on risky features of the scenarios. Their analysis indicated that novice, young and older drivers showed behaviour indicating they had recognized the risk 35.1%, 50.3%, and 66.2% of the time, respectively.

Driver training can also be argued to have positive effects on visual scanning patterns. Fisher et al. (2007) showed that drivers who had been trained to recognize risks effectively transferred that skill to both simulated and on-road driving. In both conditions, trained drivers achieved a higher percentage of fixations on regions in the scenario that held important information regarding the risk present relative to drivers who had not been trained.

To summarize the above studies, driver experience can be argued to result in several benefits with respect to visual scanning patters:

1. Horizontal scanning covers a wider range
2. Fixations cover a larger area, and are usually further away from the vehicle
3. Scanning patterns become generally more flexible, changing relative to the situation at hand
4. With respect to hazard detection, areas indicative of the risks contained in a given scenario are fixated upon more often

We have argued the importance of recognizing visual cues that are dependent on the context of the particular situation they occur in. In our theory of anticipatory competence in driving, the perception of those cues is a necessary first step that allows for cognitive processing and correct assessment of a given traffic situation. With the experiment described in this chapter we therefore wanted to extend the existing investigations of the general eye-tracking patterns of drivers with a study aiming specifically at assessing glance patterns towards visual, context-dependent cues that are relevant for the understanding of the respective traffic situation at hand. We expected differences in cue perception to be influenced by experience, and to be in line with the literature reported above, confirming that experienced drivers’ visual glance patterns are more targeted than those of novice drivers. The investigation of this reported superiority of experienced drivers’ glance patterns in the context of anticipation was also important because these findings are not unchallenged: A study by Falkmer and Gregersen (2005), for example, found that experienced drivers actually were less successful at directing visual attention to objects classified as potential hazards, have more fixations close to their vehicle than novice drivers in city routes, and look less towards the far right of the traffic scene (therefore contrasting the above reported higher horizontal scanning range of experienced drivers)..

6.3.3 The Role of Visual Scanning for Anticipation

Our theoretical understanding of anticipation in driving allocates a crucial role to the visual perception of cues. We believe that anticipation relies on the recognition of a given situation by comparing it to a stereotypical model of that situation. This would explain the superior performance of experienced drivers, since they can be argued to have a better established, larger store of reference situations. Anticipation also requires a mechanism that allows for the comparison between current situation and stereotypical situation. We believe this mechanism to rely heavily on the identification of visual cues that are characteristic for the given situation.

We have so far only identified anticipatory drivers through their driving performance, that is through actions that were taken prior to a given conflict event in a scenario. While this has proven to be a successful approach, it has yielded no insight into the question of how participants treat the visual cues in a given scenario. In section 6.3.1 we summarized how existing research suggests differences that exist in visual search patterns between experienced and novice drivers. Having established that experienced drivers outperform novices with respect to anticipation could therefore suggest differences with respect to visual search patterns also depending on the anticipatory competence of drivers. Further, hazard perception can be argued to share a comparable, recognition-based identification of a particular (high-risk) situation with anticipation – with the difference that for anticipation, cues have to be viewed as characteristic of a traffic situation as a whole, not of a particular risk. Because in hazard perception, experienced drivers have been found to attend to risky areas more so than do novice drivers, a similar tendency could be expected for cue recognition with respect to anticipation.

With our second simulator experiment, we therefore collected eye-tracking data as well, seeking to identify anticipatory drivers, again based on whether or not they exhibited clear pre-event actions in a scenario, but also investigating whether there were systematic differences in visual search between participants with and without those pre-event actions. While it is possible for a skilled driver to recognize cues and situations correctly, anticipate the likely conflict, but consciously choose to not act because a crash is not yet imminent, it should not be possible for a driver to exhibit an anticipatory pre-event action without having recognized the cues indicating the situation.

6.4 Methods

6.4.1 Experimental Design

Table 4 presents the experimental design, which was a 2x3x3 mixed factor design with experience (novice and experienced) and interface type (no interface, attentional interface, and interpretational interface) as between-subjects variables and experimental phase (pre-intervention, intervention, and post-intervention) as a within-subject variable. The different combinations of experience and interface type (2x3) were assigned to distinct groups of participants, with 8 participants in each group. In other words, the random factor ‘participant’ was nested under the interaction of experience and interface type.

Driving experience had two levels based on years of licensure (i.e., years a valid driver’s license has been held) and mileage (i.e., distance driven within the previous 12 months; Table 5). These categories were similar to the ones used in the first experiment, with the exception that the medium-experience level was merged with high-experience level as no differences were observed between these two levels. Further, due to the difficulty in recruiting participants, we relaxed the number of years of licensure required for both groups, requiring the low experience group to have held a license for a maximum of three years, and the high experience group for a minimum of eight years (in the first experiment, we used two and ten years, respectively).

Every participant drove the simulator through three different scenarios repeated in three experimental phases in identical order, for a total of nine drives (one scenario per drive). The first (pre-intervention) and third (post-intervention) phases involved no interfaces. In the second phase (intervention), the participants who were assigned to the attentional and interpretational interface conditions experienced the respective interfaces, whereas the participants assigned to the no interface condition were not presented with any interfaces. The ‘no interface’ condition served as a control group; whereas the ‘pre-intervention’ phase provided a baseline assessment of

				Within Subjects: Completed by all participants (#1-48)		
		Between Subjects		**Phase 1:** (Scenarios 1-3)	**Phase 2:** (Scenarios 1-3)	**Phase 3:** (Scenarios 1-3)
Group: Participant #	**n**	**Experience**	**Interface Type**	**Pre-Intervention**	**Intervention**	**Post-Intervention**
1: #1-8	8	Novice	No	No interface	No interface	No interface
2: #9-16	8	Experienced				
3: #17-24	8	Novice	Attentional	No interface	Attentional interface	No interface
4: #25-32	8	Experienced				
5: #32-40	8	Novice	Interpretational	No interface	Interpretational interface	No interface
6: #40-48	8	Experienced				

Table 4: Experimental design for Experiment 2, highlighted are the scenarios where an interface intervention was used

anticipatory competence for all participants. The 'post-intervention' phase enabled us to assess potential learning effects from the anticipatory interfaces.

6.4.2 Participants

Forty-eight participants completed the experiment. All participants held at least a valid G1-level[3] license in the province of Ontario (or equivalent), had driven a passenger vehicle with an automatic transmission, and reported using only their right feet to operate the accelerator and brake pedals. Both novice and experienced drivers were recruited for the study within the experience categories defined in Table 5. Most participants were recruited from the student body of the University of Toronto or from Young Drivers of Canada, although we also advertised on social media and networking services. All participants filled out an online screening questionnaire (Appendix B) 3)) to determine eligibility for the study.

The investigator reminded participants of the speed limit if they deviated from the speed limit by more than 10 mph. Hence, a participant consistently deviating from the speed limit by just under 10 mph could have deviated by approximately 10 sec in the longest scenario.

Table 5: Two levels of driver experience investigated in Experiment 2

Driving experience	Years of licensure	Distance driven within past 12-months (km/year)	n	Mean age (SD)
Low	≤ 3	< 10,000	24	19.5 (2.19)
High	≥ 8	> 20,000	24	40.2 (14.23)

6.4.3 Procedure

Participants were first told that the general purpose was to study driving behaviour in a simulator environment. Participants were instructed to drive as naturally as possible. Specifically, they were told to not treat the simulator like a game, and to not drive in a safer or more law-abiding way than they would on the road. An informed consent form (Appendix C) 3)) was then given, which detailed the experimental procedure and risks. Care was taken to never inform participants about what parts of their driving behaviour specifically were relevant for the study. After signing

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[3] A G1-level license allows drivers in Ontario to pilot a car when accompanied by a fully licensed driver. In the first experiment, we allowed only participants with a G2-level license or equivalent, which allowed them to pilot cars alone.

the informed consent document, the investigator allowed the participants to adjust the steering wheel, backrest, and seat positions, and explained the controls of the simulator. Participants were then told that the default highway speed was 60 mph, and not to overtake lead vehicles. Participants then had two practice runs to familiarize themselves with the simulator and train for the above default behaviours. The first run gave them an opportunity to drive on a rural road below 40 mph and follow a lead vehicle, while the second run involved a merge onto a highway as well as practice at maintaining a highway speed of approximately 60 mph. Participants were informed that 60 mph equates to approximately 100 km/h, and care was taken to ensure that they were aware of all speed indications being in mph. The practice sessions took approximately 10 min in total and ended when the participants and the experimenter were both content with the performance achieved. Following the practice sessions, the investigator calibrated the eye-tracker. The participants then completed the nine drives, each one lasting three to five minutes. Participants were then asked to complete a post-experiment questionnaire (Appendix B) 4)) on a laptop computer. Total time for the experiment varied between 1.5 and 2 hours per participant, and compensation was set at C$20.

6.4.4 Driving Scenarios and Displays

Each participant experienced three different driving scenarios and drove each one three times, for a total of nine drives. Each drive was relatively short, with none lasting longer than five minutes. Scenarios were constructed such that participants had time to settle at the beginning, with a single event presented towards the end of a drive. The events were again designed to assess whether drivers exhibited pre-event actions – a surrogate measure for anticipatory competence. The beginning of an event was marked by an action of a vehicle ahead of the participant resulting in a change of speed or heading that would conflict with the participant’s vehicle. This action had to be familiar and unambiguously indicate the upcoming conflict, such as the onset of lead vehicle brake lights.

Scenarios 1, 3, and 5 were adapted from the first experiment (see section 3.2); they will be referred to as scenarios 1, 2 and 3 respectively for the remainder of this chapter. Further, participants were instructed to 1) maintain a relatively constant speed around the speed limit of 60mph when traveling on the highway, and to 2) maintain a comfortable distance when instructed to follow a lead vehicle without overtaking. As mentioned earlier, each scenario was repeated three times; however, the scenarios were modified from one repetition to the next to minimize learning effects. Scenarios never took place in the same location, and as such, curvature and the surrounding environment differed significantly. Colours and types of the vehicles the participant interacted with in a given scenario were also changed from one drive to the next. Finally, care was taken to vary the traffic scenarios prior to the actual scenarios of a given drive, and insert smaller conflicts that were of no interest to the investigation (i.e., lead cars braking unexpectedly).

In comparison to the first experiment, and due to the experimental design with repeated drives, we reduced the number of scenarios from five to three, and built three iterations of each scenario that differed with respect to the types and colours of vehicles involved, as well as the road environment in the simulation. This was to ensure that participants would not easily recognize the type of conflict that was upcoming from a prior run. The number of the surrounding traffic participants as well as their behaviour however were exactly the same, so that all three iterations of a scenario caused the exact same conflict. Since the scenarios used were similar to the ones described in section 3.2, their mention here is largely to describe the two different interface types used within each of the scenarios. These interfaces were developed based on the model of anticipation introduced in Figure 16: The attentional interface sought to aid only in the pre-interpretation calibration of attention, highlighting the initial cues in the given scenario. They were, as such, acting prior to the cognitive interpretation depicted as the “mental model” in Figure 16, whereas the interpretational interfaces were designed such that interpretation of relevant cues was also facilitated. The vision here was to provide additional information, beyond the mere highlighting of relevant cues to aid in the process of inductive reasoning for correctly interpreting the present traffic situation.

Scenario 1 – Chain braking due to a slow tractor, repeated on drives 3, 6, and 9. For this scenario, the most important cue was the slow tractor, which was ahead of the chain of five vehicles and therefore not necessarily the focus of attention. Both interfaces (Figure 17) therefore concentrated on highlighting the slow tractor in the roadway, with the attentional interface limited to just warning the driver of the tractor, while the interpretational interface aided the driver in interpreting the meaning. Both interfaces used pictorial and textual representation. For the interpretational interface, two cars that follow the tractor and are braking are depicted also, highlighting a second important cue for the upcoming conflict and warning the driver of the braking vehicles.

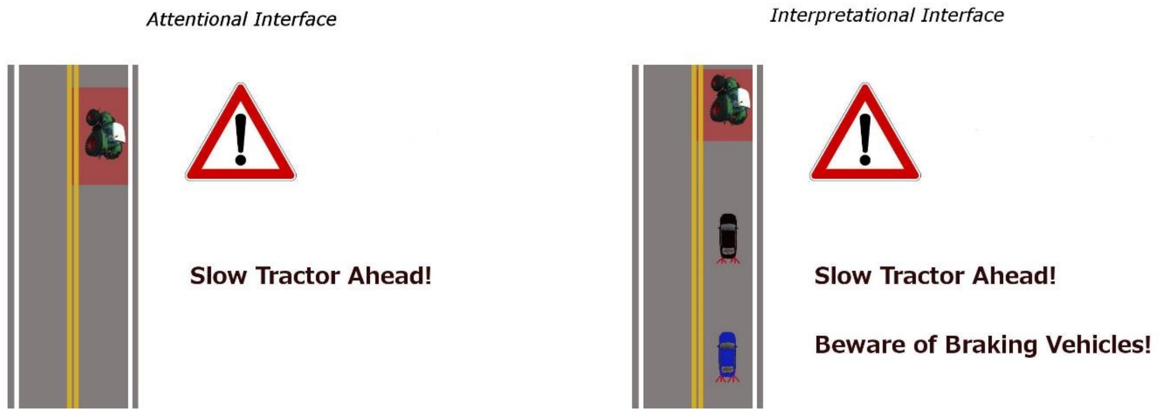

Figure 18: Attentional (left) and interpretational (right) interfaces for scenario 1 in Experiment 2

Scenario 2 – Stranded truck on highway shoulder, repeated on drives 1, 4, and 7. The first visible, and most important cue for conflict anticipation was the stranded truck itself. The consecutive signaling of vehicles in the right lane, their merging into the left and the consequential braking of the following vehicles were the cues that followed in this scenario. Both interfaces (Figure 18) therefore highlighted the stranded truck, with the attentional interface being limited to merely displaying and calling attention to it. The interpretational interface warned the participant of the potential consequence, namely the merging vehicles. It also displayed additional cars, visually showing the additional visual cues.

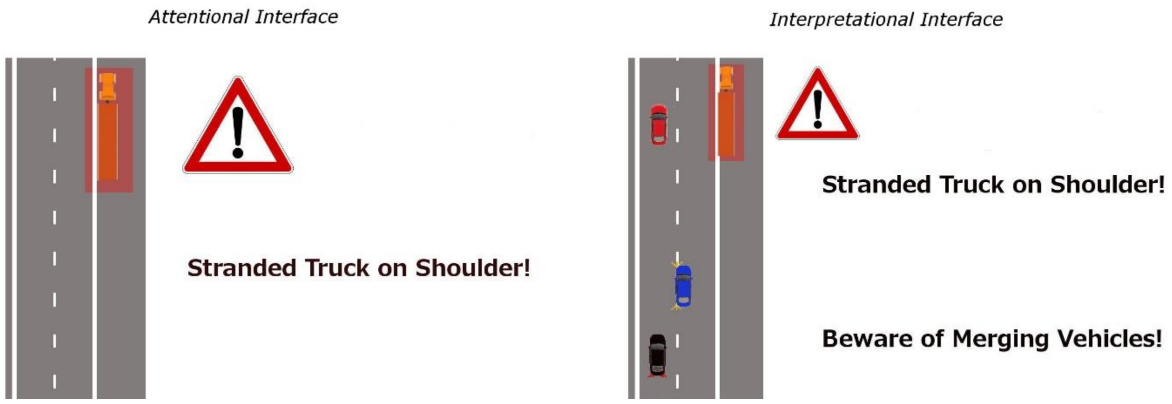

Figure 19: Attentional (left) and interpretational (right) interfaces for scenario 2 in Experiment 2

Scenario 3 – Slow moving traffic on the highway, repeated on drives 2, 5, and 8. As has been described before, we defined the event in this scenario to be the onset of the left-turn signal of the car that followed the truck. The anticipatory cues to predict the car to make a lane change to overtake were the relatively slow-moving truck, as well as the diminishing headway distance between car and truck. Hence, both interfaces (Figure 19) highlighted the slow-moving truck as the most important cue. The attentional interface showed only the slow truck and a descriptive message, whereas the interpretational interface also displayed a car behind the truck that is in the process of switching from the right to the left lane, and warned of the potential of cars merging.

Figure 20: Attentional (left) and interpretational (right) interfaces for scenario 3 in Experiment 2

Before the simulator experiment, these six anticipatory interfaces (Figures 17-19) were subjected to a small-scale usability testing to ensure that they were easily understandable and would not generate dangerously long off-road glances. First, 24 evaluators[4] interpreted the interfaces in a multiple choice survey (see Appendix D), which showed that everyone had understood the information content. Then, another five evaluators viewed the two interfaces for two seconds each and were asked to interpret them. This viewing duration was chosen due to research showing off-road glances greater than 2 s to significantly increase crash risks (Dingus et al., 2006). No evaluator failed to understand the meaning of any display within the two second exposure time.

6.5 Results

6.5.1 Pre-event and Post-event Actions

Drivers were categorized into pre- and post-event response groups based on whether or not they acted prior to the defined event in each scenario using the same methods employed in the first experiment. Deceleration was always considered an appropriate pre-event action, and in fact was the only pre-event action we observed from participants in Scenarios 1 and 2. In Scenario 3, some participants also accelerated to pass the vehicle ahead before it signaled its lane change, which was also considered an appropriate pre-event action. Drivers were categorized into pre- and post-event response groups by the author, who was blind to the corresponding experimental conditions, including driving experience, interface type, and experimental phase.

As shown in Figure 20, novice drivers assigned to the ‘no interface’ condition appeared to have a relatively stable number of pre-event responses across the different experimental phases. In contrast, the novice drivers assigned to the attentional or interpretational interface conditions appeared to exhibit a higher numbers of pre-event actions during the intervention phases. The number of pre-event actions taken by experienced drivers appeared to be much higher than those of novice drivers in general (Figure 21), with some participants exhibiting all three pre-event actions before the interfaces were presented. However, there were no major improvements apparent with the interfaces. It is also noteworthy that no differences were evident across the

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[4] None of these 24 evaluators was part of the pool of 48 who participated in the follow-up simulator experiment.

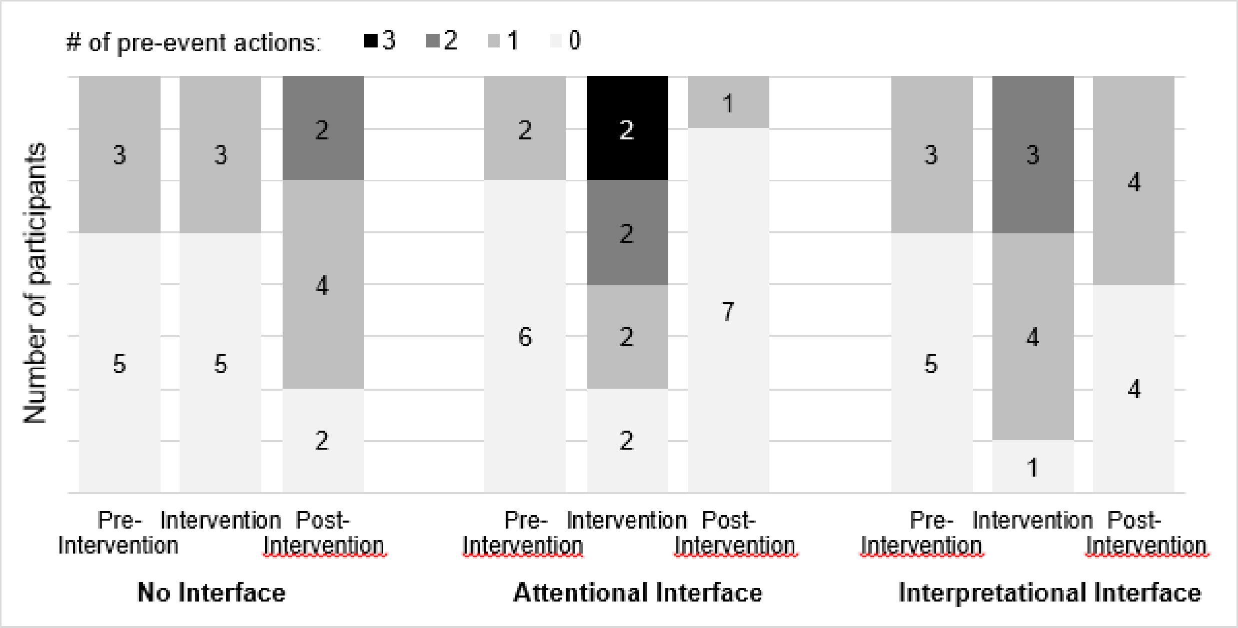


Figure 21: Number of pre-event actions taken by <u>novice</u> drivers across three blocks of drives (pre-intervention, intervention, and post-intervention) in each of the three interface conditions (no interface, attentional interface, and interpretational interface)

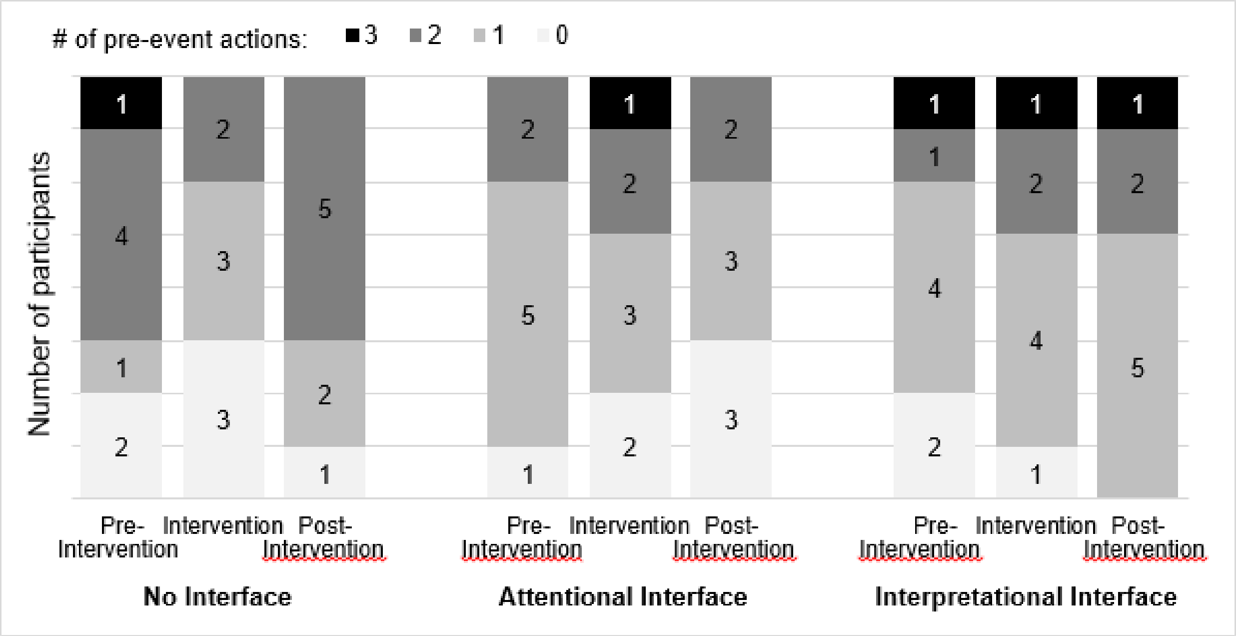


Figure 22: Number of pre-event actions taken by <u>experienced</u> drivers across three blocks of drives (pre-intervention, intervention, and post-intervention) in each of the three interface conditions (no interface, attentional interface, and interpretational interface)

three experimental phases in the no interface condition for both the novice and the experienced driver groups (i.e., between the leftmost three bars of Figures 20 and 21 respectively), providing support to the lack of learning effects.

A cumulative logit model was built to analyze number of pre-event responses per experimental phase exhibited by each driver. Given that there were three scenarios per phase, this dependent variable could take on values of 0, 1, 2, or 3. Because the number of participants who acted pre-event in all three scenarios was small, we collapsed the dependent variable into three categories: 0, 1, and ≥ 2 pre-event actions. Through this model, we compared the pre-event responses of novice and experienced drivers across the pre-intervention phase (i.e., baseline) and then investigated the effectiveness of the anticipatory interfaces for each experience group. The latter was achieved through specific contrasts which, for a given anticipatory interface (i.e., attentional or interpretational), first obtained the change from the pre-intervention phase to the intervention phase and then compared it to that obtained for the 'no interface' condition (i.e., control group). We fit the model using the GENMOD procedure in SAS 9.1, with the specifications of cumulative logit link function and multinomial distribution. Generalized Estimating Equations were utilized for repeated measures. The specific contrasts were set through the 'Estimate' statement.

6.5.1.1 Novice Driver Performance

For both interface conditions, the likelihood of novice drivers exhibiting pre-event actions increased from the pre-intervention to the intervention phase. With the interfaces, the odds of exhibiting pre-event actions increased more than tenfold (attentional interface: Odds Ratio (OR) = 19.8, $\chi^2(1) = 6.10$, $p = .01$; interpretational interface: OR = 10.2, $\chi^2(1) = 6.91$, $p = .009$). In contrast, novice drivers who were in the 'no interface' condition did not show any significant changes from the pre-intervention to the intervention phase, suggesting that there were no major learning effects from the first phase to the second when there was no anticipatory interface present. As an additional check, we compared the change from the pre-intervention to the intervention phase obtained for the interface conditions (i.e., attentional and interpretational) to that obtained for the 'no interface' condition. Both comparisons led to marginally significant results (attentional interface: OR = 19.8, $\chi^2(1) = 3.56$, $p = .06$; interpretational interface: OR = 10.2, $\chi^2(1) = 2.96$, $p = .09$). The improvements with the two interfaces appeared to bring novice drivers' performance on par with the experienced group. In particular, there were no significant differences observed when pre-event actions were compared across the two experience groups when they were presented with the interfaces.

Going from the intervention phase to the post-intervention phase, the 'no interface' group showed an increased likelihood in exhibiting pre-event actions, suggesting a learning effect (OR = 5.4, χ^2 (1) = 10.89, p = .001), while both the attentional (OR = 0.02, χ^2 (1) = 5.37, p = .02) and the interpretational interface groups (OR = 0.15, χ^2 (1) = 4.59, p = .03) showed a decline in pre-event response likelihood in the post-intervention phase. When the change from pre-intervention to post-intervention phases was compared across different interface types, the attentional interface was found to perform marginally worse compared to the 'no interface' condition (OR = 0.08, χ^2(1) = 3.29, p = .07).

6.5.1.2 Experienced Driver Performance

A comparison of novice and experienced drivers during the pre-intervention phase revealed that, as expected, experienced drivers exhibited more pre-event actions (OR = 10.8, χ^2(1) = 16.40, $p < .0001$). Going from the pre-intervention to the intervention phase, the anticipatory interfaces were not found to make a difference for the experienced drivers. A marginally significant difference was found for the 'no interface' condition, with a decline in pre-event response likelihood from the pre-intervention to the intervention phase (OR = 0.2, χ^2 (1) = 3.39, p = .07). Overall, the change from the pre-intervention to the intervention phase for the attentional interface was not significantly different than that of the 'no interface' condition. However, the change from the pre-intervention to the intervention phase for the interpretational interface was marginally better than that of the 'no interface' condition (OR = 9.5, χ^2 (1) = 3.42, p = .06).

Going from the intervention phase to the post-intervention phase, the 'no interface' group showed a marginally significant increase in likelihood of exhibiting pre-event actions (OR = 11, χ^2 (1) = 3.31, p = .07). In contrast, performance changes in both interface groups were not significant. When the change from pre-intervention to post-intervention phases was compared across the three interface types, no significant differences were observed.

6.5.2 Glances towards the Interfaces

Overall, 32 participants completed three scenarios with the attentional or interpretational interface conditions during the intervention phase. The following glance measures were analyzed to assess how these participants interacted with the interfaces over these three scenarios: 1) total number of glances towards the in-vehicle display, 2) maximum display glance duration, and 3) mean display glance duration. These variables were analyzed through mixed linear models built in SAS 9.1 MIXED procedure, with interface type, experience, and interface type – experience interaction as predictors.

Overall, the participants glanced at the interpretational display more frequently (Figure 22), with an average total glance number of 5 with the attentional interface and 6.44 with the interpretational interface (F(1,28) = 6.58, p = .02). A marginally significant finding was observed for mean glance duration (F(1,28) = 3.30, p = .08), with the interpretational interface having a 0.15 s longer mean glance duration (Figure 23 (a)).

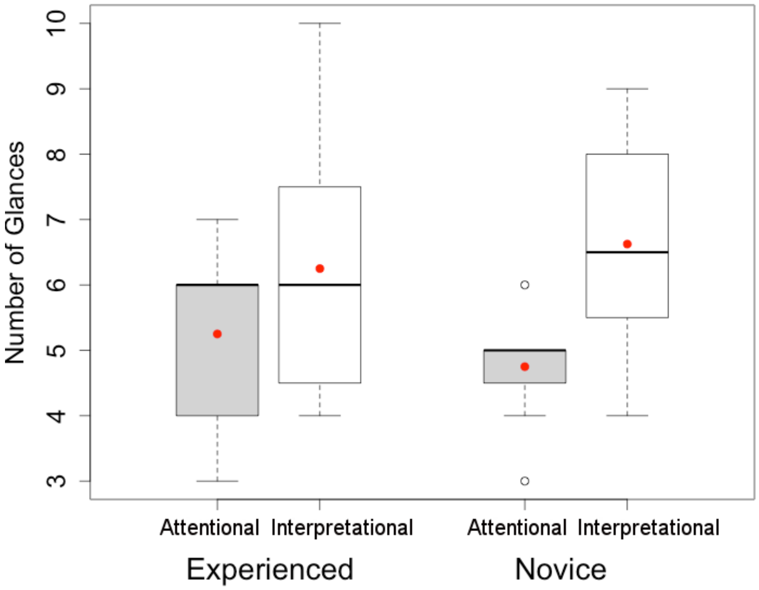
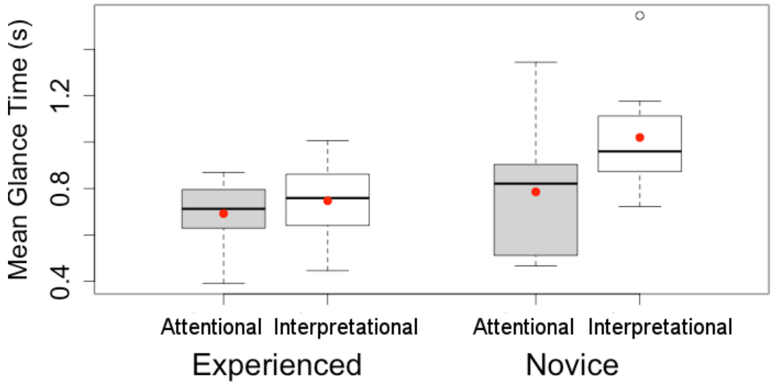
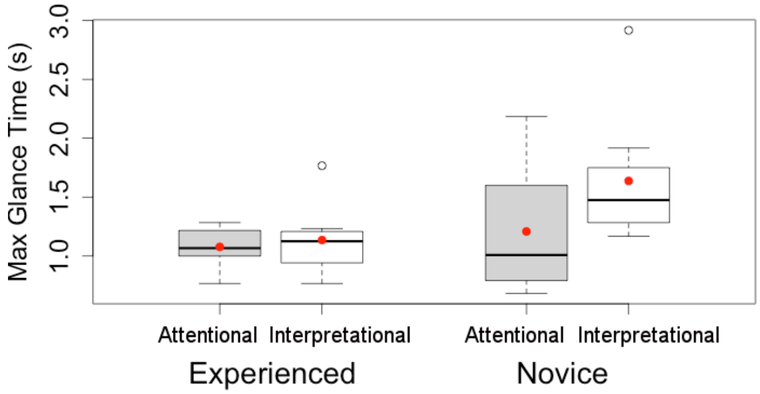


Figure 23: Number of glances towards the display across interface type and experience level in Experiment 2 (in this and the following boxplots we present minimum, first quartile, median, third quartile, and maximum, as well as potential outliers indicated with hollow circles and means with solid circles



(a)



(b)

Figure 24: Mean (a) and maximum (b) glance duration towards the display across interface type and experience level in Experiment 2

There was no interface type – experience interaction for glance metrics; however, differences were observed between novice and experienced drivers. On average, novice drivers had longer mean (difference: 0.18 s, F(1,28) = 5.29, p = .03) and maximum glance durations (difference: 0.32 s, F(1.28) = 4.39, p = .045) towards the display. There was one experienced driver who had one glance longer than 1.6 s (a margin used in previous research, e.g., Bischoff (2007) and Wierwille (1993)), whereas six glances longer than 1.6 s were recorded for novice drivers (4 drivers total), one of which was longer than 2 s. The breakdown of these long glances across the two interfaces was fairly even.

6.5.3 Glances towards Relevant Cues

6.5.3.1 The Influence of Experience and Anticipatory Competence on Glances

All dependent variables were coded manually through video analysis. We used the EyeWorks software to overlay gaze fixations on top of the simulated environment and manually recorded all gazes towards the cues. The timeframe analyzed for each participant was from visibility of the first cue to the event, and number of glances, maximum and mean glance durations were coded according to the ISO definitions (ISO/FDIS, 2013). Video coding of the first two scenarios was entirely done by the author. For the third scenario, an undergraduate and a graduate student assisted with video coding, both to aid with quicker processing of the data and to ensure that the author's interpretation of video data was not biased. Inter-rater reliability was therefore tested on three videos that all three raters had processed. Given the continuous nature of time data, we compared onset times, as well as offset times for each recorded glance at the pre-defined cues using Krippendorff's Alpha in the R statistical software. Ratings of inter-rater reliability were excellent for both onset times (α =1) and offset times (α =.99).

Figure 24 shows results for the pre-intervention block: the three eye-glance measures relative to driver experience are shown in (a), b) and c)), and the same three measures relative to number of pre-event actions in (d), e) and f)). Due to the small number of participants with two and three pre-event actions, we collapsed both categories for all analyses, combining them with participants who had one pre-event action. Hence, the graphs below, as well as the statistical models represent only a binary variable of whether a given participant had or did not have a pre-event action, and did not distinguish participants with more than one pre-event action. The graphical results show a consistent picture of experienced drivers using different glance patterns than novices. They looked at the visual cues for the conflict events a) more often, and with longer b) mean- and c) maximum glance durations. The same tendency is true for participants who exhibited pre-event actions, as opposed to those without: The graphs show d) a higher number of glances, as well as e) longer mean- and f) maximum glance durations.

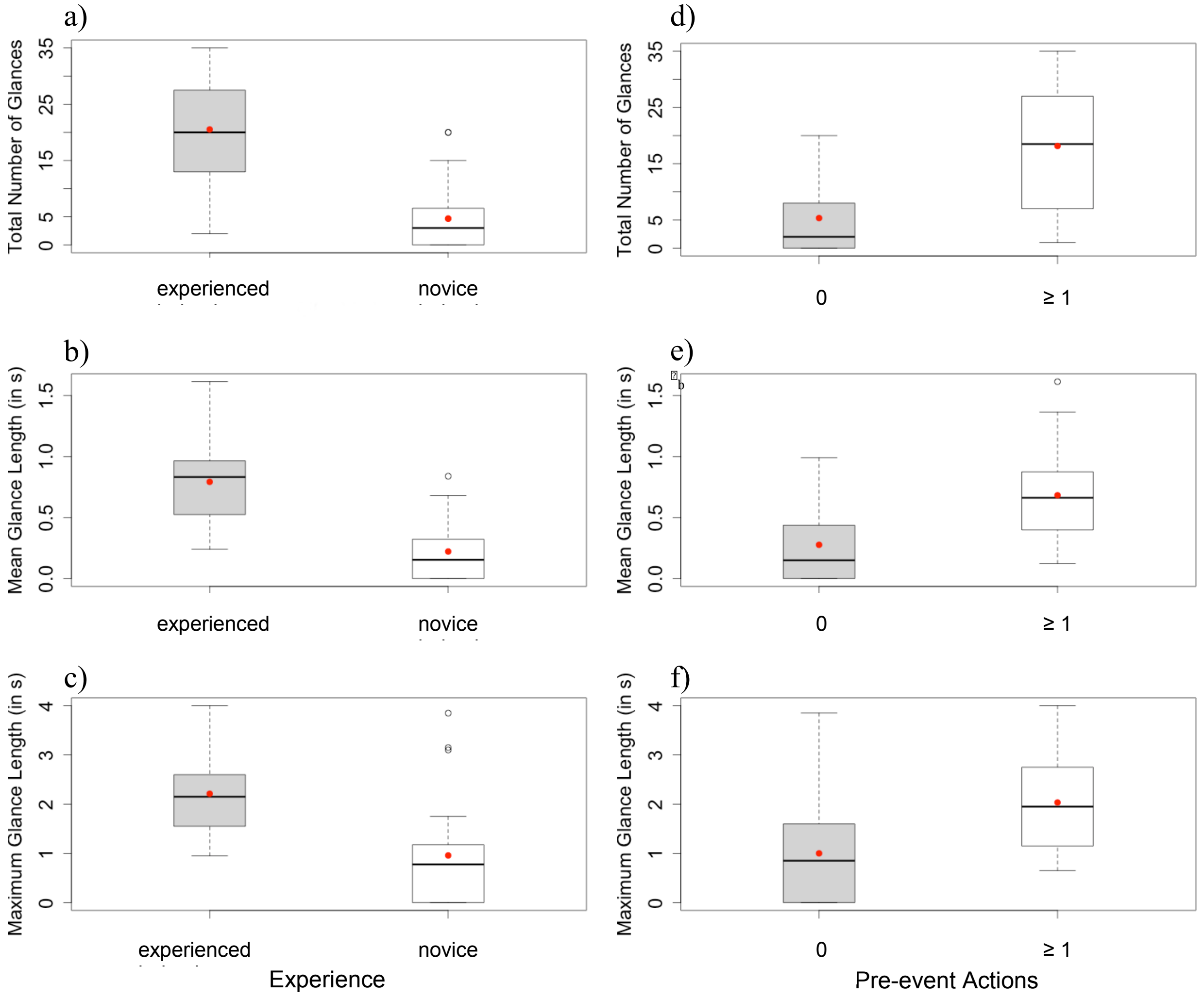


Figure 25: Boxplots of a) total number of glances towards relevant cues, b) mean glance length, and c) maximum glance length across the two experience categories, as well as d) total number of glances, e) mean glance length, and f) maximum glance length across number of pre-event actions in the pre-intervention phase in Experiment 2

We built statistical models in SAS 9.3 with the "mixed" procedure, testing the influence of driver experience and number of pre-event actions on the three glance measures. We refrained from combining both independent variables in one model to avoid issues as a result of multi-colinearity, having established a high influence of experience on number of pre-event actions in this dataset. The influence of experience was significant for all three eye-glance measures. Experience influenced total number of glances (F(1,45) = 42.93, p < .0001), with experienced drivers looking at cues on average 20.52 times, and novice drivers only 4.67 times (t(45) = 6.55, p < .0001). A similar tendency was evident for mean length of glances (F(1,45) = 45.18, p < .0001), with experienced drivers spending on average 0.80s per glance and novices spending only 0.22s per glance on the cues (t(45) = 6.72, p < .0001). Finally, maximum glance length also differed significantly (F(1,45) = 19.77, p < .0001), with experienced drivers having a mean maximum glance length of 2.21s, and novice drivers of 0.96s at the cues (t(45) = 4.45, p < .0001).

The effect of existence of pre-event actions on number of glances was also significant (F(1,45) = 20.76, p < .0001), in that participants with pre-event actions glanced on average 18.15 times, whereas participants without had on average only 5.33 glances (t(45) = 4.56, p < .0001). Likewise, pre-event actions also influenced mean glance time (F(1,45) = 15.03, p = .0003), resulting in an average glance length of 0.68s for participants with, and of only 0.28s for participants without pre-event action (t(45) = 3.88, p = .0003). Maximum glance duration was also significantly influenced by pre-event actions (F(1,45) = 11.62, p = .001), with an average maximum glance length of 2.03s for participants with, as compared to 1.00s for participants without, pre-event action (t(45) = 3.41, p = .001).

To investigate interaction effects, we collapsed both explanatory variables into one combined explanatory variable with four levels: experienced drivers without pre-event actions, experienced drivers with pre-event actions, novice drivers without pre-event actions, and finally novice drivers with pre-event actions. The associated boxplots are displayed in Figure 25. Graphical results again show that experienced drivers appear to glance more frequently and longer towards the cues, as do participants who exhibit pre-event actions. However, it can also be seen that differences between the two novice driver groups are relatively small for all three dependent variables. Experienced drivers with pre-event actions in contrast appear to glance more frequently, and with longer mean and maximum glance durations than expert drivers who did not exhibit pre-event actions.

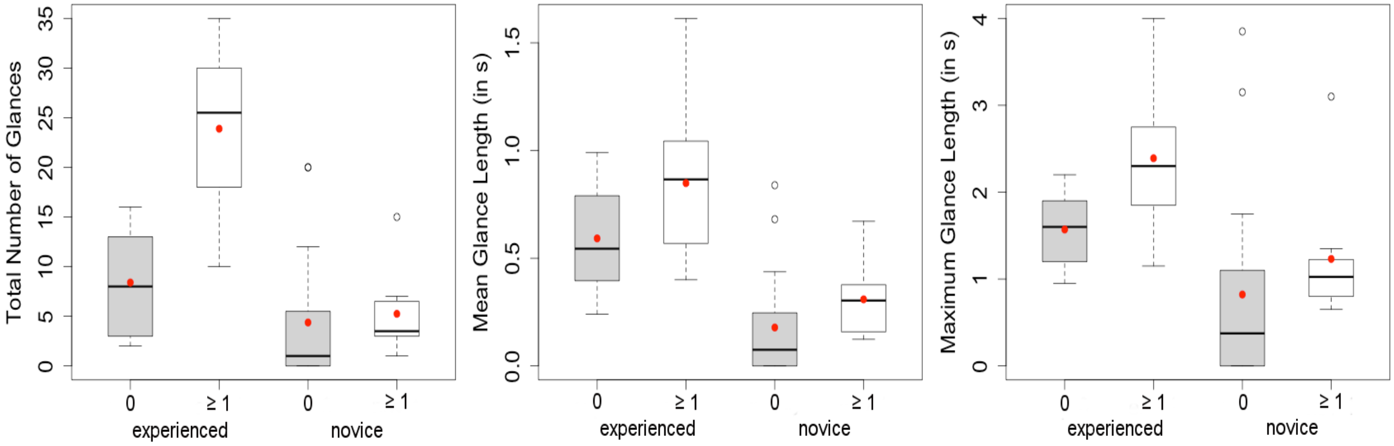


Figure 26: Boxplots of total number of glances towards relevant cues, mean glance length, and maximum glance length across experience x number of pre-event action (data from pre-intervention phase in Experiment 2)

Statistics confirmed the visual impression. For total number of glances, experienced drivers with pre-event actions glanced on average 23.89 times, while experienced drivers without pre-event actions glanced only 8.40 times (t(43) = 4.33, p < .0001). Significant differences were also found between novice drivers with (t(43) = 6.20, p < .0001) and without (t(43) = 8.03, p < .0001) pre-event actions, who glanced 5.25 and 4.38 times, respectively. For mean glance length, experienced drivers with pre-event actions glanced on average for 0.85 sec, which was significantly longer than novice drivers with (t(43) = 4.47, p < .0001) and without pre-event actions (t(43) = 6.87, p < .0001), who glanced for 0.31 and 0.18 sec, respectively. Experienced drivers without pre-event actions glanced on average for 0.59 sec, which was significantly longer than novice drivers without pre-event actions (t(43) = 2.84, p = .007), and marginally longer than novice drivers with pre-event actions (t(43) = 1.75, p = .09). The difference between the two groups of experienced drivers was also marginally significant (t(43) = 1.79, p = .08). Finally, experienced drivers with pre-event actions had a maximum glance length of 2.39 sec on average, which differed marginally from experienced drivers without pre-event actions (t(43) = 1.72, p = .09), who had maximum glance durations of 1.57 sec on average. Maximum glance durations of experienced drivers with pre-event actions also was significantly longer than novice drivers with pre-event actions (t(43) = 2.88, p = .006) and novice drivers without pre-event actions (t(43) = 4.82, p < .0001). Novice drivers had maximum glance durations of 1.23 sec and 0.82 sec, respectively.

Figure 26 shows the boxplots of eye-glance measures in the intervention phase. The figure is organized parallel to Figure 24, but accounts for the presence of the three different interface conditions (no interface, attentional interface, and interpretational interface). We see consistent trends of experienced drivers having a) a higher number of glances towards the cues, as well as b) higher mean glance durations towards the cues, independent of interface condition. For c) maximum glance duration however, no systematic differences are apparent from the boxplots. While experienced drivers without an interface still appear to choose slightly higher maximum glance durations, this does not seem to be the case for participants who received either interface aid. With respect to the existence of pre-event actions, a similar tendency is apparent for all three eye-glance measures: Participants with pre-event actions who did not receive either interface intervention appear to have d) a higher number of glances towards the cues, e) slightly higher mean glance durations, and also f) higher maximum glance durations. However, these differences appear to disappear for the two interface conditions.

Statistical testing on the data from the intervention phase included interface condition (none, attentional and interpretational) as a second independent variable, and supported the visual analysis of the boxplots. For number of glances, experience had a significant impact (F(1,38) = 11.41, p = .002), with experienced drivers glancing on average 19.06 times, while novice drivers had 9.12 glances (t(38) = 3.38, p = .002). Experience also had a significant effect on mean glance length (F(1,38) = 9.11, p = .005), with experienced drivers spending on average 0.52s on a cue, while novice drivers looking for only 0.33s (t(38) = 3.02, p = .005). No statistically significant effect was found for the impact of experience on maximum glance length in the intervention phase. Existence of pre-event actions did not have a significant impact on any of the three glance measures in the intervention phase, and in none of the statistical models did the interface condition, or an interaction effect with the interface condition, result in a statistically significant influence.

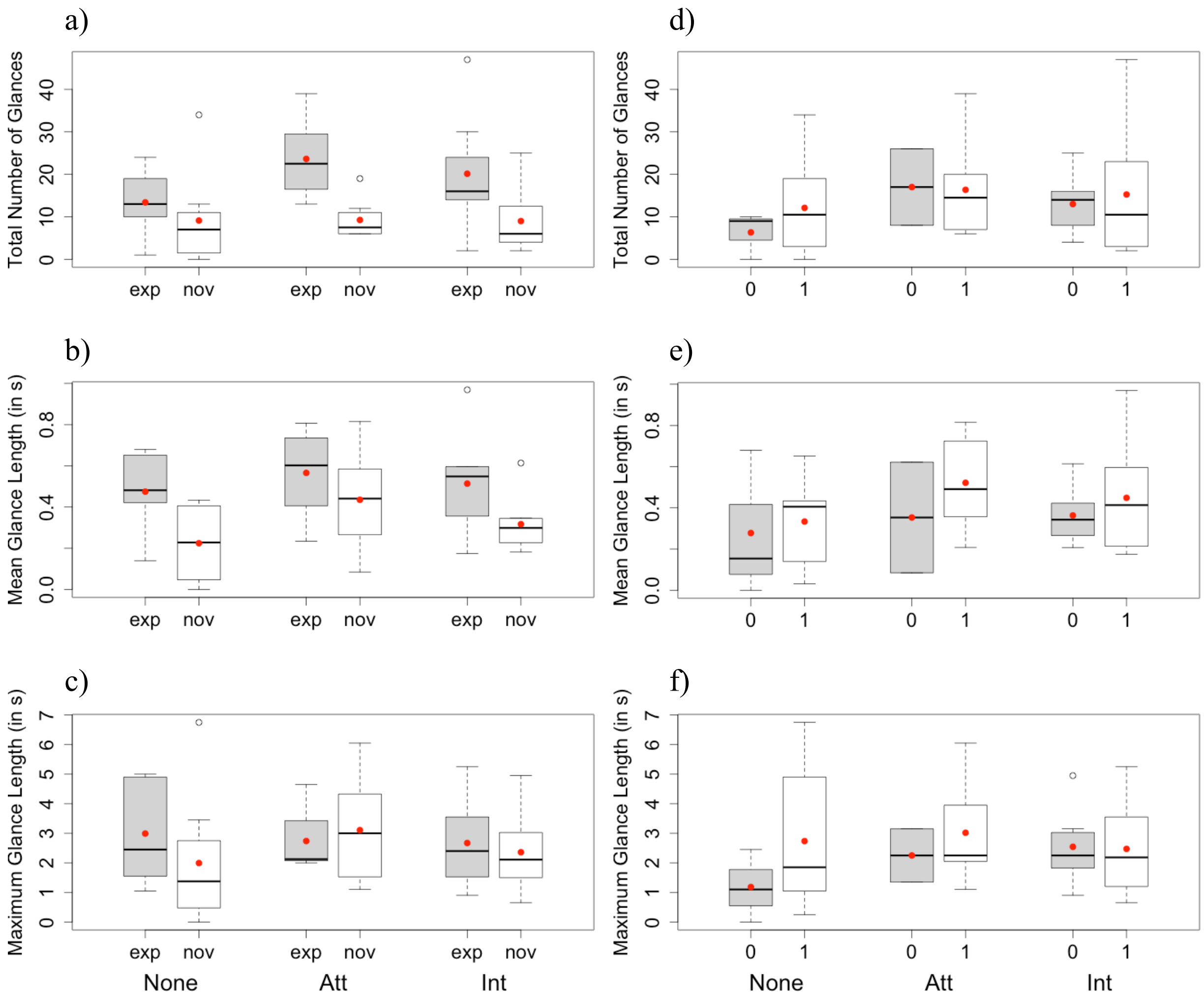


Figure 27: Boxplots of a) total number of glances, b) mean glance length, and c) maximum glance length across the two experience categories, as well as d) total number of glances, e) mean glance length, and f) maximum glance length across number of pre-event actions in the intervention phase, grouped by interface condition in Experiment 2

6.5.3.2 Cue Monitoring for Drivers with Pre-event Actions

An important question yet to be answered is whether anticipatory drivers consistently attend to the visual cues when exhibiting a pre-event response. According to our rationale, anticipation after all relies on the identification of characteristic cues. The correct identification of the situation at hand, and with it the anticipation of its development, should be impossible unless the cues characteristic for the situation are perceived.

Table 6 therefore presents summative data on the participants who exhibited pre-event actions in each scenario in the pre-intervention phase, with n being the number of participants who exhibited pre-event actions. We see that all participants with pre-event actions also looked at the visual cues.

Table 6: Numbers of pre-event responders with glances towards visuals cues and with no glances towards the cues in each scenario for the pre-intervention phase in Experiment 2

Scenario	n	# of drivers with glances at cues	# of drivers without glances at cues
1	14	14	0
2	13	13	0
3	9	9	0

Table 7 presents the same data for the intervention phase, but now also accounting for the participants potentially acting on just the interface aid and still exhibiting a pre-event action. The large majority of drivers who demonstrated pre-event actions also attended to the visual cues indicative of the scenario (11/15, 15/17, and 19/20 for scenarios 1, 2 and 3, respectively). The behaviour of some of the remaining drivers who exhibited pre-event actions without focusing on the visual cues necessary for correct situational assessments and anticipation can be explained by including glances towards the two interfaces. A relatively small percentage of participants (1/15, 2/17, and 1/19, respectively) appear to have acted only in response to the respective interface that was present in their drive. Finally, the last column highlights participants who exhibited pre-event actions, but never looked at the cues or the interface. For scenarios two and three, no participants fell into this category. However, in the first scenario three out of 15 participants acted in a seemingly anticipatory fashion without ever looking at the cues or the interface.

Table 7: Numbers of pre-event responders with glances towards visual cues, towards the anticipatory interface but none of the visual cues, and to neither cue nor interface in each scenario for the intervention phase in Experiment 2

Scenario	n	# of drivers with glances at cues	# of drivers looking only at interface	# of drivers with glances at neither
1	15	11	1	3
2	17	15	2	0
3	20	19	1	0

6.6 Discussion

6.6.1 Efficacy of the Interfaces

One of the main goals of this experiment was to investigate the attentional and interpretational interface types with respect to their efficacy for both, novice and experienced drivers. Without the interfaces, experienced drivers demonstrated superior anticipatory competence by taking more pre-event actions than novice drivers (see Figures 16 and 17), a finding in line with the results from our first experiment (see chapter 4). Novice drivers using the interfaces exhibited more anticipatory actions than those not using them, whereas no significant effects were observed for experienced drivers. The benefits of the interfaces diminished once they were removed.

Contrary to our expectation, experienced drivers did not show significant improvements in performance with either display. We hypothesized that directing the attention of this group of drivers to relevant cues would increase the number of pre-event actions taken. The lack of significant findings here might be due to sample size limitations, or to the fact that experienced drivers were already attending to relevant cues. Notably, however, there were no distractions present in the experimental scenario. In general, driver distraction is a growing concern with the continual introduction of technologies to the vehicle (Regan, Lee, & Young, 2008). Anticipatory interfaces may prove beneficial in mitigating distractions and future research should investigate the effectiveness of these displays under multitasking scenarios.

As expected, novice drivers exhibited an increased number of pre-event actions with the two anticipatory interfaces. In fact, the improvement was high enough for novice drivers' performance to match that of experienced drivers. However, we did hypothesize the interpretational interface to generate additional benefits for the novice drivers. This was based on the assumption that novice drivers would not only lack the competency to focus on important cues, but also have more difficulty interpreting the situation correctly due to a smaller catalog of stereotypical situations. Focusing attention on the relevant cue for an upcoming conflict proved sufficient to improve performance. The lack of significant difference between the two interface types may suggest that novice drivers suffer more from improper attention allocation and less from correct interpretation of the traffic situation. It is also possible that alerting participants to a particular cue in itself may trigger a defensive action by proxy. That is, participants may not necessarily have understood the meaning of the attentional interface, but may have just released the accelerator to be cautious. This hypothesis can be tested in the future by comparing the anticipatory interfaces to a warning-only condition, which does not refer to the relevant anticipatory cues. It can also be tested by employing scenarios in which deceleration would be disadvantageous. Other potential explanations include the sample size limitations as well as how the interfaces were operationalized. In particular, the information included in the attentional interfaces may have, to some extent, helped in interpretation. In order to further investigate the effect of interface information content on driver's interpretation of the traffic situation, query- or probe-based measures can be used in future research.

Although the interfaces proved to be beneficial for novice drivers, the benefits appeared to disappear once the interfaces were removed in the post-intervention phase. It should be stressed however that participants were only exposed to the interface aids three times for several seconds, and that hence potential learning effects were extremely small. More regular use of the interfaces may create more lasting effects, eventually training drivers to recognize traffic situations and anticipate their development more effectively. Future research could conduct longitudinal studies and seek to assess how quickly drivers develop anticipatory competence with and without the interface aids.

6.6.2 Potential for Distraction of Both Interfaces

Another positive finding about the interfaces were the relatively short durations participants chose to look at them. Glances longer than 2 s have been shown to increase crash risks (Dingus et al., 2006). As has already been pointed out in section 6.4.4, a small usability study of the interfaces alone already confirmed that participants were able to correctly interpret the interfaces within two seconds, even without the context of driving in the actual scenario they represented. While the interfaces were only displayed for two seconds in that study, the interfaces in the simulator experiment were shown significantly longer, appearing shortly after the initial cue and lasting until the event had passed[5]. While participants would therefore have been able to choose long, unsafe glances towards the interfaces, only one glance longer than 2 s was recorded. From the perspective of driver distraction, the use of the interfaces proposed in this research is therefore also feasible.

Overall, and independent of experience level, the attentional interface resulted in fewer and shorter glances than the interpretational interface. This is likely due to the smaller amount of information communicated via the attentional interface. Given the lack of measurable benefit of the interpretational interface even for novice drivers (where an added benefit of the interpretational interface had originally been hypothesized), the attentional interface therefore appears the superior choice.

Driver experience also affected glances directed towards the interfaces. Novice drivers had higher mean and maximum glance durations than experienced drivers. Thus, while novice drivers profited far more from the interface intervention, they also took their eyes off the road more frequently and for longer durations. Requiring fewer and shorter glances, the attentional interface is therefore also the better choice specifically with respect to novice drivers: It resulted in the same benefits and caused less distraction.

6.6.3 Cue Perception of Anticipatory Drivers

With respect to the perception of cues in relation to anticipatory competence, we have found evidence that anticipatory drivers do indeed perceive the cues we believe to be indicative of the scenario and its particular conflict. In all instances where participants exhibited pre-event actions in the pre-intervention phase, they also looked at the cues that were indicative of the situation.

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[5] The duration of time the interfaces were visible depended on the participant’s actions, but were always in the magnitude of >10s.

Likewise in scenarios 2 and 3 in the intervention phase, no cases were found in which a participant exhibiting a pre-event action had not looked at any of the cues. However, we observed three cases of participants who exhibited a pre-event action without gazing at a cue in scenario 1. This could be indicative of an error in our method, in particular if there were other cues that indicated the upcoming conflict that we were not aware of. However, we believe this to be unlikely having watched the videos of the three participants in question repeatedly without finding evidence for them acting on any other cue. More likely is that these three participants acted favourably by chance, or for reasons not directly related to the development of the stereotypical traffic scenario. Specifically, participants may have chosen to release the accelerator due to road properties at the time just prior to the conflict, which were characterized by a curve in the road that was visually busy, with trees coming up relatively close to the road. In the other scenarios where no uncued actions were observed, this was not the case. Prior to this, the scenario had been characterized by a long stretch of straight highway without any objects close to the road in the landscape. It is quite possible that some participants did not act on the cues for the conflict with the merging cars, but simply reacted to changes in the road. In any case, it should be noted again that there is the possibility of participants in both experiments to have taken correct pre-event action by coincidence. However, as demonstrated in the counts for pre-event responders without identifiable glances towards cues, these numbers were likely low.

Otherwise, anticipatory drivers did attend to the cues we believe crucial for the anticipatory reasoning in the scenarios. The interfaces can be argued to serve as an artificial, highly salient replacement cue. While they were intended to support the understanding of the physical cues in traffic, some participants were able to act to avoid conflict based solely on these interfaces and without attending to the physical cues in the scenario at all. As we have argued in section 6.6.1, participants may have treated the interfaces as warnings, resulting in default responses such as slowing down even without adequate anticipation of the imminent conflict.

6.6.4 The Role of Glance Patterns for Anticipation

Participants with pre-event actions had significantly different scanning patterns when not being aided in the process of anticipating the traffic situation via either of the two interfaces. However, this tendency did not persist when the interfaces were used – scanning patterns for drivers exhibiting pre-event actions with the use of an interface did not show statistically significant differences to those without pre-event actions. However, the heightened ability of trained drivers to attend to areas of a given traffic scenario that are indicative of potential risks (Pradhan et al., 2005), as well as the theoretical importance of cue-recognition for the concept of anticipation, we propose speak against the possibility of correct anticipation without differences in visual scanning. The lack of difference in scanning patterns for drivers who anticipate correctly when using the interfaces therefore should be seen as another indicator that the interfaces are being treated as warnings that trigger automated, conservative actions (i.e., deceleration), independent of whether or not the traffic situation is correctly interpreted and the upcoming conflict anticipated.

Independent of the somewhat surprising lack of impact of the interface interventions on glance patterns, we recognize the difficulties of using glance patterns to deduce cognitive processes such as anticipation. While we theorize that the perception of cues is a necessary condition for a correct situational assessment and the anticipation of future development, mere cue-recognition as proven by eye-tracking is not a sufficient condition for correct situational assessment. Further, the eye-tracking measures we collected are limited in that they represent only foveal vision. The useful field of view however is as large as 30°**,** and studies into visual conspicuity have shown that targets smaller than 1° in angular size are usually noticed when they are less than 10° off the line of sight (Cole & Hughes, 1984). Drivers may therefore also attend to cues even if eye-glance patterns do not directly fall on those cues. In the scenarios described in our experiment, cues were often very small in size (several cues were below 1° in angular size), so that future research may profit from defining appropriate target areas around such small visual cues, therefore accounting for the potential of cues being actively monitored even when not in focus.

Finally, we have noted the possibility of drivers consciously deciding not to act upon a correctly anticipated scenario – drivers may simply not perceive the likelihood and potential severity of the upcoming conflict as high enough to act. In this case, drivers would not exhibit a pre-event action, but still have shown the eye-glance patterns of an anticipatory driver. In our experiment, these participants would be among those without pre-event action, but obscure an otherwise potentially clear differentiation of eye-glance patterns between anticipatory and non-anticipatory drivers. It should be noted here also that an investigation of the temporal sequence of glances towards cues is not necessarily helpful to separate passive anticipation from reactive post-event respondse: Cues are visible most often in the areas of the roadway that a driver would check in any case, and while anticipatory drivers appear to monitor them more frequently and for longer periods of time, the likelihood is high that non-anticipatory drivers will also glance towards them. While it could be theorized that the sequence in which glances towards cues take place is important, practically a distinction between meaningful and coincidental glances towards cues cannot be made.

Eye-tracking is an important tool for the study of driver behaviour, but due to the issues identified above, we see its use for the discussion of anticipatory competence in particular, and situational assessments of traffic generation in general as supportive in nature. Assessing eye-glances alone would not allow for causal conclusions.

6.6.5 The Impact of Experience on Glance Patterns

Driver experience has a significant effect on driver's gaze patterns. The results from our experiment confirm this in particular with respect to the visual cues that are important for the correct interpretation of the traffic situation at hand. Experienced drivers looked at the cues more often, suggesting a more targeted visual search that is led by the understanding of the importance of specific elements in a traffic scenario. Experienced drivers' glances to those cues on average were also longer than those of novice drivers, and they spent a longer time in total monitoring the cues. These results are in line with the finding that with respect to hazard perception, experienced and trained drivers generally outperform novice, untrained drivers due to differences in visual search and the interpretation of the situation at hand (Garay-Vega & Fisher, 2005; Jackson et al., 2009). They particularly confirm the heightened skill of experienced, older drivers at attending to areas of the traffic scenario that indicate risks (Pradhan et al., 2005) and extend this observation by showing that experienced drivers focus their visual attention specifically on relevant visual cues that are crucial for the understanding of the traffic situation at hand.

Finally, it is noteworthy that especially the combination of experience and anticipatory competence, as reflected in the display of pre-event actions, influenced all three glance measures investigated such that experienced drivers with pre-event actions in particular glanced at the cues in the scenarios more frequently, and with longer mean and maximum glance lengths. Experience alone did not always result in significantly different glance patterns, as is evident in the lack of significant differences in total number of glances and maximum glance length between experienced drivers without pre-event actions and novice drivers.

6.7 Chapter Summary

The second experiment investigated participants' ability to anticipate in the same manner as the first experiment, and anticipation was again identified via the surrogate measure of time of action relative to the events. Having established the feasibility of this approach, and having determined the significant influence of driver experience on anticipation, this experiment focused on (1) investigating the potential of facilitating anticipation through appropriate interfaces, and (2) investigating glance patterns towards relevant cues in a traffic scenario of both anticipatory and non-anticipatory drivers.

The interfaces used were based on the mechanism behind the anticipation of developments in traffic, as explained in the context of the model of anticipation presented in the previous chapter. We designed one attentional interface focused on calibrating attention appropriately, such that relevant cues are highlighted, and one interpretational interface that calibrated attention and also suggested possible meanings of those cues. We had hypothesized that all drivers need to attend to the cues to make a correct assessment of the situation possible. However, we also hypothesized that experienced drivers would require little more than the perception of cues, due to the skill-based, automated process of comparative analysis that compares cues to similar situations from memory. Novice drivers however would not possess this skill, and would therefore need more cognitive processing and conscious interpretation of the meaning of perceived cues. Hence, we expected improvements in anticipatory competence with both interfaces, but hypothesized additional improvements for novices when switching from the attentional interface to the interpretational one that would not obtain for experienced drivers.

Results showed both interfaces to improve performance for novice drivers. However, the interfaces did not result in statistically significant improvements for experienced drivers. More importantly, novices showed similar improvements in anticipatory competence with either interface. We have discussed that this is most likely due to the interfaces acting as a general warning, and that the content of the interface aids may not have influence drivers' reactions. It is therefore desirable to investigate interface alternatives that merely warn of an unspecified, impending danger without providing context-sensitive information about the specific situation. In this way, the importance of context-sensitive information for appropriate action could be determined. Further, longitudinal studies investigating long-term learning effects and adaption to the interfaces should be conducted.

Gaze patterns towards the interfaces showed that fewer and shorter glances were used with the attentional interface. Therefore, while both interfaces had similar effects with respect to improving the number of pre-event actions, the attentional interface can be argued to be the superior choice due to posing a lower potential for distraction. Especially for novice drivers, who generally chose longer glances towards the interfaces, this may be an important factor.

Finally, gaze patterns towards the cues were also investigated. Results confirmed existing findings that experienced drivers have superior glance patterns by showing that experienced drivers looked at the visual cues more frequently and longer. This difference was also evident for participants exhibiting pre-event actions: Relative to participants without pre-event actions, more frequent and longer glances towards relevant cues were recorded in the pre-intervention condition. However, when interfaces were used, this difference disappeared: The interface aids in many cases appeared to trigger appropriate, timely action even without participants looking at the cues in detail.

Chapter 7
Summary and Conclusions

7.1 Summary

7.1.1 Anticipation: Theoretical Background

A literature review on anticipatory competencies in driving showed that applications were largely limited to situations requiring deceleration, and specifically to the study of interface aids to support the early anticipation of deceleration. These interfaces have been shown to improve safety (Laquai et al., 2011; Popiv et al., 2010) and eco-driving (Baer et al., 2011; Barkenbus, 2010; Rommerskirchen et al., 2013; Thisjen et al., 2014). We also briefly described the relation between response preparation and anticipation in driving, and further described how hazard perception appears to rely on anticipation.

In more theoretical works on driver behaviour, anticipation has been characterized as an important cognitive function rooted in the recognition of familiar stimuli (Treat et al., 1977), that allows for efficient rule- and skill-based behaviour (Onken, 1993). As part of Fuller's threat-avoidance model (1984), anticipation is proposed as a strategy to avoid potential conflicts in the roadway, thereby again arguing the benefit for safety from a more theoretical perspective.

Based on these isolated references to anticipation in driving, we proposed key characteristics for anticipation in sections 2.2.2, describing (1) anticipation as the manifestation of a high level cognitive competence that (2) relies on the identification of stereotypical situations (3) on a tactical level and (4) based on relevant visual cues. These requirements led directly to our definition of anticipatory driving competence.

Having highlighted the importance of stereotypical situations for anticipation, we then briefly discussed different elements in the traffic environment that can be anticipated. We suggested three general categories of anticipation focusing on the anticipation of changes in (1) the natural environment, (2) the road environment, and (3) the traffic situation as a result of other traffic participants' behaviour. With respect to this dissertation, these distinctions served to further specify the research focus on the third category, but they also can be seen as the basis for a taxonomy of foreseeable situations. Further, we have described how task analysis can be used to systematically analyze the logical development of a given stereotypical situation from the driver's perspective. Using the Decision Ladder as the tool of choice, the left branch represents the required analysis of the situation at hand and its projected development, while the right hand branch represents the subjective decision making of the driver, including the desired target states and appropriate actions to reach them. Finally, we have described how the Skills, Rules, Knowledge Taxonomy can be superimposed over Decision Ladders for the stereotypical situations. Knowledge-based behaviour would be situated at the top of the ladder, and given the high cognitive resources involved is not desirable as a strategy for anticipation. Rule- and skill-based behaviour however can be used to create shortcuts from various stages of the left side of the Decision Ladder, directly towards target states or even appropriate procedures on the right side. We have argued that these shortcuts represent skilled driver behaviour, and that the development of aids for anticipation should enable similar shortcuts. These theoretical considerations on anticipatory driving competency form a systematic basis for future research into anticipatory competence in driving.

7.1.2 Measuring Anticipation: Pre-event Actions

Chapter 4 summarized the first simulator experiment. The two main research questions were (1) how anticipatory driving competence as a cognitive competence can be measured, and (2) whether driver experience had a similarly beneficial influence on the ability to anticipate, as had been reported in other investigations of driver behaviour.

With respect to the first research question, we did not measure anticipation directly, but rather the resulting, measurable actions of anticipation. The strategy to do so goes back to the stereotypical scenarios as the foundational basis for the entire concept of anticipation. Within each scenario, we defined visual cues that predict the development of the scenario, up to the resulting event. This event served as the reference for any action taken by a given driver. If appropriate action was taken prior to the event, we considered it a pre-event action; while action after an event was labeled a post-event action. This temporal classification relative to the event acted as a surrogate measure for anticipation (pre-event action), and reaction (post-event action), respectively, and proved to be a feasible approach.

However, pre-event and post-event actions do not map to anticipation and reaction unambiguously. In particular, drivers exhibiting post-event actions may still have correctly interpreted the traffic situation and anticipated its development, but consciously chose not to act. Since we cannot directly measure the cognitive process of anticipation, these cases of passive anticipation cannot be reliably identified. However, the study of glance patterns in the second experiment revealed a small fraction of participants who appeared to monitor the development of certain cues consciously without choosing to act. In an experiment with a larger sample size, subdividing post-event groups based on their reaction times may prove helpful. Participants who do indeed correctly anticipate but choose consciously not to act would be expected to show quicker reaction times than those who are truly surprised by the developments, since expectancy appears to be the biggest influence on perception reaction time (Green, 2010). It should also be noted that the scenarios used in our experiments were consciously unconstrained. While crashes would happen in these scenarios if participants did not act at all, no imminent crash risk was purposefully created. For a study of passive anticipation, scenarios may have to be constrained more strictly, creating imminent crash risks in which the participants would be forced to act.

7.1.3 Anticipation and the Role of Driver Experience

With respect to the influence of experience, the findings in both experiments clearly showed superior performance of experienced drivers. The first experiment showed that experienced drivers exhibited more pre-event actions, thereby confirming our hypothesis. It furthermore presented evidence that both number of years of driver experience and annual mileage driven play a role in anticipatory competence.

The second experiment confirmed the superior performance of experienced drivers, and also supported this difference in performance by showing significant differences in gaze patterns. Experienced drivers consistently looked at the visual cues more often, and for longer mean- and maximum glance durations. These findings are consistent with existing literature, which has found experience to have a positive impact on drivers’ ability to identify risks in the roadway (Jackson et al., 2009), and has also found several key differences with respect to gaze patterns of experienced and novice drivers (Fisher et al., 2007).

We argued that this difference in performance between novice and experienced drivers was attributable to the degree of automaticity in assessing the situation. Novice drivers will be more likely to require step-by-step processing of the entire decision ladder, while experienced drivers are able to use shortcuts. In this sense, experienced drivers share characteristics with skilled operators and can use skill- and rule-based behaviour to leap across phases in the decision ladder. Participants exhibiting pre-event actions in the first experiment frequently were able to remember cues in the post-experiment reviews. They also were able to connect these cues temporally and causally to present detailed situational assessments, and frequently made reference to comparable situations they had experienced on the road. In conclusion, driver experience should be seen as an efficient shortcut to connect perceived cues in the roadway to similar instances in memory, which then allows for the effective anticipation of the traffic development.

7.1.4 Operationalizing Anticipation as an Act of Information Processing

Having observed how skilled drivers anticipate the development of traffic and having interviewed them post-experiment to investigate their processing of the situations, chapter 5 described an information processing model of anticipation. This anticipatory process described in this model (Figure 12) begins with the perception of a given cue, describing the way it is taken into our sensory apparatus through filters of attention and into our conscience. Once consciously perceived, the cognitive processing can start, with the goal of correctly interpreting the traffic situation based on those cues. Here we hypothesized two distinct types of analysis to aid in the interpretation: a high level, inductive analysis that aims at logically interpreting the cues, and a comparative analysis that aims at comparing the specific combination of cues to similar situations in memory, trying to find a close match. Anticipation was then understood as a projection of the situation at hand, guided by both types of analysis. Once an anticipated situation is established, the final step is the determination of appropriate action based on the desired target state.

These two distinct mechanisms for interpretation are crucial because they offer an explanation for the performance difference between novice and experienced drivers: While experienced drivers are very likely to have developed a detailed and extensive catalogue of memorized reference situations, novice drivers will largely lack such a memorized catalogue. As a consequence, experienced drivers can rely more heavily on comparative analysis. With respect to the decision ladders analyzing the driver’s task in a given scenario, comparative analysis would be the mechanism allowing skill-based shortcuts across the ladder. Meanwhile, novice drivers have to rely to a greater extent on inductive analysis and the cognitively effortful, logical processing of the situation at hand.

There were two important take-away messages from the model, namely:

(1) The two most crucial steps in the operationalization of anticipation are (a) ensuring that relevant cues are consciously perceived, and that (b) correct cognitive processing takes place based on the cues perceived.

(2) Within this cognitive processing then, two distinct mechanisms aid drivers. Experienced drivers are hypothesized to rely more heavily on comparative analysis, while inductive analysis plays a more important role for novice drivers.

Consequently, both points guided the development of the interfaces significantly: The attentional interface was designed with the experienced driver in mind. It highlights the most important cue, and thereby tries to ensure appropriate attention – comparative analysis can now take place. The interpretational interface however was geared more towards novices. It tries to calibrate attention to relevant cues as well, but also suggests potential consequences of those cues. Hence, it also aids with inductive analysis.

7.1.5 Facilitating Anticipation

The second experiment sought to aid drivers in anticipating traffic events. Attentional and intepretational interfaces were designed for each of three scenarios tested in a driving simulator study. Results showed that both interfaces improved the number of pre-event actions taken for novice drivers. For experienced drivers, baseline performance was already relatively high, and improvements were small and not statistically significant. Surprisingly, we found no evidence that novice drivers profited more from the interpretational interface, as we had originally hypothesized prior to the experiment.

Eye-tracking was used to track gaze patterns towards the interfaces, and showed that novice drivers had longer mean- and maximum glance durations towards the interfaces. Differences were also evident with respect to the type of interface: Participants glanced more frequently towards the interpretational interface, and mean glance duration was also higher when participants were looking at the interpretational interface. Therefore, while both interfaces fared equally well with respect to facilitating anticipation, glance characteristics towards the interfaces showed the attentional interface to require less visual attention, and hence was less distracting.

The attentional interface therefore is the superior choice, especially for novice drivers. Having been identified as a group over-represented in crash statistics at least in part due to a lack of the skill of interpreting situations quickly, they profited from the interfaces to the point that their performance was equal to that of experienced drivers. Since they also required longer glances towards the interface, minimizing required glance time while maintaining the positive impact on anticipation is crucial.

Finally, we also investigated glance patterns towards the visual cues with the second experiment. Research into gaze patterns on the road already has established that experienced drivers use superior glance patterns (see chapter 6.3.2), and that in particular with respect to hazard perception, experienced drivers are more attentive to areas that indicate risks in the roadway (Fisher et al., 2007). This appeared to be consistent with the information we had gathered from cognitive walkthroughs in the first experiment. Experienced drivers seemed to refer to visual cues that were relevant for the development of the traffic situation more consistently. Hence, the two main findings with respect to the recorded gaze measures in the second experiment were expected: Experienced drivers glanced towards visual cues more frequently and for longer durations than did novice drivers. This tendency held for both the pre-intervention block without, and the intervention block with, the interface aids. For the pre-intervention block, the ability to anticipate also influenced gaze patterns: Participants who exhibited pre-event actions glanced towards the cues more frequently and longer. This tendency however did not hold true for the intervention block: Here, no statistically significant difference was found between anticipatory and non-anticipatory participants. This finding was due in large to the interfaces offering sufficient cue to trigger appropriate anticipatory action.

7.2 Conclusions

7.2.1 Contributions

Anticipation has been mentioned in driving research frequently. Both interface applications as well as theoretical concepts on driver behaviour refer to anticipation as an important concept, with some research going so far as to describe driving as a task that is largely automated and governed by anticipatory mechanisms (Tanida & Poeppel, 2006). Yet, anticipation as a concept in driving has not yet been studied systematically. This dissertation addresses this gap and provides a basis for a more systematic study of anticipation. To this end, we have defined anticipation as a manifestation of cognitive competence that focuses on the recognition of stereotypical situations. It can be described from an information-processing perspective and relies on the perception of relevant cues that allow a driver to identify a given situation and project its development into the future. Anticipation is not a tangible behaviour with a pre-determined outcome, but rather should be viewed as a high-level competence that increases the range of possible actions for a driver by allowing earlier adaption to a given situation. The result of successful anticipation is therefore dependent largely on the individual driver's goals – it could be used to drive more safely, more fuel-efficiently, or more aggressively.

The dissertation has also investigated potential ways of identifying anticipation. Given the cognitive nature of anticipation, providing an unambiguous measure currently appears unrealistic. However, we have described a way to identify the actions resulting from successful anticipation. By clearly defining an event within a given driving scenario, meaningful actions drivers take within the scenario can be temporally categorized as happening prior to, or after, this event. Our data have shown that post-event action often is indicative of reactionary driving, but we have also seen cases of participants acting post-event, who showed clear indication of successful cognitive anticipation (especially when analyzing gaze patterns). In this sense, no final determination can be made as to whether post-event responders were truly unaware of the traffic development, or whether they consciously chose to not act. Pre-event responses however appear a largely unambiguous indicator for anticipation – according to the eye-tracking data in the second experiment, pre-event actions are highly dependent on the conscious perception of relevant cues.

Further, we have presented evidence that driver experience plays a crucial role for anticipatory competence, and also that not just years of licensure, but also the amount of driving usually undertaken define this experience effect. While the measurement of this performance difference in the original experiment was rooted in simulator performance measures only, the eye-tracking used in the second experiment confirmed the difference by identifying that drivers identified as anticipatory also had superior glance patterns towards the cues. Since experienced drivers also showed these superior glance patterns, these findings connect well with already existing research into the benefits of driver experience (Crundall & Underwood, 1998; Fisher et al., 2007; Garay-Vega & Fisher, 2005; Jackson et al., 2009).

We proposed a model that operationalizes anticipation akin to information processing, and have within this model described two cognitive mechanisms that explain the performance difference between novice and experienced drivers. Finally we developed two interface interventions based on this model to aid drivers in the process of anticipation, one of which focused on ensuring attention allocation to cues only, and one which also sought to aid in the interpretation of cues. Investigating both interfaces in a simulator experiment showed that an interface that effectively highlights relevant cues is an effective way of facilitating the desired pre-event actions. We have therefore also contributed and tested effective interface solutions.

7.2.2 Limitations and Future Research

We have already discussed limitations where applicable, but want to summarize them in this final chapter. With respect to the theory of anticipation proposed in this dissertation, limitations were in large conscious decisions. While it may very well be feasible to extend the research presented here to longer temporal horizons, we have chosen to investigate anticipatory competence only on a tactical level. We have furthermore limited our focus to anticipation of upcoming actions of other traffic participants. Future research could investigate the anticipation of other types of traffic elements, could investigate anticipation on different time horizons, and could also investigate anticipatory competence of operators in domains other than driving.

We have also discussed limitations with respect to the measurement of anticipation, it being a cognitive competence that cannot currently be measured directly. The surrogate measure of timing of meaningful action relative to a defined event is sufficient for identifying instances of anticipation that lead to measurable actions prior to the event. However, it cannot clearly identify when pre-event actions happen by coincidence, nor can it account for drivers who cognitively anticipate correctly, but decide consciously to not act. Future research could investigate potential differences in reaction time to distinguish truly reactive drivers from passive anticipation (that is, correct anticipation without observable pre-event action). Passive anticipation should have a similar effect as response priming, such that quicker reaction times should be observed. Query-based methods in which the simulation is interrupted prior to an event could offer an alternative way of identifying anticipation.

Another clear limitation is apparent with respect to the proposed model of anticipation. While the interfaces tested in the second experiment succeeded in facilitating anticipation, the expected difference in usefulness between the two interface types, particularly for novice drivers, was not observed. It is unclear whether this indicates a fault with the model for anticipation and how it applies to novice and experienced drivers, or whether the interfaces acted as warnings that triggered automatic, defensive actions in the participants. However, the development of glance patterns in the second experiment from the pre-intervention phase to the intervention phase strengthens the argument for the latter. It appears that enough participants acted appropriately on the interface alone, and without checking the actual cues on the road in detail, that the difference from the unsupported pre-intervention phase disappeared. It is hence likely that some participants did not actually anticipate, but merely acted on the perceived warning from the interface. In this case, there would obviously not be the hypothesized effect of an added benefit for novice drivers with the interpretational interface.

Future research should seek to resolve this ambiguity. Again, query-based methods could be used to test participant’s understanding of the given traffic situation after the interface has been shown, but prior to the actual event. Querying would also address the potential biases introduced due to the top-down view used in the cognitive walkthroughs of experiment one. An experiment much like the second simulator study described in this dissertation could be undertaken, but with an added interface condition that does not communicate context-sensitive information to the participants. If participants still showed appropriate pre-event actions with an interface that does not refer to the cues in the situation or explain them, but merely displays a general warning message, then providing context-independent warnings may be sufficient to trigger appropriate action.

Finally, we have not investigated the transferability of this simulator research to on-road contexts. While many simulator performance measures, such as braking responses, reaction times, and vehicle position show some real-world validity, requirements for absolute validity cannot be met, and in particular driver skill appears to be inflated in simulator studies (i.e., results for poor drivers may be less valid) (Mullen, Charlton, Devlin, & Bedard, 2011). Perception of speed in particular appeared relatively unrealistic in the driving simulator used, in that multiple participants perceived a slower speed than indicated on the instruments. Further, our scenarios came with specific instructions: Participants were asked to follow lead vehicles and not overtake, and were corrected when their speed deviated from the speed limit by more than 10 mph. Hence, participants' driving behaviour may not have been natural. Also, as a result of simulator limitations, we were not able to investigate the behaviour of several drivers concurrently; even though the vehicles around the participant were acting relative to the participant's behaviour, they were ultimately programmed by us. Future research should investigate the more realistic case of several traffic participants anticipating each other's actions.

Neither have we investigated the long-term development of anticipatory competence. We currently only know that experienced drivers outperform novices in terms of anticipatory competence, but do not know how much experience is necessary, or how severe individual differences are. Especially with respect to safety applications relying on anticipatory competence, this knowledge would however be necessary. In particular, it appears likely that the continued use of interface interventions like those proposed here would eventually result in a lasting learning effect.

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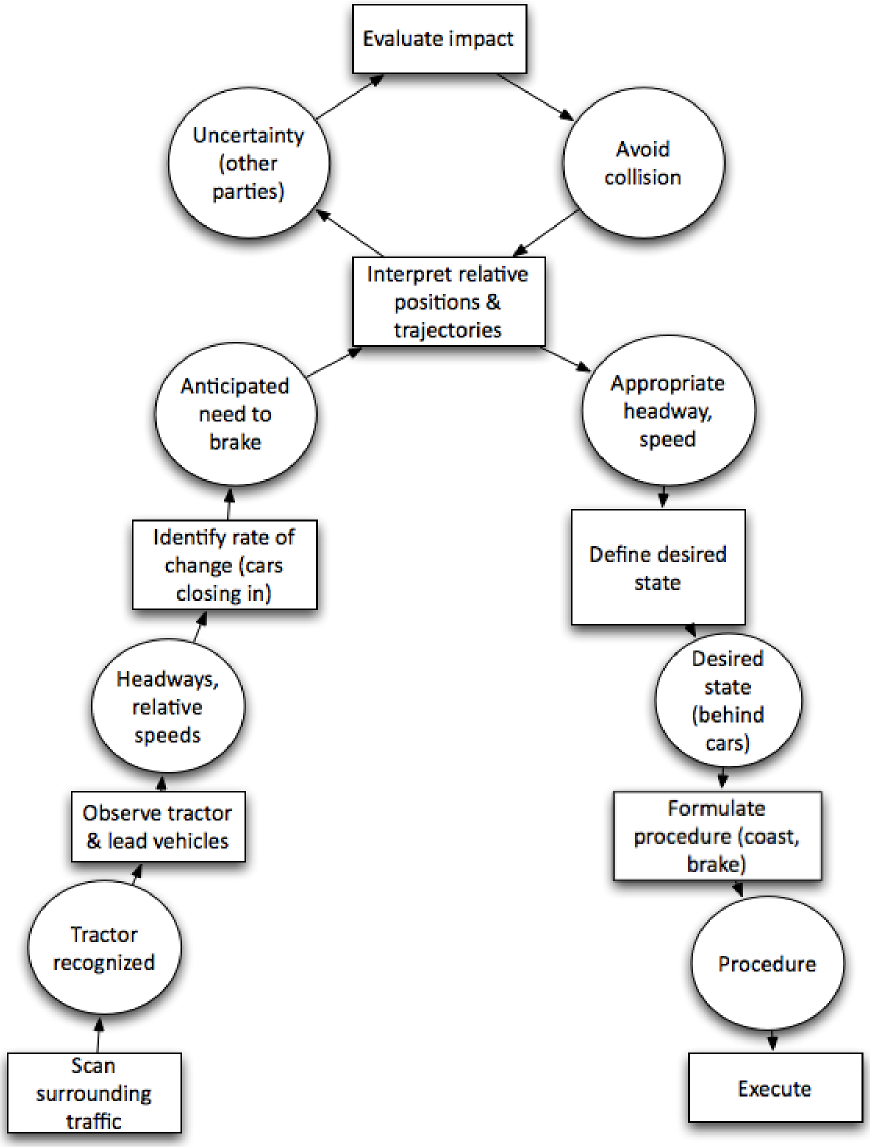
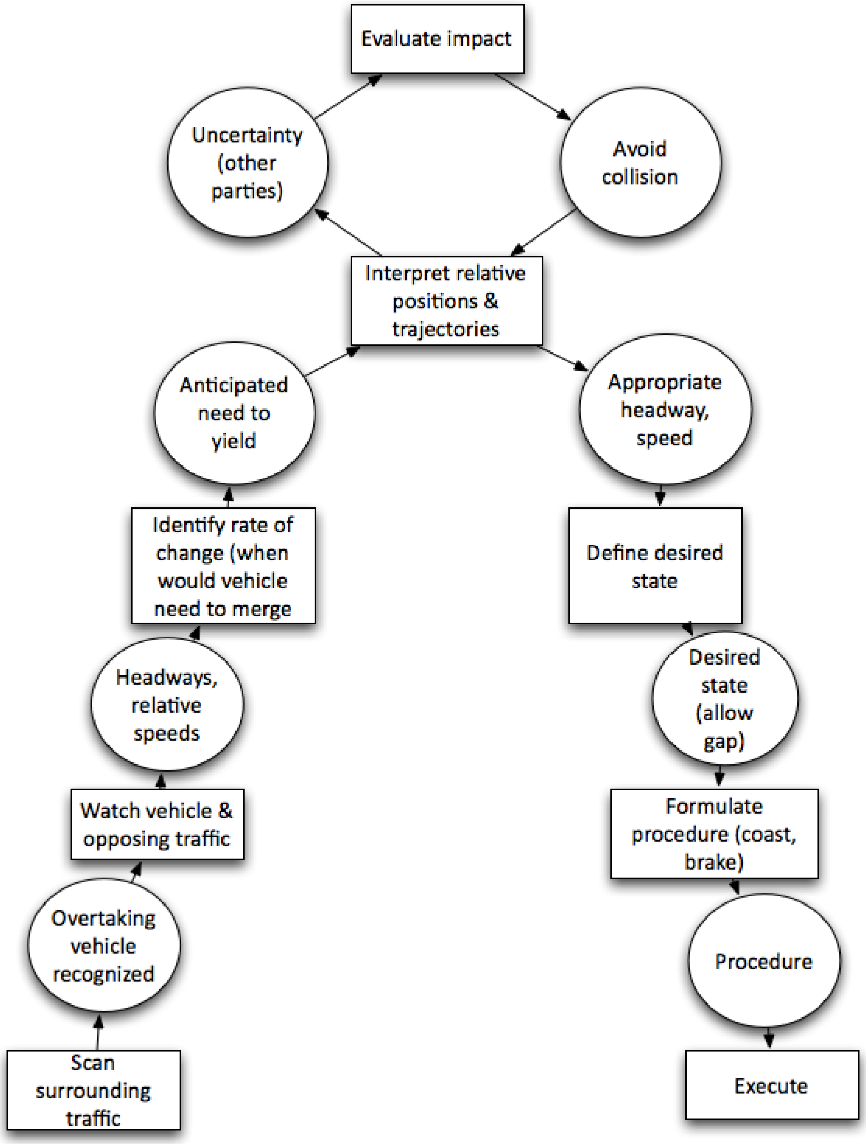
Appendices

A) Decision Ladders for Scenarios

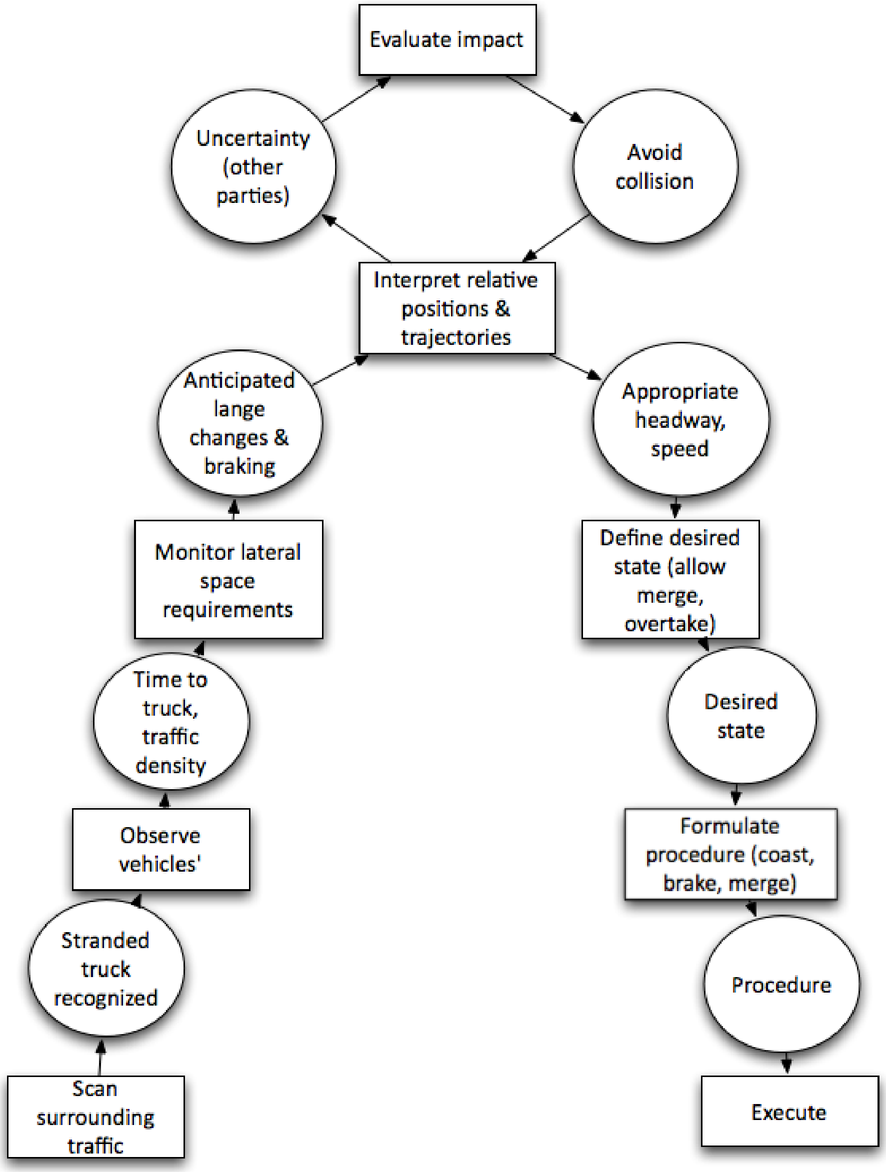
As explained in Section 2.2.5, decision ladders can be used to model the steps necessary to anticipate in a given scenario. They were also useful as part of the development of simulator scenarios, helping define specific alerts, sets of observations, and identification of system state for each scenario. Hence, they ensured a systematic, comparable development of scenarios. The ladders for each of the five scenarios are attached below.



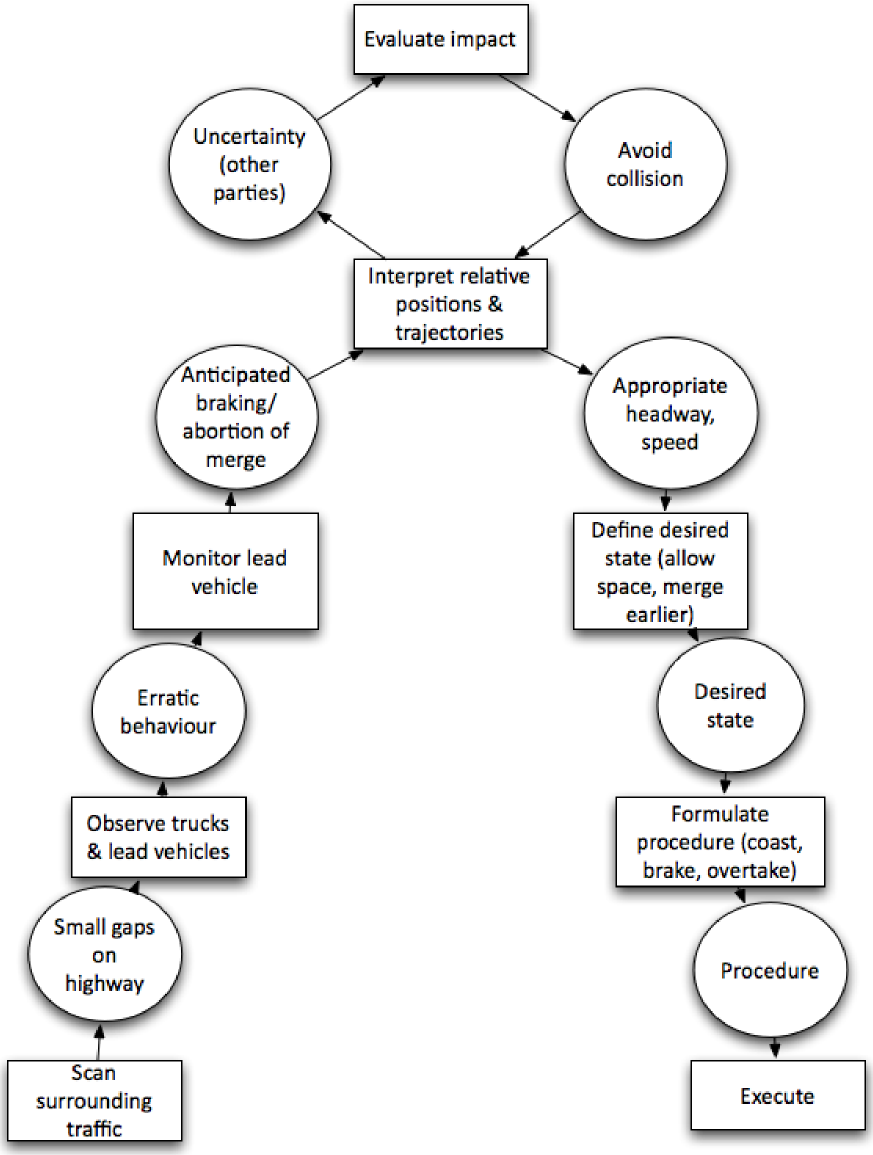
Scenario 1: Chain-braking due to a slow tractor. The left side of the ladder describes the perception of the slow tractor, which consequently should lead to the monitoring of relative speeds, and the conclusion that vehicles will be closing in and need to brake or overtake to avoid collision. From this assessment of system state, the need to brake can be anticipated. Shunts are possible especially from the recognition of the tractor into adequate response-procedures, such as coasting.



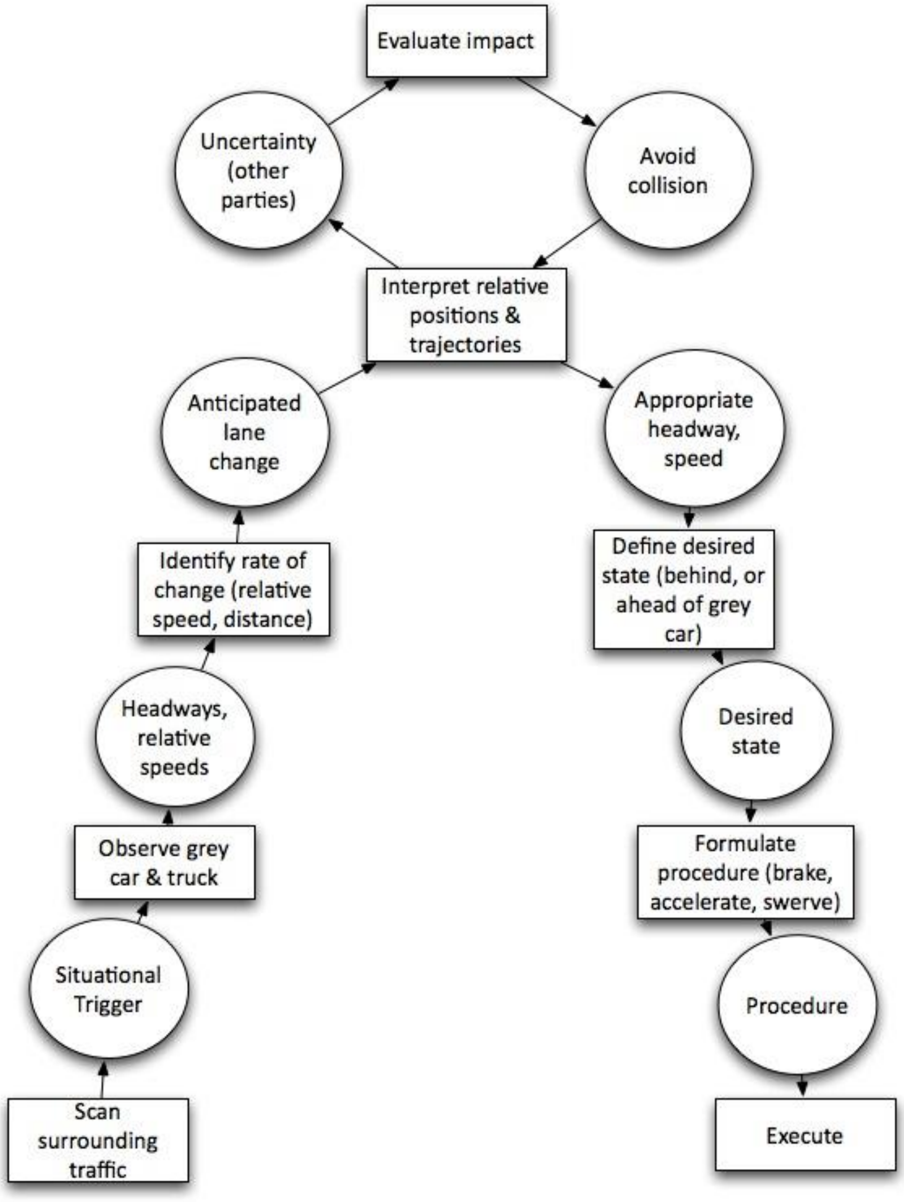
Scenario 2: Vehicle behind cutting in-front. For successful anticipation, a driver needs to recognize that he is being overtaken by another vehicle. Again, for an experienced driver a shunt into adequate responses, such as coasting or braking, may already take place at this point. Less experienced drivers would need to continuously monitor the vehicle and assess its space to oncoming traffic, as well as the possible spaces for it to merge back into the right lane.



Scenario 3: Stranded truck on highway shoulder: Correct anticipation in this scenario depends in large on the initial cue of the stranded truck. Following observations of the cars in front of the driver, the likelihood of vehicles merging into the left lane, and therefore slowing down traffic can be anticipated. Again, an experienced driver is likely to expect this behaviour, merging and coasting automatically in response to the stranded truck already.



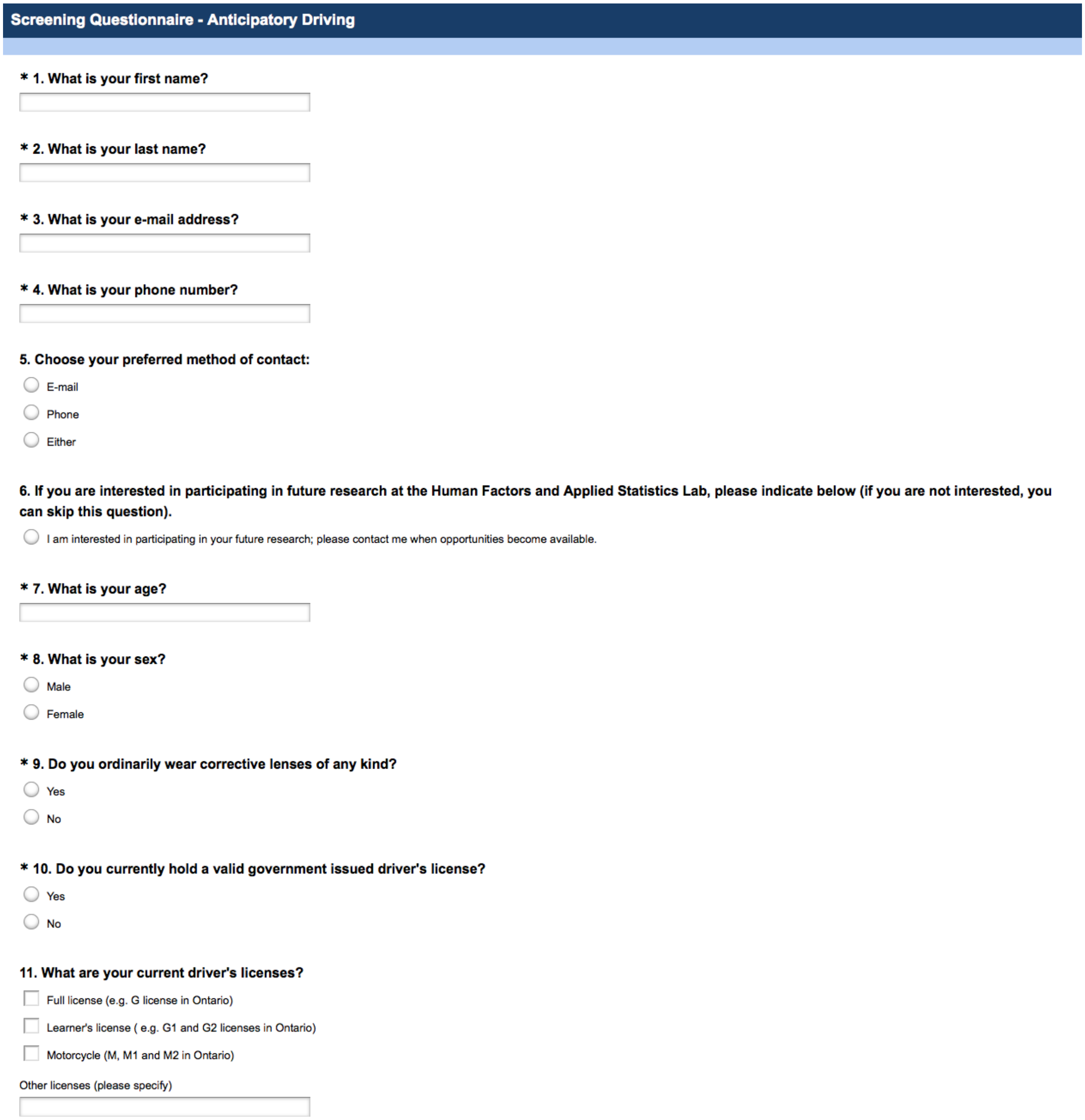
Scenario 4: Merging onto a highway: While the erratic behaviour of the lead vehicle can be noticed earlier in time, the first indicator of a tangible conflict is the observation of the chain of trucks in the right lane of the highway that the lead vehicle is intending to merge onto, and the resulting small gaps between those trucks. Again, an experienced driver may already anticipate the potential of difficulties to merge from this cue alone, and in response stay further back, or quickly merge even before the lead vehicle did so. Further observation of the lead vehicle and its erratic behaviour would provide further information to interpret the traffic situation, such that the possibility of it decelerating can be anticipated.



Scenario 5: Slow moving traffic on the highway: This scenario has been discussed as an example within the dissertation (Figure 2). Shunts are likely especially once the decreasing headway distance between the truck and blue car has been identified.

B) Questionnaires

1) Screening Questionnaire, Experiment 1



Screening Questionnaire - Anticipatory Driving

*** 1. What is your first name?**

*** 2. What is your last name?**

*** 3. What is your e-mail address?**

*** 4. What is your phone number?**

5. Choose your preferred method of contact:

○ E-mail
○ Phone
○ Either

6. If you are interested in participating in future research at the Human Factors and Applied Statistics Lab, please indicate below (if you are not interested, you can skip this question).

○ I am interested in participating in your future research; please contact me when opportunities become available.

*** 7. What is your age?**

*** 8. What is your sex?**

○ Male
○ Female

*** 9. Do you ordinarily wear corrective lenses of any kind?**

○ Yes
○ No

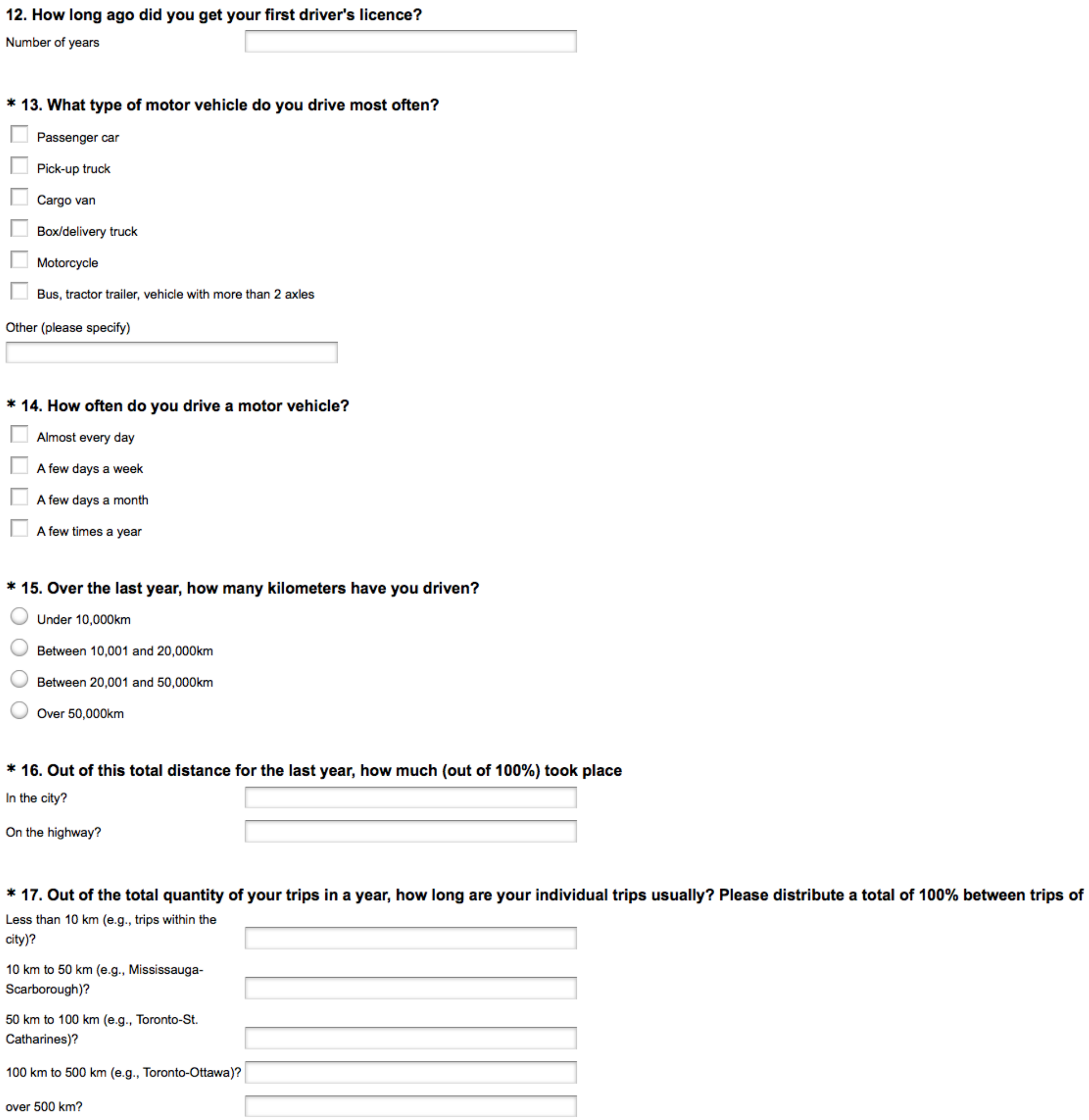
*** 10. Do you currently hold a valid government issued driver's license?**

○ Yes
○ No

11. What are your current driver's licenses?

☐ Full license (e.g. G license in Ontario)
☐ Learner's license (e.g. G1 and G2 licenses in Ontario)
☐ Motorcycle (M, M1 and M2 in Ontario)

Other licenses (please specify)



12. How long ago did you get your first driver's licence?

Number of years

*** 13. What type of motor vehicle do you drive most often?**

☐ Passenger car
☐ Pick-up truck
☐ Cargo van
☐ Box/delivery truck
☐ Motorcycle
☐ Bus, tractor trailer, vehicle with more than 2 axles

Other (please specify)

*** 14. How often do you drive a motor vehicle?**

☐ Almost every day
☐ A few days a week
☐ A few days a month
☐ A few times a year

*** 15. Over the last year, how many kilometers have you driven?**

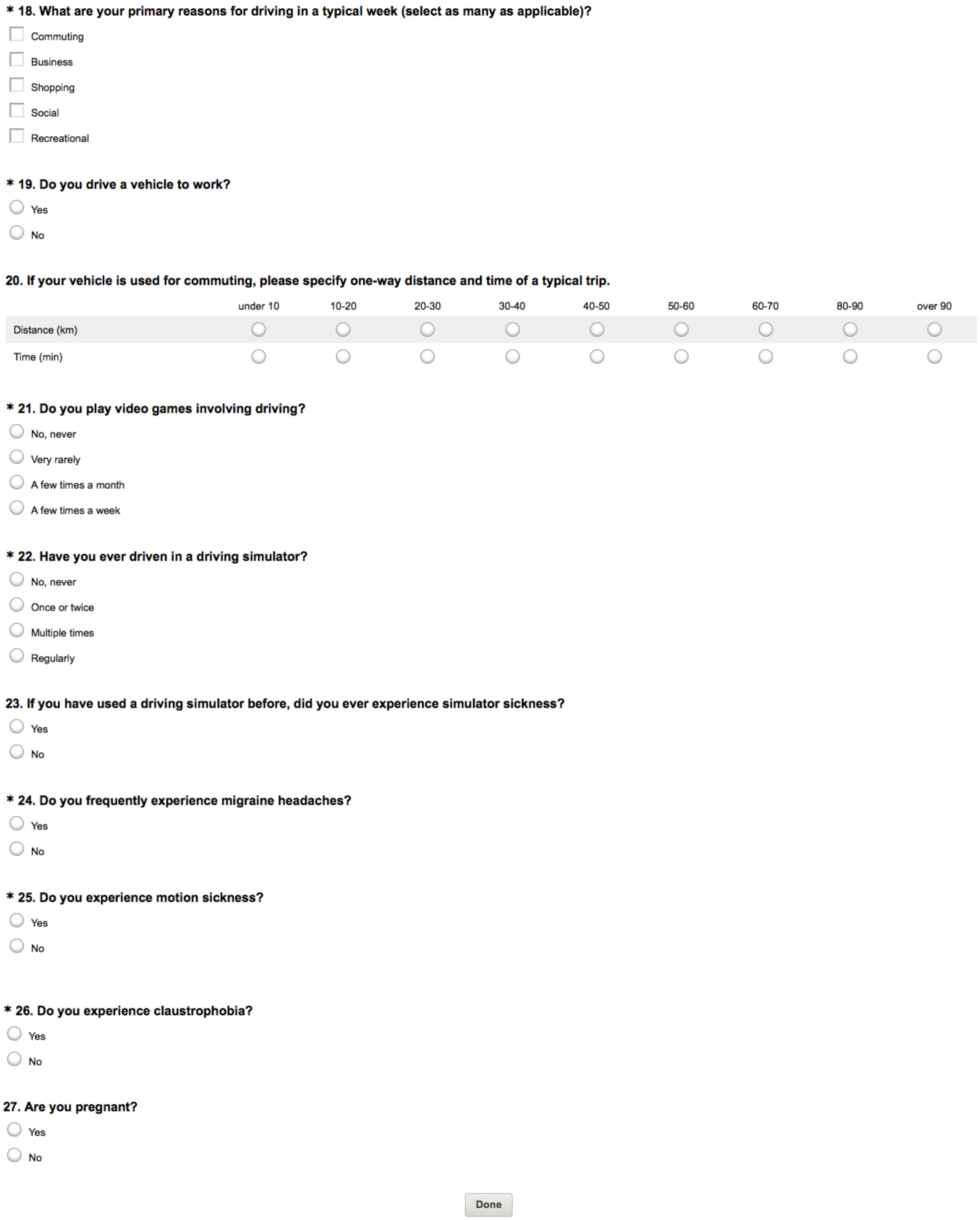
○ Under 10,000km
○ Between 10,001 and 20,000km
○ Between 20,001 and 50,000km
○ Over 50,000km

*** 16. Out of this total distance for the last year, how much (out of 100%) took place**

In the city?
On the highway?

*** 17. Out of the total quantity of your trips in a year, how long are your individual trips usually? Please distribute a total of 100% between trips of**

Less than 10 km (e.g., trips within the city)?
10 km to 50 km (e.g., Mississauga-Scarborough)?
50 km to 100 km (e.g., Toronto-St. Catharines)?
100 km to 500 km (e.g., Toronto-Ottawa)?
over 500 km?



*** 18. What are your primary reasons for driving in a typical week (select as many as applicable)?**

☐ Commuting
☐ Business
☐ Shopping
☐ Social
☐ Recreational

*** 19. Do you drive a vehicle to work?**

○ Yes
○ No

20. If your vehicle is used for commuting, please specify one-way distance and time of a typical trip.

	under 10	10-20	20-30	30-40	40-50	50-60	60-70	80-90	over 90
Distance (km)	○	○	○	○	○	○	○	○	○
Time (min)	○	○	○	○	○	○	○	○	○

*** 21. Do you play video games involving driving?**

○ No, never
○ Very rarely
○ A few times a month
○ A few times a week

*** 22. Have you ever driven in a driving simulator?**

○ No, never
○ Once or twice
○ Multiple times
○ Regularly

23. If you have used a driving simulator before, did you ever experience simulator sickness?

○ Yes
○ No

*** 24. Do you frequently experience migraine headaches?**

○ Yes
○ No

*** 25. Do you experience motion sickness?**

○ Yes
○ No

*** 26. Do you experience claustrophobia?**

○ Yes
○ No

27. Are you pregnant?

○ Yes
○ No

2) Post-Experiment Questionnaire, Experiment 1

Questionnaire – Driving Strategies

Participant Number: ______________ Date: ______________

1. **Please answer the following questions with respect to the five events from your two simulator runs.**

1) Chain-Braking due to slow tractor

Were you surprised when the car(s) ahead of you braked?

Not at all | | | | | | | Very much

Which cues did you recognize that indicated the car in front of you would brake?

____

Did you take any pre-emptive action?

Yes No

If yes, which action did you take?

____

2) Being overtaken

Were you surprised when the car overtook you and then braked?

Not at all | | | | | | | Very much

Which cues did you recognize that indicated this would happen?

____

Did you take any pre-emptive action?

Yes No

If yes, which action did you take?

____

3) Stranded truck on highway shoulder

Were you surprised when the cars changed lanes and braked?

Not at all | | | | | | | Very much

Which cues did you recognize that indicated this would happen?

____

Did you take any pre-emptive action?

Yes No

If yes, which action did you take?

____

4) Merging onto highway

Were you surprised when the car ahead of you braked on the acceleration lane instead of merging?

Not at all Very much

Which cues did you recognize that indicated this would happen?

____

Did you take any pre-emptive action?

Yes No

If yes, which action did you take?

____

5) Overtaking truck with conflicting car

Were you surprised when the car pulled out to overtake the truck?

Not at all Very much

Which cues did you recognize that indicated this would happen?

____

Did you take any pre-emptive action?

Yes No

If yes, which action did you take?

____

2. Please indicate your level of workload for the respective categories on the scale below.

Event 1: Chain-braking due to slow tractor

1. How mentally demanding was the task?

   Mental Demand

   Low High

2. How hurried or rushed was the pace of the task?

   Temporal Demand

   Low High

3. How hard did you have to work to accomplish your level of performance?

   Effort

   Low High

4. How insecure, discouraged, irritated, stressed, and annoyed were you?

   Frustration

   Low High

5. How successful were you in accomplishing what you were asked to do?

   Performance

   Perfect Failure

Event 2: Being overtaken

1. How mentally demanding was the task?

   Mental Demand

   Low High

2. How hurried or rushed was the pace of the task?

   Temporal Demand

   Low High

1. How hard did you have to work to accomplish your level of performance?

   Effort

   Low High

2. How insecure, discouraged, irritated, stressed, and annoyed were you?

   Frustration

   Low High

3. How successful were you in accomplishing what you were asked to do?

   Performance

   Perfect Failure

Event 3: Stranded truck on highway shoulder

1. How mentally demanding was the task?

   Mental Demand

   Low High

2. How hurried or rushed was the pace of the task?

   Temporal Demand

   Low High

3. How hard did you have to work to accomplish your level of performance?

   Effort

   Low High

4. How insecure, discouraged, irritated, stressed, and annoyed were you?

   Frustration

   Low High

5. How successful were you in accomplishing what you were asked to do?

   Performance

   Perfect Failure

Event 4: Merging onto highway

1. How mentally demanding was the task?

   Mental Demand

   Low High

2. How hurried or rushed was the pace of the task?

   Temporal Demand

   Low High

3. How hard did you have to work to accomplish your level of performance?

   Effort

   Low High

4. How insecure, discouraged, irritated, stressed, and annoyed were you?

   Frustration

   Low High

5. How successful were you in accomplishing what you were asked to do?

   Performance

   Perfect Failure

Event 5: Overtaking truck with conflicting car

1. How mentally demanding was the task?

   Mental Demand

   Low High

2. How hurried or rushed was the pace of the task?

   Temporal Demand

   Low High

1. How hard did you have to work to accomplish your level of performance?

   Effort

   Low High

2. How insecure, discouraged, irritated, stressed, and annoyed were you?

   Frustration

   Low High

3. How successful were you in accomplishing what you were asked to do?

   Performance

   Perfect Failure

3. Please indicate how risky you perceived the events just discussed in the cognitive walkthrough to be. Use numbers from 1-10 (see riskiness scale in box) to indicate the riskiness, as explained below.

Perceived risk: ____________________

Event 2: Being overtaken

Perceived risk: ____________________

Event 3: Stranded truck on highway shoulder

Perceived risk: ____________________

Event 4: Merging onto highway

Perceived risk: ____________________

Event 5: Overtaking truck with conflicting car

Perceived risk: ____________________

Riskiness:

10: driving with my eyes closed; a crash is bound to occur every time I do this

9: passing a school bus that has its red lights flashing and the stop arm in full view

8: driving just under the legal alcohol limit with observed weaving in the lane

7: in between 6 & 8

6: driving 20 miles per hour faster than traffic on an expressway

5: in between 4 & 6

4: driving 10 miles an hour faster than traffic on an expressway

3: in between 2 & 4

2: driving on an average road under average conditions

1: driving on an easy road with no traffic, pedestrians, or animals while perfectly alert

4. Please indicate, by marking the vertical axis below, how much effort it took for you to drive in the respective events. Use numbers from 1-5 to indicate them (as thez were numbered in question 1).

Rating Scale Mental Effort

Please indicate, by marking the vertical axis below, how much effort it took for you to complete the task you've just finished

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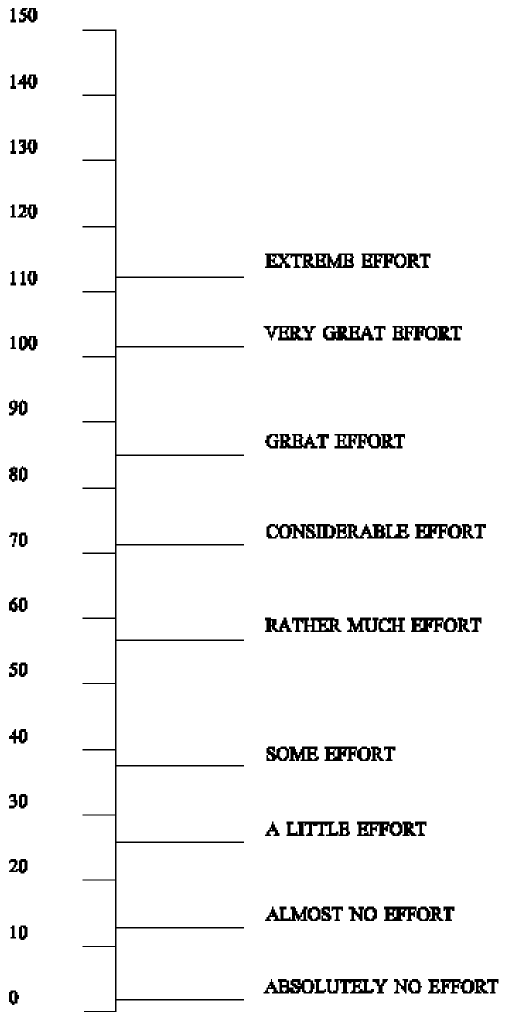


5. To what extent do these driving behaviors apply to you?

		Not at all			Neutral		very much	
a.	Fuel-conserving	☐	☐	☐	☐	☐	☐	☐
b.	Aggressive	☐	☐	☐	☐	☐	☐	☐
c.	Relaxed	☐	☐	☐	☐	☐	☐	☐
d.	Lawful	☐	☐	☐	☐	☐	☐	☐
e.	Conservative	☐	☐	☐	☐	☐	☐	☐
f.	Distracted	☐	☐	☐	☐	☐	☐	☐
g.	Time-conscious	☐	☐	☐	☐	☐	☐	☐
h.	Tense		☐	☐	☐	☐	☐	☐
		☐						
i.	Attentive	☐	☐	☐	☐	☐	☐	☐
j.	Calm	☐	☐	☐	☐	☐	☐	☐
k.	Environmentally-conscious	☐	☐	☐	☐	☐	☐	☐
l.	Sporty	☐	☐	☐	☐	☐	☐	☐
m.	Safe	☐	☐	☐	☐	☐	☐	☐
n.	Risky	☐	☐	☐	☐	☐	☐	☐
o.	Predictive/anticipatory	☐	☐	☐	☐	☐	☐	☐
p.	Courteous	☐	☐	☐	☐	☐	☐	☐
q.	Passive	☐	☐	☐	☐	☐	☐	☐
r.	Fluid/smooth	☐	☐	☐	☐	☐	☐	☐
s.	Intentional	☐	☐	☐	☐	☐	☐	☐
t.	Reactionary	☐	☐	☐	☐	☐	☐	☐
u.	Deliberate	☐	☐	☐	☐	☐	☐	☐

6. **How often do you do each of the following?**

		Never	Hardly ever	Occasionally	Quite often	Frequently	Nearly all the time
a.	Try to pass another car that is signalling a left turn.	○	○	○	○	○	○
b.	Select the wrong turn lane when approaching an intersection.	○	○	○	○	○	○
c.	Fail to 'Stop' or 'Yield' at a sign, almost hitting a car that has the right of way.	○	○	○	○	○	○
d.	Misread signs and miss your exit.	○	○	○	○	○	○
e.	Fail to notice pedestrians crossing when turning onto a side street.	○	○	○	○	○	○

7. **How often do you do each of the following?**

		Never	Hardly ever	Occasionally	Quite often	Frequently	Nearly all the time
f.	Drive very close to a car in front of you as a signal that they should go faster or get out of the way.	○	○	○	○	○	○
g.	Forget where you parked your car in a parking lot.	○	○	○	○	○	○
h.	When preparing to turn from a side road onto a main road, you pay too much attention to the traffic on the main road so that you nearly hit the car in front of you.	○	○	○	○	○	○
i.	When you back up, you hit something that you did not observe before but was there.	○	○	○	○	○	○
j.	Pass through an intersection even though you know that the traffic light has turned yellow and may go red.	○	○	○	○	○	○

8. **How often do you do each of the following?**

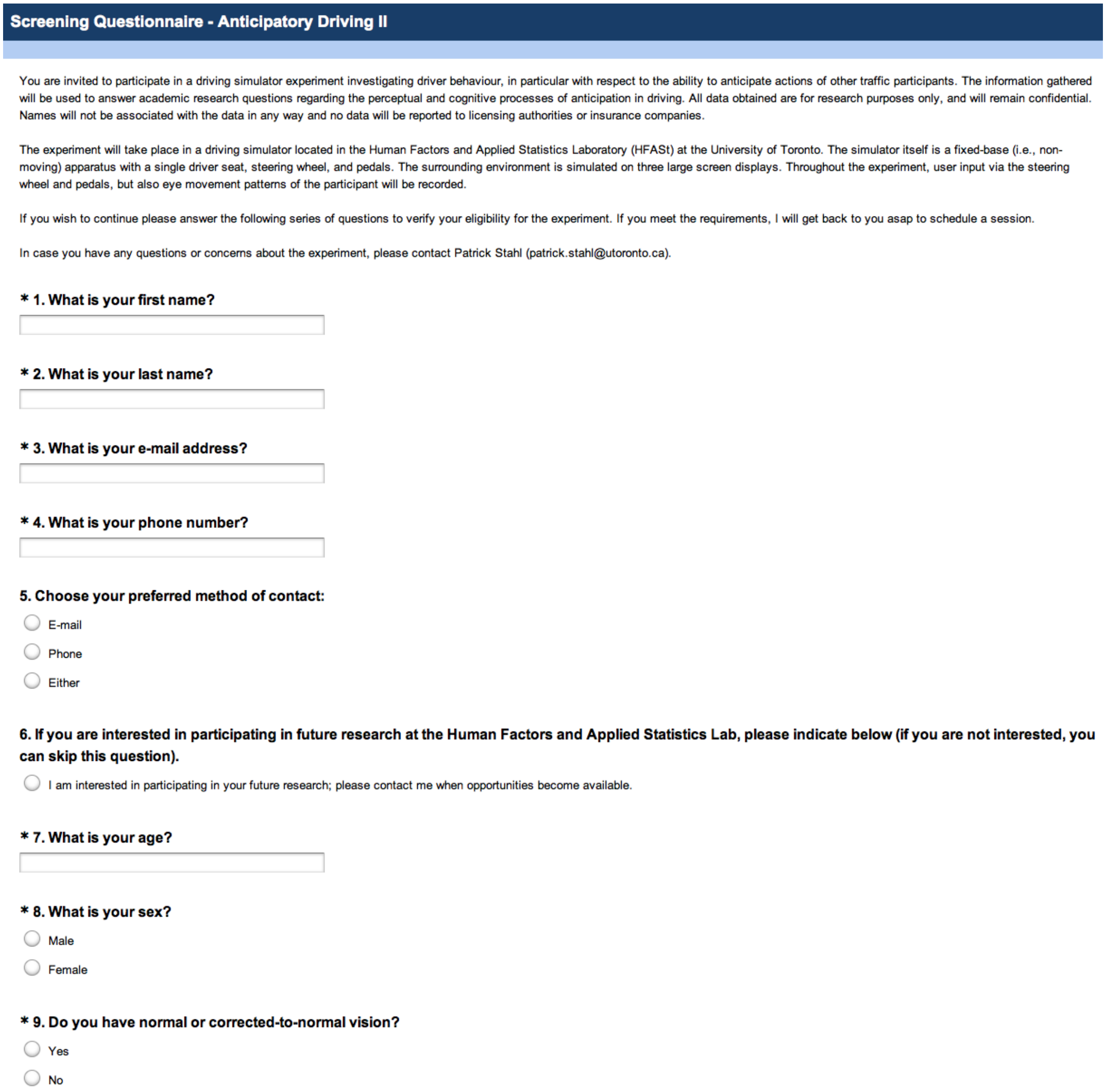
		Never	Hardly ever	Occasionally	Quite often	Frequently	Nearly all the time
k.	When making a turn, you almost hit a cyclist or pedestrian who has come up on your right side.	○	○	○	○	○	○
l.	Ignore speed limits late at night or very early in the morning.	○	○	○	○	○	○
m.	Forget that your lights are on high beam until another driver flashes his headlights at you.	○	○	○	○	○	○

n.	Fail to check your rear-view mirror before pulling out and changing lanes.	○	○	○	○	○	○
o.	Have a strong dislike of a particular type of driver, and indicate your dislike by any means that you can.	○	○	○	○	○	○

9.	**How often do you do each of the following?**	Never	Hardly ever	Occasionally	Quite often	Frequently	Nearly all the time
p.	Become impatient with a slow driver in the left lane and pass on the right.	○	○	○	○	○	○
q.	Underestimate the speed of an oncoming vehicle when passing.	○	○	○	○	○	○
r.	Switch on one thing, for example, the headlights, when you meant to switch on something else, for example, the windshield wipers.	○	○	○	○	○	○
s.	Brake too quickly on a slippery road, or turn your steering wheel in the wrong direction while skidding.	○	○	○	○	○	○
t.	You intend to drive to destination A, but you ‘wake up’ to find yourself on the road to destination B, perhaps because B is your more usual destination.	○	○	○	○	○	○

10.	**How often do you do each of the following?**	Never	Hardly ever	Occasionally	Quite often	Frequently	Nearly all the time
u.	Drive even though you realize that your blood alcohol may be over the legal limit.	○	○	○	○	○	○
v.	Get involved in spontaneous, or spur-of-the moment, races with other drivers.	○	○	○	○	○	○
w.	Realize that you cannot clearly remember the road you were just driving on.	○	○	○	○	○	○
x.	You get angry at the behavior of another driver and you chase that driver so that you can give him/her a piece of your mind.	○	○	○	○	○	○

3) Screening Questionnaire, Experiment 2



Screening Questionnaire - Anticipatory Driving II

You are invited to participate in a driving simulator experiment investigating driver behaviour, in particular with respect to the ability to anticipate actions of other traffic participants. The information gathered will be used to answer academic research questions regarding the perceptual and cognitive processes of anticipation in driving. All data obtained are for research purposes only, and will remain confidential. Names will not be associated with the data in any way and no data will be reported to licensing authorities or insurance companies.

The experiment will take place in a driving simulator located in the Human Factors and Applied Statistics Laboratory (HFASt) at the University of Toronto. The simulator itself is a fixed-base (i.e., non-moving) apparatus with a single driver seat, steering wheel, and pedals. The surrounding environment is simulated on three large screen displays. Throughout the experiment, user input via the steering wheel and pedals, but also eye movement patterns of the participant will be recorded.

If you wish to continue please answer the following series of questions to verify your eligibility for the experiment. If you meet the requirements, I will get back to you asap to schedule a session.

In case you have any questions or concerns about the experiment, please contact Patrick Stahl (patrick.stahl@utoronto.ca).

*** 1. What is your first name?**

*** 2. What is your last name?**

*** 3. What is your e-mail address?**

*** 4. What is your phone number?**

5. Choose your preferred method of contact:

○ E-mail
○ Phone
○ Either

6. If you are interested in participating in future research at the Human Factors and Applied Statistics Lab, please indicate below (if you are not interested, you can skip this question).

○ I am interested in participating in your future research; please contact me when opportunities become available.

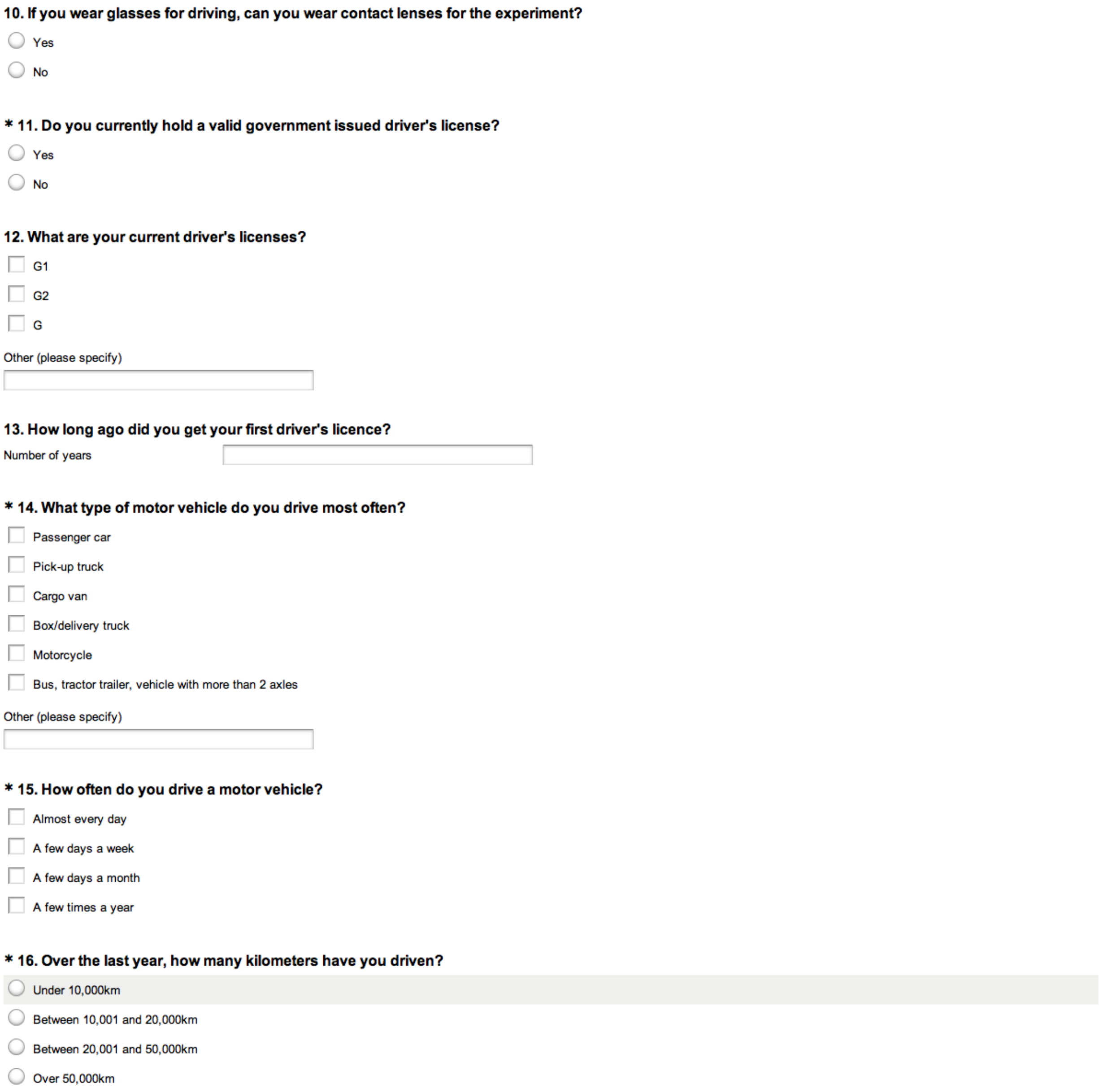
*** 7. What is your age?**

*** 8. What is your sex?**

○ Male
○ Female

*** 9. Do you have normal or corrected-to-normal vision?**

○ Yes
○ No



10. If you wear glasses for driving, can you wear contact lenses for the experiment?

○ Yes

○ No

*** 11. Do you currently hold a valid government issued driver's license?**

○ Yes

○ No

12. What are your current driver's licenses?

☐ G1

☐ G2

☐ G

Other (please specify)

13. How long ago did you get your first driver's licence?

Number of years

*** 14. What type of motor vehicle do you drive most often?**

☐ Passenger car

☐ Pick-up truck

☐ Cargo van

☐ Box/delivery truck

☐ Motorcycle

☐ Bus, tractor trailer, vehicle with more than 2 axles

Other (please specify)

*** 15. How often do you drive a motor vehicle?**

☐ Almost every day

☐ A few days a week

☐ A few days a month

☐ A few times a year

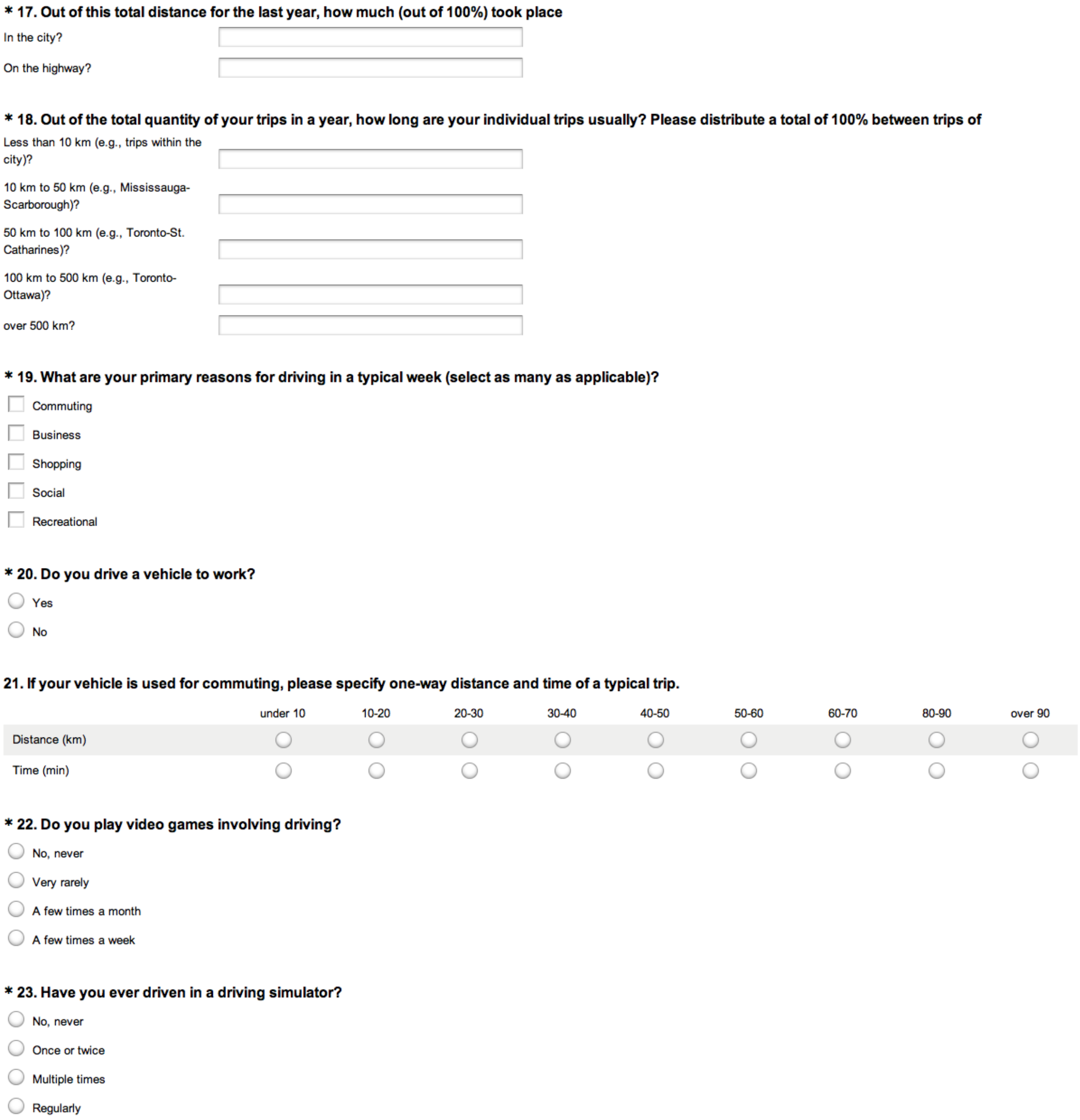
*** 16. Over the last year, how many kilometers have you driven?**

○ Under 10,000km

○ Between 10,001 and 20,000km

○ Between 20,001 and 50,000km

○ Over 50,000km



*** 17. Out of this total distance for the last year, how much (out of 100%) took place**

In the city?

On the highway?

*** 18. Out of the total quantity of your trips in a year, how long are your individual trips usually? Please distribute a total of 100% between trips of**

Less than 10 km (e.g., trips within the city)?

10 km to 50 km (e.g., Mississauga-Scarborough)?

50 km to 100 km (e.g., Toronto-St. Catharines)?

100 km to 500 km (e.g., Toronto-Ottawa)?

over 500 km?

*** 19. What are your primary reasons for driving in a typical week (select as many as applicable)?**

☐ Commuting
☐ Business
☐ Shopping
☐ Social
☐ Recreational

*** 20. Do you drive a vehicle to work?**

○ Yes
○ No

21. If your vehicle is used for commuting, please specify one-way distance and time of a typical trip.

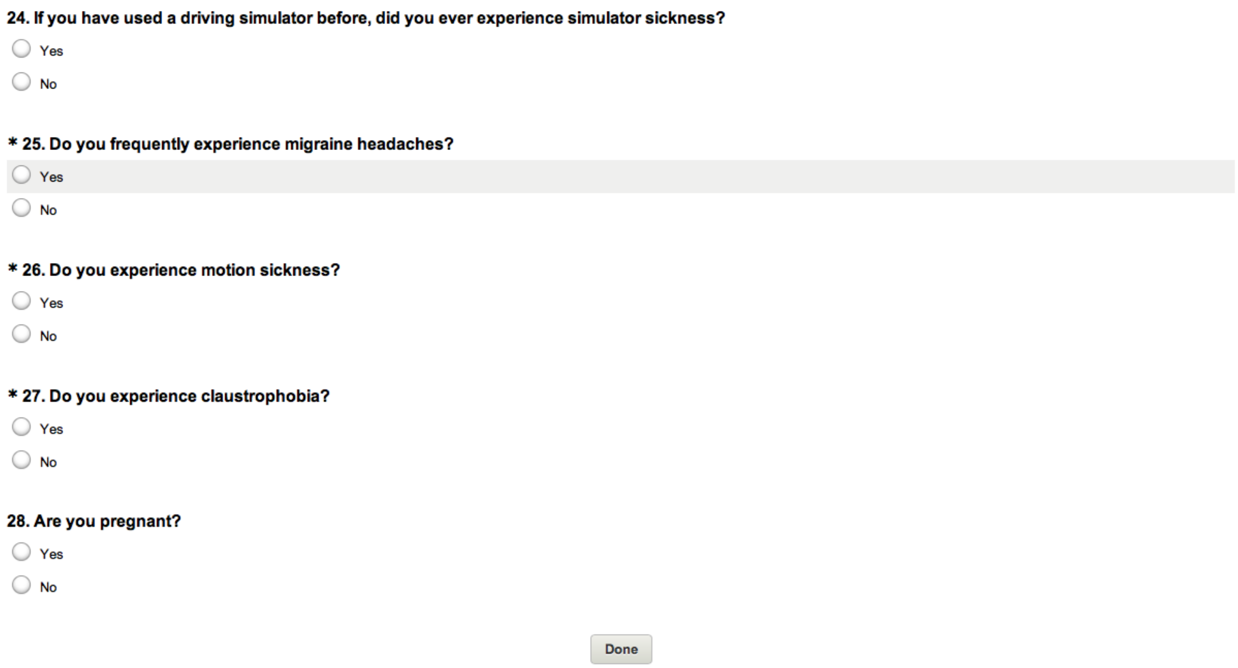
	under 10	10-20	20-30	30-40	40-50	50-60	60-70	80-90	over 90
Distance (km)	○	○	○	○	○	○	○	○	○
Time (min)	○	○	○	○	○	○	○	○	○

*** 22. Do you play video games involving driving?**

○ No, never
○ Very rarely
○ A few times a month
○ A few times a week

*** 23. Have you ever driven in a driving simulator?**

○ No, never
○ Once or twice
○ Multiple times
○ Regularly



24. If you have used a driving simulator before, did you ever experience simulator sickness?

○ Yes

○ No

*** 25. Do you frequently experience migraine headaches?**

○ Yes

○ No

*** 26. Do you experience motion sickness?**

○ Yes

○ No

*** 27. Do you experience claustrophobia?**

○ Yes

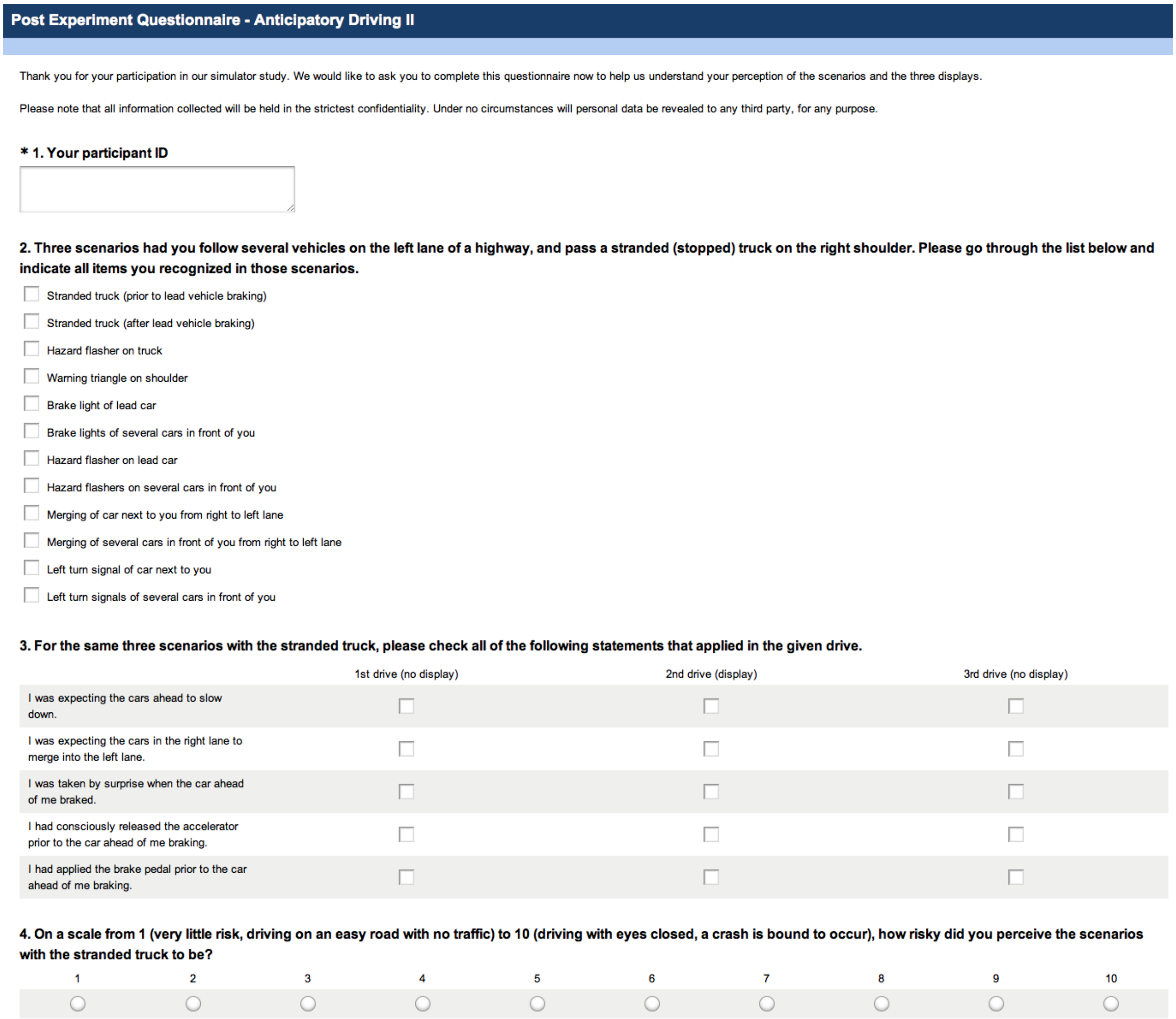
○ No

28. Are you pregnant?

○ Yes

○ No

4) Post-Experiment Questionnaire, Experiment 2



Post Experiment Questionnaire - Anticipatory Driving II

Thank you for your participation in our simulator study. We would like to ask you to complete this questionnaire now to help us understand your perception of the scenarios and the three displays.

Please note that all information collected will be held in the strictest confidentiality. Under no circumstances will personal data be revealed to any third party, for any purpose.

*** 1. Your participant ID**

2. Three scenarios had you follow several vehicles on the left lane of a highway, and pass a stranded (stopped) truck on the right shoulder. Please go through the list below and indicate all items you recognized in those scenarios.

- ☐ Stranded truck (prior to lead vehicle braking)
- ☐ Stranded truck (after lead vehicle braking)
- ☐ Hazard flasher on truck
- ☐ Warning triangle on shoulder
- ☐ Brake light of lead car
- ☐ Brake lights of several cars in front of you
- ☐ Hazard flasher on lead car
- ☐ Hazard flashers on several cars in front of you
- ☐ Merging of car next to you from right to left lane
- ☐ Merging of several cars in front of you from right to left lane
- ☐ Left turn signal of car next to you
- ☐ Left turn signals of several cars in front of you

3. For the same three scenarios with the stranded truck, please check all of the following statements that applied in the given drive.

	1st drive (no display)	2nd drive (display)	3rd drive (no display)
I was expecting the cars ahead to slow down.	☐	☐	☐
I was expecting the cars in the right lane to merge into the left lane.	☐	☐	☐
I was taken by surprise when the car ahead of me braked.	☐	☐	☐
I had consciously released the accelerator prior to the car ahead of me braking.	☐	☐	☐
I had applied the brake pedal prior to the car ahead of me braking.	☐	☐	☐

4. On a scale from 1 (very little risk, driving on an easy road with no traffic) to 10 (driving with eyes closed, a crash is bound to occur), how risky did you perceive the scenarios with the stranded truck to be?

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

5. On a scale from 0 (absolutely no effort), to 120 (extreme effort), please indicate how much mental effort it took for you to drive through the scenarios with the stranded truck.

0 - absolutely no effort	10 - almost no effort	20	30 - a little effort	40 - some effort	50	60 - rather much effort	70 - considerable effort	80	90 - great effort	100 - very great effort	110	120 - extreme effort
○	○	○	○	○	○	○	○	○	○	○	○	○

In the second of the three instances of this scenario, one of the two displays below may have been used to aid you in recognizing the upcoming traffic situation. Please indicate which display (if any) you saw in your drive, and then rate the usefulness of both displays.

6. Which display did you see during the drive?

- ○ Display 1
- ○ Display 2
- ○ No display

7. I find display 1 to be...

Useful (2)	(1)	(0)	(-1)	Useless (-2)
○	○	○	○	○

8. I find display 2 to be...

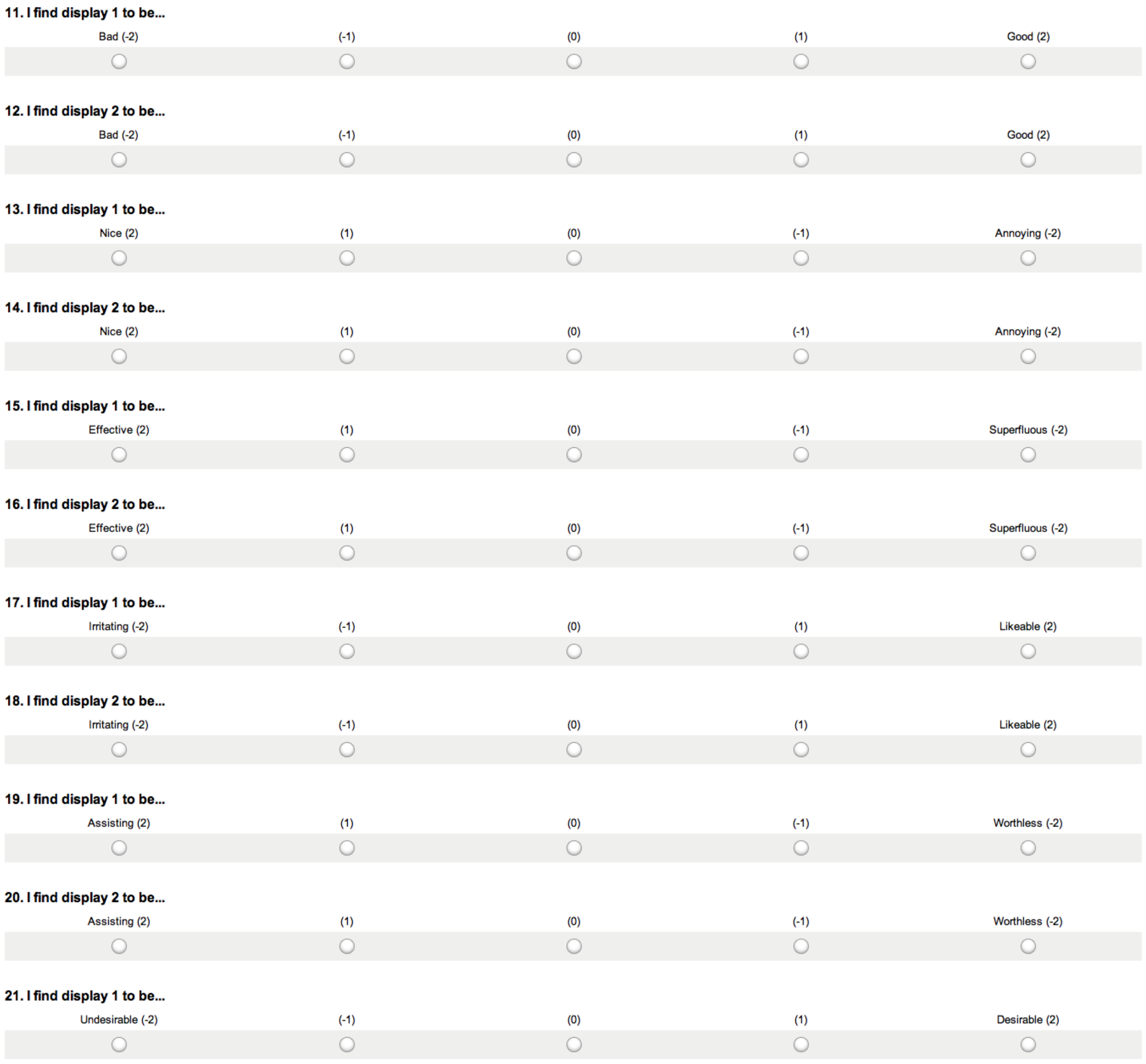
Useful (2)	(1)	(0)	(-1)	Useless (-2)
○	○	○	○	○

9. I find display 1 to be...

Pleasant (2)	(1)	(0)	(-1)	Unpleasant (-2)
○	○	○	○	○

10. I find display 2 to be...

Pleasant (2)	(1)	(0)	(-1)	Unpleasant (-2)
○	○	○	○	○



11. I find display 1 to be...

Bad (-2)	(-1)	(0)	(1)	Good (2)
○	○	○	○	○

12. I find display 2 to be...

Bad (-2)	(-1)	(0)	(1)	Good (2)
○	○	○	○	○

13. I find display 1 to be...

Nice (2)	(1)	(0)	(-1)	Annoying (-2)
○	○	○	○	○

14. I find display 2 to be...

Nice (2)	(1)	(0)	(-1)	Annoying (-2)
○	○	○	○	○

15. I find display 1 to be...

Effective (2)	(1)	(0)	(-1)	Superfluous (-2)
○	○	○	○	○

16. I find display 2 to be...

Effective (2)	(1)	(0)	(-1)	Superfluous (-2)
○	○	○	○	○

17. I find display 1 to be...

Irritating (-2)	(-1)	(0)	(1)	Likeable (2)
○	○	○	○	○

18. I find display 2 to be...

Irritating (-2)	(-1)	(0)	(1)	Likeable (2)
○	○	○	○	○

19. I find display 1 to be...

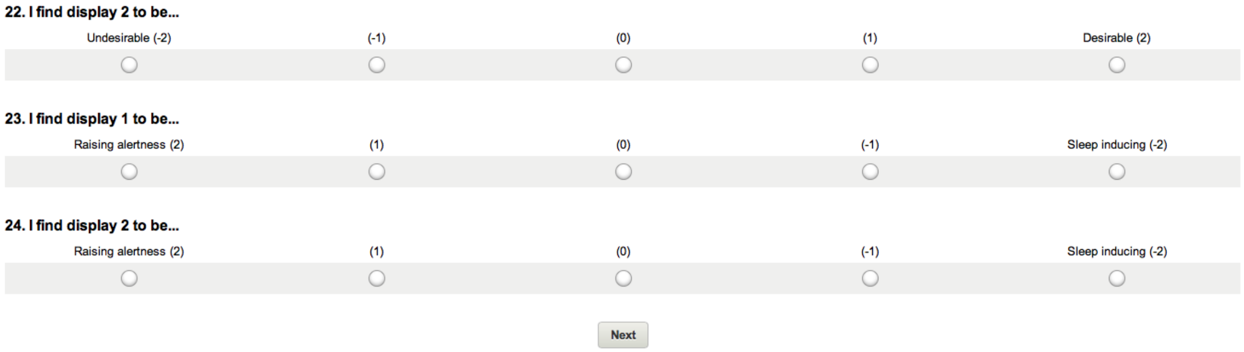
Assisting (2)	(1)	(0)	(-1)	Worthless (-2)
○	○	○	○	○

20. I find display 2 to be...

Assisting (2)	(1)	(0)	(-1)	Worthless (-2)
○	○	○	○	○

21. I find display 1 to be...

Undesirable (-2)	(-1)	(0)	(1)	Desirable (2)
○	○	○	○	○



22. I find display 2 to be...

Undesirable (-2)	(-1)	(0)	(1)	Desirable (2)
○	○	○	○	○

23. I find display 1 to be...

Raising alertness (2)	(1)	(0)	(-1)	Sleep inducing (-2)
○	○	○	○	○

24. I find display 2 to be...

Raising alertness (2)	(1)	(0)	(-1)	Sleep inducing (-2)
○	○	○	○	○

25. In three scenarios you were driving on a highway in the left lane and overtaking a slower car and truck in the right lane. The slower car then merged into the left lane to overtake the truck itself, thereby cutting you off (you may also have accelerated enough to pass the car just prior to it merging left). Please go through the list below and indicate all items you recognized in those scenarios.

☐ Slow speed of truck

☐ Hazard flasher on truck

☐ Decreasing distance between truck and car

☐ Car repeatedly edging towards median

☐ Left turn signal of car

26. For the same three scenarios with the slow truck, please check all of the following statements that applied in the given drive.

	1st drive (no display)	2nd drive (display)	3rd drive (no display)
I was expecting the car to stay behind the truck and let me pass.	☐	☐	☐
I was expecting the car to change lanes and accelerate much earlier.	☐	☐	☐
I was surprised when the car merged left.	☐	☐	☐
I was expecting to be cut off by the car.	☐	☐	☐
I had released the accelerator to provide space for the car to merge left.	☐	☐	☐
I had depressed the brake to provide space for the car to merge left.	☐	☐	☐
I tried to accelerate in order to pass the car before it could change lanes.	☐	☐	☐

27. On a scale from 1 (very little risk, driving on an easy road with no traffic) to 10 (driving with eyes closed, a crash is bound to occur), how risky did you perceive the scenarios with the slow truck and overtaking car to be?

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

28. On a scale from 0 (absolutely no effort), to 120 (extreme effort), please indicate how much mental effort it took for you to drive through the scenarios with the slow truck and overtaking car.

0 - absolutely no effort	10 - almost no effort	20	30 - a little effort	40 - some effort	50	60 - rather much effort	70 - considerable effort	80	90 - great effort	100 - very great effort	110	120 - extreme effort
○	○	○	○	○	○	○	○	○	○	○	○	○

In the second of the three instances of this scenario, one of the two displays below may have been used to aid you in recognizing the upcoming traffic situation. Please indicate which display (if any) you saw in your drive, and then rate the usefulness of both displays.

29. Which display did you see during the drive?

○ Display 3
○ Display 4
○ No display

30. I find display 3 to be...

Useful (2)	(1)	(0)	(-1)	Useless (-2)
○	○	○	○	○

31. I find display 4 to be...

Useful (2)	(1)	(0)	(-1)	Useless (-2)
○	○	○	○	○

32. I find display 3 to be...

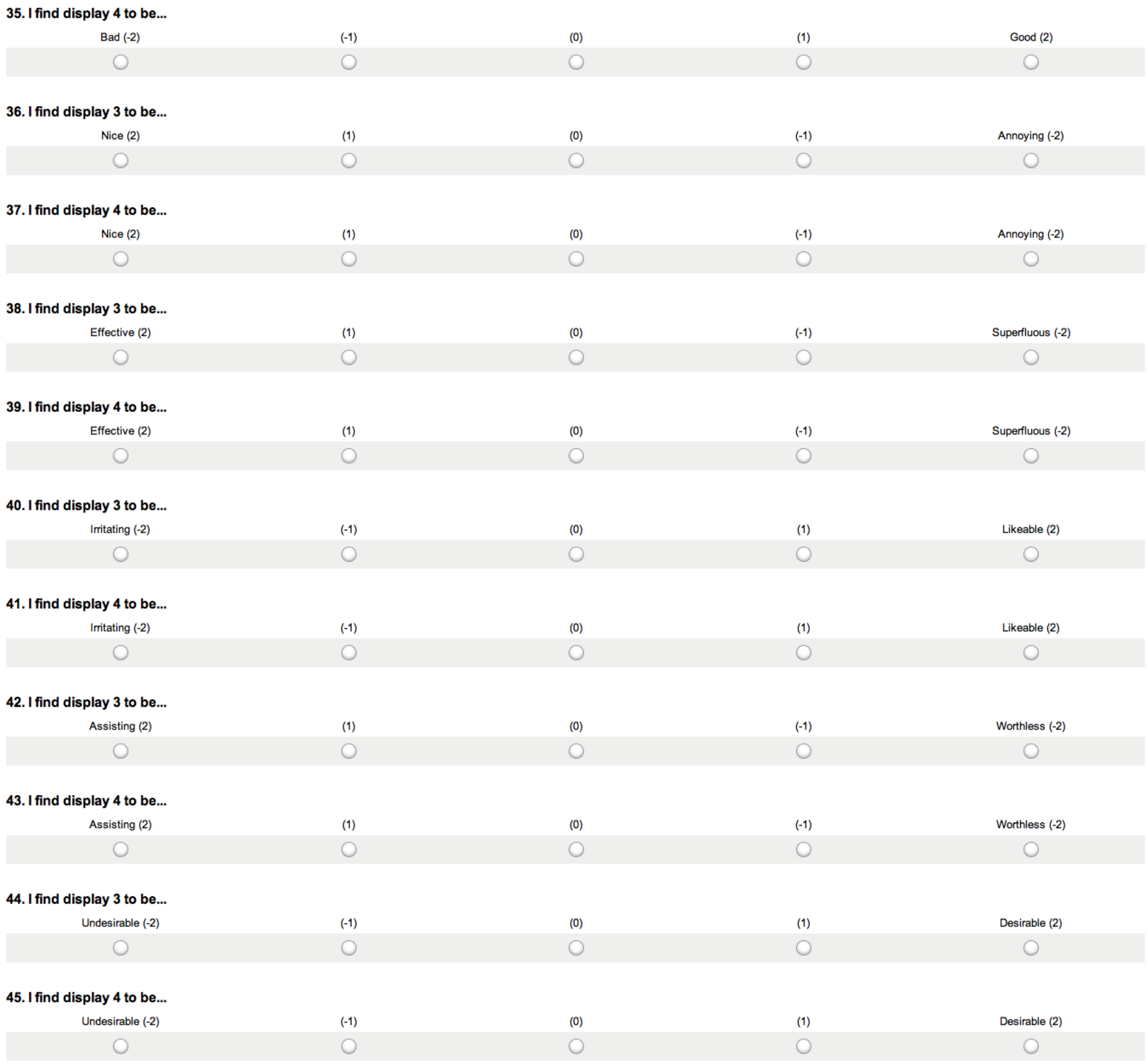
Pleasant (2)	(1)	(0)	(-1)	Unpleasant (-2)
○	○	○	○	○

33. I find display 4 to be...

Pleasant (2)	(1)	(0)	(-1)	Unpleasant (-2)
○	○	○	○	○

34. I find display 3 to be...

Bad (-2)	(-1)	(0)	(1)	Good (2)
○	○	○	○	○



35. I find display 4 to be...

Bad (-2)	(-1)	(0)	(1)	Good (2)
○	○	○	○	○

36. I find display 3 to be...

Nice (2)	(1)	(0)	(-1)	Annoying (-2)
○	○	○	○	○

37. I find display 4 to be...

Nice (2)	(1)	(0)	(-1)	Annoying (-2)
○	○	○	○	○

38. I find display 3 to be...

Effective (2)	(1)	(0)	(-1)	Superfluous (-2)
○	○	○	○	○

39. I find display 4 to be...

Effective (2)	(1)	(0)	(-1)	Superfluous (-2)
○	○	○	○	○

40. I find display 3 to be...

Irritating (-2)	(-1)	(0)	(1)	Likeable (2)
○	○	○	○	○

41. I find display 4 to be...

Irritating (-2)	(-1)	(0)	(1)	Likeable (2)
○	○	○	○	○

42. I find display 3 to be...

Assisting (2)	(1)	(0)	(-1)	Worthless (-2)
○	○	○	○	○

43. I find display 4 to be...

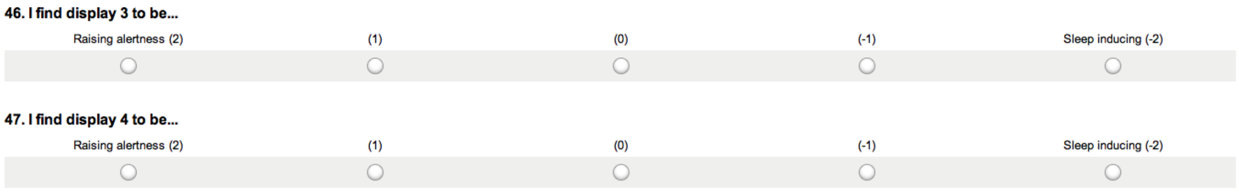
Assisting (2)	(1)	(0)	(-1)	Worthless (-2)
○	○	○	○	○

44. I find display 3 to be...

Undesirable (-2)	(-1)	(0)	(1)	Desirable (2)
○	○	○	○	○

45. I find display 4 to be...

Undesirable (-2)	(-1)	(0)	(1)	Desirable (2)
○	○	○	○	○



46. I find display 3 to be...

Raising alertness (2)	(1)	(0)	(-1)	Sleep inducing (-2)
○	○	○	○	○

47. I find display 4 to be...

Raising alertness (2)	(1)	(0)	(-1)	Sleep inducing (-2)
○	○	○	○	○

48. Finally, three scenarios had you follow a stream of five cars on a rural road. Those cars consecutively braked during a particular period. Please go through the list below and indicate all items you recognized in those scenarios.

☐ Tractor ahead of the cars
☐ Emergency flasher on tractor
☐ Brake light of lead car
☐ Brake lights of several cars ahead
☐ Emergency flasher of lead car
☐ Emergency flashers on several cars ahead

49. For the same three scenarios with the chain-braking, please check all of the following statements that applied in the given drive.

	1st drive (no display)	2nd drive (display)	3rd drive (no display)
I was surprised when some of the cars ahead started braking, but realized then all cars behind would have to brake, too.	☐	☐	☐
I was surprised when the car directly ahead braked.	☐	☐	☐
I realized the tractor was going significantly slower than the cars.	☐	☐	☐
I expected the cars ahead of me to brake because of the tractor.	☐	☐	☐
I had consciously released the accelerator prior to the car ahead of me braking.	☐	☐	☐
I had depressed the brake pedal prior to the car ahead of me braking.	☐	☐	☐

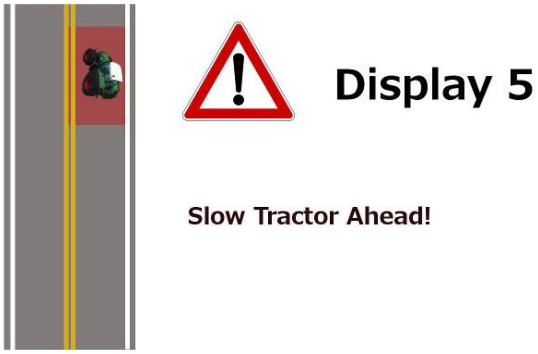
50. On a scale from 1 (very little risk, driving on an easy road with no traffic) to 10 (driving with eyes closed, a crash is bound to occur), how risky did you perceive the scenarios with the chain-braking caused by the slow tractor to be?

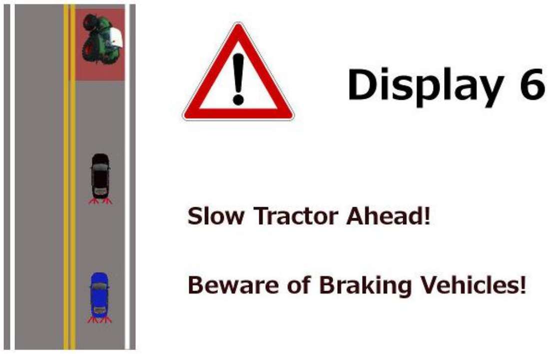
1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

51. On a scale from 0 (absolutely no effort), to 120 (extreme effort), please indicate how much mental effort it took for you to drive through the scenarios with the chain-braking caused by the slow tractor.

0 - absolutely no effort	10 - almost no effort	20	30 - a little effort	40 - some effort	50	60 - rather much effort	70 - considerable effort	80	90 - great effort	100 - very great effort	110	120 - extreme effort
○	○	○	○	○	○	○	○	○	○	○	○	○

In the second of the three instances of this scenario, one of the two displays below may have been used to aid you in recognizing the upcoming traffic situation. Please indicate which display (if any) you saw in your drive, and then rate the usefulness of both displays.





52. Which display did you see during the drive?

○ Display 5

○ Display 6

○ No display

53. I find display 5 to be...

Useful (2)	(1)	(0)	(-1)	Useless (-2)
○	○	○	○	○

54. I find display 6 to be...

Useful (2)	(1)	(0)	(-1)	Useless (-2)
○	○	○	○	○

55. I find display 5 to be...

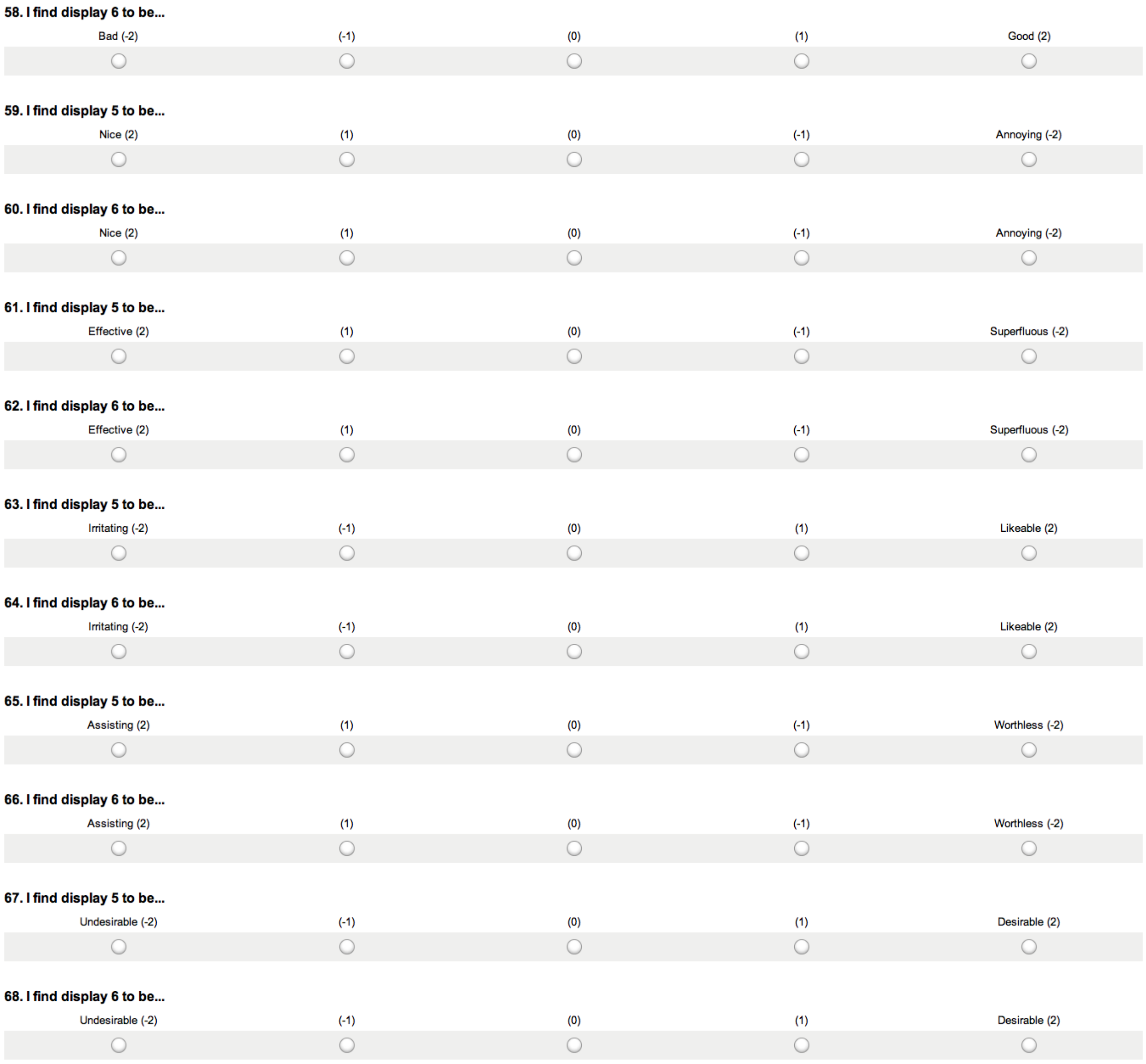
Pleasant (2)	(1)	(0)	(-1)	Unpleasant (-2)
○	○	○	○	○

56. I find display 6 to be...

Pleasant (2)	(1)	(0)	(-1)	Unpleasant (-2)
○	○	○	○	○

57. I find display 5 to be...

Bad (-2)	(-1)	(0)	(1)	Good (2)
○	○	○	○	○



58. I find display 6 to be...

Bad (-2)	(-1)	(0)	(1)	Good (2)
○	○	○	○	○

59. I find display 5 to be...

Nice (2)	(1)	(0)	(-1)	Annoying (-2)
○	○	○	○	○

60. I find display 6 to be...

Nice (2)	(1)	(0)	(-1)	Annoying (-2)
○	○	○	○	○

61. I find display 5 to be...

Effective (2)	(1)	(0)	(-1)	Superfluous (-2)
○	○	○	○	○

62. I find display 6 to be...

Effective (2)	(1)	(0)	(-1)	Superfluous (-2)
○	○	○	○	○

63. I find display 5 to be...

Irritating (-2)	(-1)	(0)	(1)	Likeable (2)
○	○	○	○	○

64. I find display 6 to be...

Irritating (-2)	(-1)	(0)	(1)	Likeable (2)
○	○	○	○	○

65. I find display 5 to be...

Assisting (2)	(1)	(0)	(-1)	Worthless (-2)
○	○	○	○	○

66. I find display 6 to be...

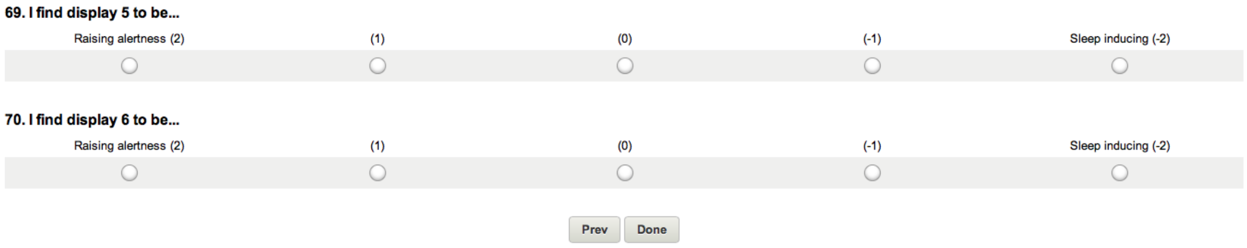
Assisting (2)	(1)	(0)	(-1)	Worthless (-2)
○	○	○	○	○

67. I find display 5 to be...

Undesirable (-2)	(-1)	(0)	(1)	Desirable (2)
○	○	○	○	○

68. I find display 6 to be...

Undesirable (-2)	(-1)	(0)	(1)	Desirable (2)
○	○	○	○	○



69. I find display 5 to be...

Raising alertness (2)	(1)	(0)	(-1)	Sleep inducing (-2)
○	○	○	○	○

70. I find display 6 to be...

Raising alertness (2)	(1)	(0)	(-1)	Sleep inducing (-2)
○	○	○	○	○

C) Forms

1) Participant Consent Form, Experiment 1

Participant Consent Form

Title: Driving behaviour and strategies

Investigators: Patrick Stahl (416-978-0881; pstahl@mie.utoronto.ca)
Dr. Birsen Donmez (416-978-7399; donmez@mie.utoronto.ca)
Dr. Greg A. Jamieson (416 946 8504; jamieson@mie.utoronto.ca)

You are being asked to take part in a research study. Before agreeing to participate in this study, it is important that you read and understand the following explanation of the proposed study procedures. The following information describes the purpose, procedures, benefits, discomforts, risks and precautions associated with this study. In order to decide whether you wish to participate or withdraw in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is known as the informed consent process. Please ask the investigator to explain any words you don't understand before signing this consent form. Make sure all your questions have been answered to your satisfaction before signing this document.

Purpose

This study looks into the behaviour of drivers in specific, stereotypical situations in traffic. The goal is to investigate different strategies of drivers to deal with those situations, and as a participant you will be asked to:

1. Drive through a simulated traffic environment
2. Participate in a post-experiment cognitive walkthrough (explained below)
3. Fill out a questionnaire after the experimental trials

Procedure

This study contains three phases. In the first phase, you will be introduced to the simulator, and have time to test it and become comfortable driving with it. In the second phase, you will drive through the scenarios of the experiment. We ask that you attempt to treat the simulation just like you were driving your own car, thinking of all elements of the simulation as if they were encountered in the real world. There will be two driving scenarios of 10 minutes each, with small five minute breaks in between. In the final phase of the experiment, you will be asked to review a video recording of your trials with the investigator in a so-called "cognitive walkthrough". The investigator will ask you about how you perceived specific elements in the environment, and how you reacted to them. We will also ask you to fill out a brief questionnaire with respect to your general driving behaviour and the scenarios you just drove.

Risks

There are no major risks involved with this experiment, the tasks are not physiologically demanding, psychologically stressing, and there is no manipulation or deception involved. We want to make you aware of the possibility of simulator sickness (a form of motion sickness specific to simulators), however. Especially upon first using a driving simulator, there is a small chance of feeling dizzy, nauseous, or fatigued. If you feel any of these symptoms appear, please immediately stop the experiment and inform the investigator. The investigator will also monitor for any signs of simulator sickness.

Benefits

There are several benefits to conducting this study. The most important benefit is your contribution to research in driving behaviour, which will help understand different strategies of dealing with specific traffic situations, and guide the development of aids to help drivers deal with those situations. You will also gain experience with academic research and be able to use and test out a state of the art driving simulator. Last, we hope that you will personally benefit from the cognitive walkthrough in that you become more aware of your own driving behaviour.

Compensation

You will receive $10/hour for your participation at the end of this study. The experiment should take about two hours.

Confidentiality

All information obtained during the study will be held in strict confidence. You will be identified with a study number only, and this study number will only be identifiable by the primary investigator. No names or identifying information will be used in any publication or presentation. No information identifying you will be transferred outside the investigators in this study.

Please be advised that we video-record the experimental trials with four small web-cameras. One camera will be pointed at you, one will capture the steering wheel, one the pedals, and the final camera the overall scene. The videos will only be seen by the investigators and the primary investigator's research assistant. No video data will be released to any other party.

Participation

Your participation in this study is voluntary. You can choose to not participate or withdraw at any time.

Questions

If you have any general questions about this study, please call Patrick Stahl at 416-978-0881 or e-mail him at pstahl@mie.utoronto.ca.

Consent

I have had the opportunity to discuss this study and my questions have been answered to my satisfaction. I consent to take part in the study with the understanding I may withdraw at any time. I have received a signed copy of this consent form. I voluntarily consent to participate in this study

Participant's Name (please print)	Signature	Date

I confirm that I have explained the nature and purpose of the study to the participant named above. I have answered all questions.

Investigator's Name	Signature	Date

2) Simulator Instructions, Experiment 1

Simulator Scenario Instructions

Summary

The experiment you are partaking in consists of four independent runs. The first two are practice runs in which you can familiarize yourself with the simulator. The actual data will be collected during the two following experimental runs.

Practice Scenario 1:

In this scenario, you will mostly be driving on rural roads. Please start out slowly, and avoid sudden and forceful input at the beginning to minimize the risk for simulator sickness – you'll need to get used to the way the simulator feels first. The goal is to develop a feel for the simulator, so please try to practice the following:

- Familiarize yourself with steering response, as well as gas- and brake pedal response.
- Pay attention to speed limit signs, and practice keeping the vehicle at a constant speed. Rural roads will have speed limits between 40 and 50 mph, and other cars will generally go between 30 and 50 mph.
- Practice keeping realistic following distances to lead cars. Do not let them speed away, but do not drive bumper to bumper either.

Practice Scenario 2:

In this scenario, you will be driving from a rural road onto a highway. The goal here is specifically to develop a feeling for the difference in driving on a one-lane road with relatively low speed limits, to a two-lane highway with higher speed limits. Please pay particular attention to the following here:

- Pay attention to the speed limit signs again – on the highway there is a constant speed limit of 60 mph in this experiment. Please choose 60 mph as your travelling speed on highways throughout this experiment, and practice keeping the car at 60 mph.
- Practice overtaking other cars and trucks on the highway. Especially trucks can appear very wide, but you will need to overtake them later.
- Practice merging onto the highway. Unfortunately, the simulator does not allow for you to check your blind spot, and a few highway on-ramps don't have acceleration lanes. You will need to watch the vehicles already on the highway and merge into an appropriate gap

Experimental Scenario 1:

In this scenario, you will start on a rural road and later merge onto a highway. There are two tasks to carry out:

1. Safely follow the line of cars ahead. You will start out stopped on a road behind several cars. As soon as you start moving, the cars ahead will do so as well. Follow these cars in a realistic fashion, that is, keep normal distance to the car ahead. Do not let it get away, and do not drive bumper to bumper. Do not overtake the cars.

2. After a significant amount of driving on rural roads, there will be a merge onto a highway. The other cars will drive by it, but you are to take a right and go onto the highway. As you drive onto the ramp you will see several cars already on the highway to your left. You are to merge in with these cars and again follow them without overtaking, letting them drive away, or following too closely.

Experimental Scenario 2:

1. In this scenario, you will start on a highway, again behind a lead car. Follow this car until it has changed from the original highway onto a perpendicular highway. Once you are on the new highway, orient yourself at the 60 mph speed limit and overtake any other vehicles going slower.
2. Later in this scenario, you will encounter a single truck ahead of you. Your task is to overtake the truck.

3) *Participant Consent Form, Experiment 2*

Participant Consent Form

Title: Driving behaviour and strategies

Investigators: Patrick Stahl (416-978-0881; pstahl@mie.utoronto.ca)
Dr. Birsen Donmez (416-978-7399; donmez@mie.utoronto.ca)
Dr. Greg A. Jamieson (416 946 8504; jamieson@mie.utoronto.ca)

You are being asked to take part in a research study. Before agreeing to participate in this study, it is important that you read and understand the following explanation of the proposed study procedures. The following information describes the purpose, procedures, benefits, discomforts, risks and precautions associated with this study. In order to decide whether you wish to participate or withdraw in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is known as the informed consent process. Please ask the investigator to explain any words you don't understand before signing this consent form. Make sure all your questions have been answered to your satisfaction before signing this document.

Purpose

This study looks into the behaviour of drivers in specific, stereotypical situations in traffic. The goal is to investigate different strategies of drivers to deal with those situations, and as a participant you will be asked to:

1. Drive through a simulated traffic environment
2. Participate in a post-experiment cognitive walkthrough (explained below)
3. Fill out a questionnaire after the experimental trials

Procedure

This study contains three phases. In the first phase, you will be introduced to the simulator, and have time to test it and become comfortable driving with it. In the second phase, you will drive through the scenarios of the experiment. We ask that you attempt to treat the simulation just like you were driving your own car, thinking of all elements of the simulation as if they were encountered in the real world. There will be nine short trials that you will be driving through. In the final phase of the experiment, you will be asked to review your drives together with the investigator and answer a questionnaire with respect to your general driving behaviour and the scenarios you just drove.

Risks

There are no major risks involved with this experiment, the tasks are not physiologically demanding, psychologically stressing, and there is no manipulation or deception involved. We want to make you aware of the possibility of simulator sickness (a form of motion sickness specific to simulators), however. Especially upon first using a driving simulator, there is a small chance of feeling dizzy, nauseous, or fatigued. If you feel any of these symptoms appear, please immediately stop the experiment and inform the investigator. The investigator will also monitor for any signs of simulator sickness.

Benefits

There are several benefits to conducting this study. The most important benefit is your contribution to research in driving behaviour, which will help understand different strategies of dealing with specific traffic situations, and guide the development of aids to help drivers deal with those situations. You will also gain experience with academic research and be able to use and test out a state of the art driving simulator. Last, we hope that you will personally benefit from the cognitive walkthrough in that you become more aware of your own driving behaviour.

Compensation

You will receive $10/hour for your participation at the end of this study. The experiment should take about two hours.

Confidentiality

All information obtained during the study will be held in strict confidence. You will be identified with a study number only, and this study number will only be identifiable by the primary investigator. No names or identifying information will be used in any publication or presentation. No information identifying you will be transferred outside the investigators in this study.

Please be advised that we video-record the experimental trials with four small web-cameras. One camera will be pointed at you, one will capture the steering wheel, one the pedals, and the final camera the overall scene. The videos will only be seen by the investigators and the primary investigator's research assistant. No video data will be released to any other party.

Participation

Your participation in this study is voluntary. You can choose to not participate or withdraw at any time.

Questions

If you have any general questions about this study, please call Patrick Stahl at 416-978-0881 or e-mail him at pstahl@mie.utoronto.ca.

Consent

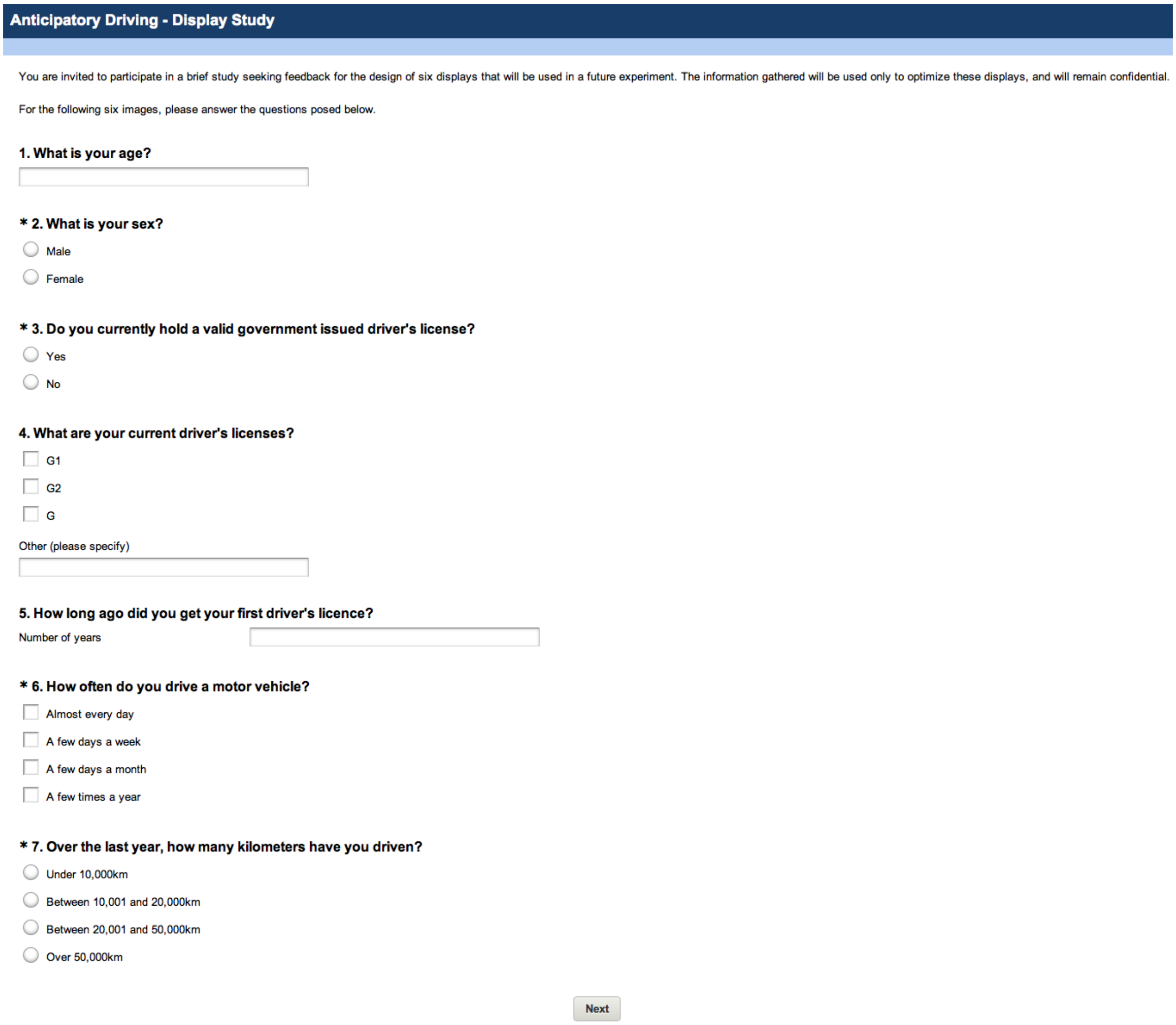
I have had the opportunity to discuss this study and my questions have been answered to my satisfaction. I consent to take part in the study with the understanding I may withdraw at any time. I have received a signed copy of this consent form. I voluntarily consent to participate in this study

______________________	______________	______________
Participant's Name (please print)	Signature	Date

I confirm that I have explained the nature and purpose of the study to the participant named above. I have answered all questions.

______________________	______________	______________
Investigator's Name	Signature	Date

D) Interface Study



Anticipatory Driving - Display Study

You are invited to participate in a brief study seeking feedback for the design of six displays that will be used in a future experiment. The information gathered will be used only to optimize these displays, and will remain confidential.

For the following six images, please answer the questions posed below.

1. What is your age?

*** 2. What is your sex?**

○ Male
○ Female

*** 3. Do you currently hold a valid government issued driver's license?**

○ Yes
○ No

4. What are your current driver's licenses?

☐ G1
☐ G2
☐ G

Other (please specify)

5. How long ago did you get your first driver's licence?

Number of years

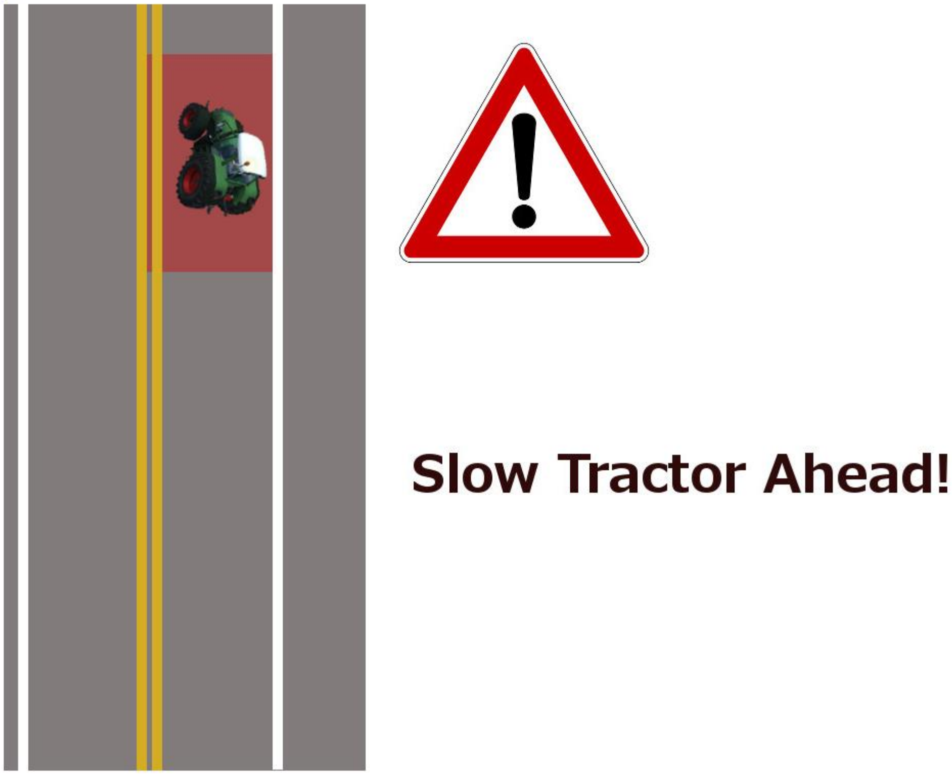
*** 6. How often do you drive a motor vehicle?**

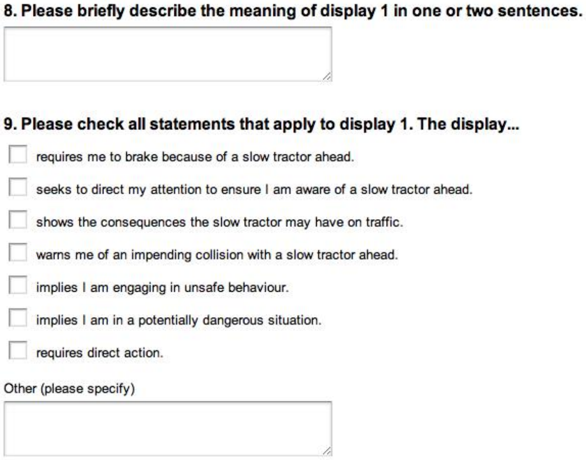
☐ Almost every day
☐ A few days a week
☐ A few days a month
☐ A few times a year

*** 7. Over the last year, how many kilometers have you driven?**

○ Under 10,000km
○ Between 10,001 and 20,000km
○ Between 20,001 and 50,000km
○ Over 50,000km

Display I





8. Please briefly describe the meaning of display 1 in one or two sentences.

9. Please check all statements that apply to display 1. The display...

☐ requires me to brake because of a slow tractor ahead.

☐ seeks to direct my attention to ensure I am aware of a slow tractor ahead.

☐ shows the consequences the slow tractor may have on traffic.

☐ warns me of an impending collision with a slow tractor ahead.

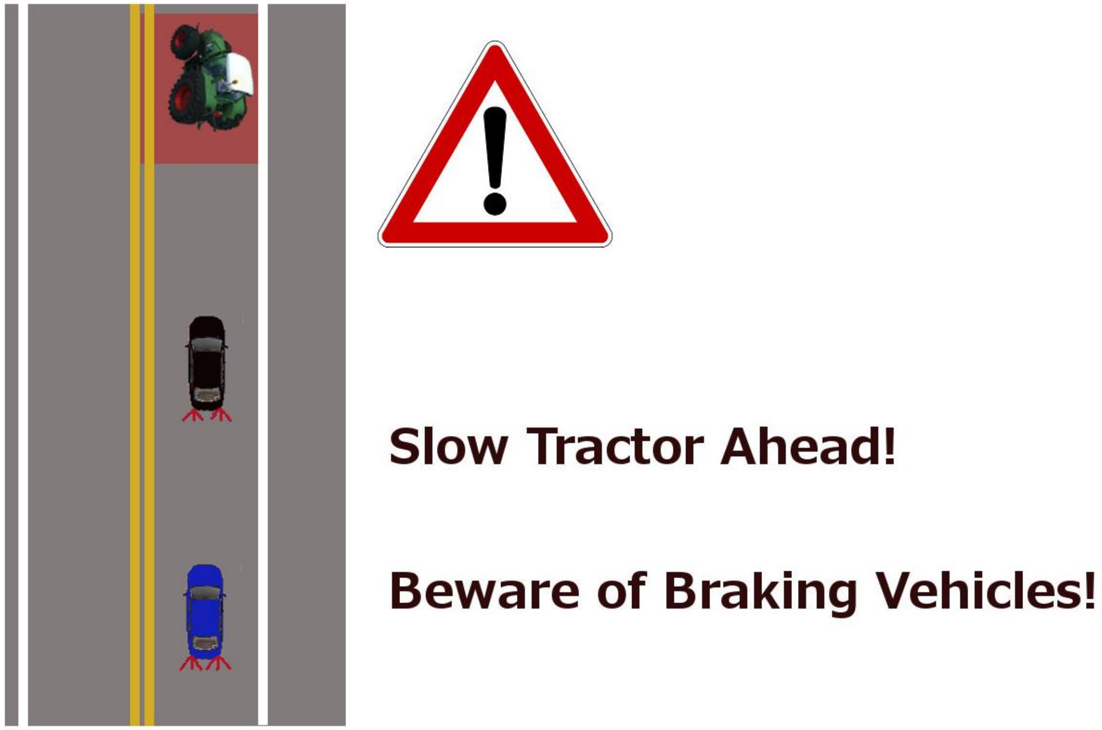
☐ implies I am engaging in unsafe behaviour.

☐ implies I am in a potentially dangerous situation.

☐ requires direct action.

Other (please specify)

Display II



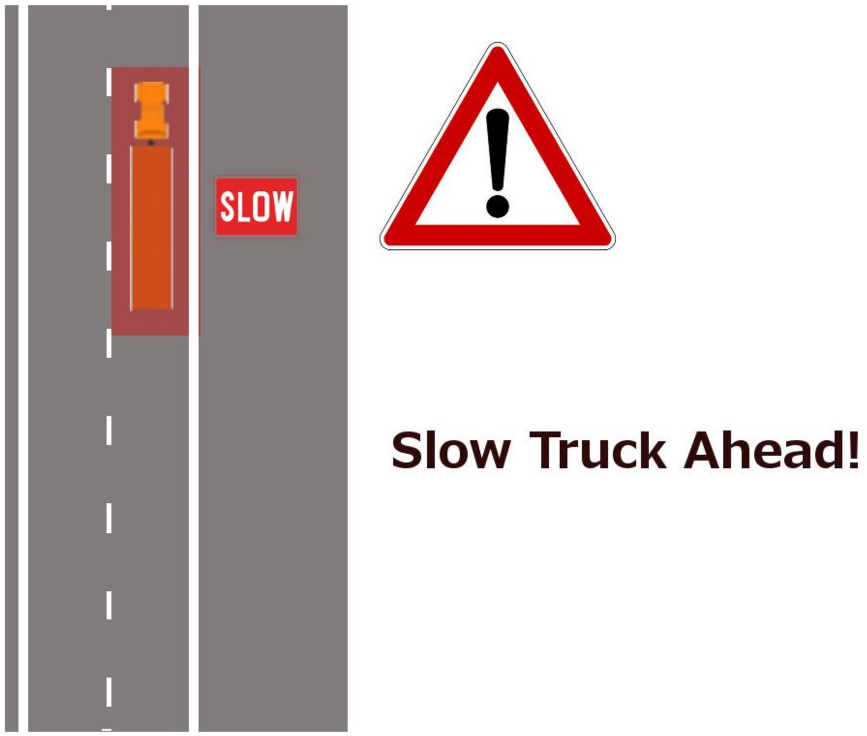
10. Please describe the meaning of display 2 in one or two sentences.

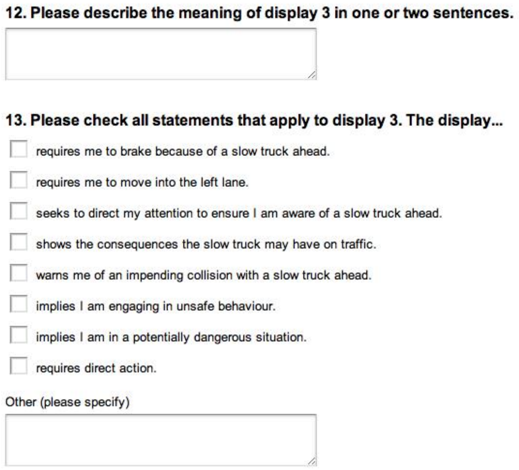
11. Please check all statements that apply to display 2. The display...

- ☐ requires me to brake because of a slow tractor ahead.
- ☐ requires me to brake because of braking cars ahead.
- ☐ seeks to direct my attention to ensure I am aware of a slow tractor ahead.
- ☐ seeks to prepare me for braking cars ahead of me.
- ☐ shows the consequences the slow tractor may have on traffic.
- ☐ warns me of an impending collision with a slow tractor ahead.
- ☐ warns me of an impending collision with the cars ahead.
- ☐ implies I am engaging in unsafe behaviour.
- ☐ implies I am in a potentially dangerous situation.
- ☐ requires direct action.

Other (please specify)

Display III





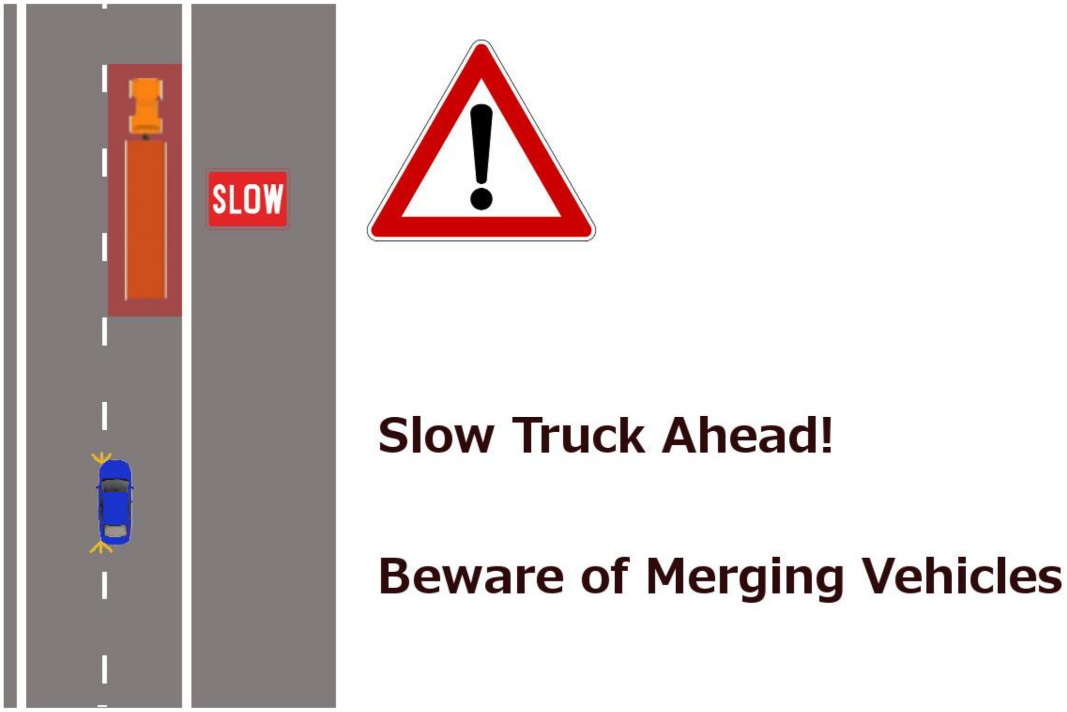
12. Please describe the meaning of display 3 in one or two sentences.

13. Please check all statements that apply to display 3. The display...

☐ requires me to brake because of a slow truck ahead.
☐ requires me to move into the left lane.
☐ seeks to direct my attention to ensure I am aware of a slow truck ahead.
☐ shows the consequences the slow truck may have on traffic.
☐ warns me of an impending collision with a slow truck ahead.
☐ implies I am engaging in unsafe behaviour.
☐ implies I am in a potentially dangerous situation.
☐ requires direct action.

Other (please specify)

Display IV

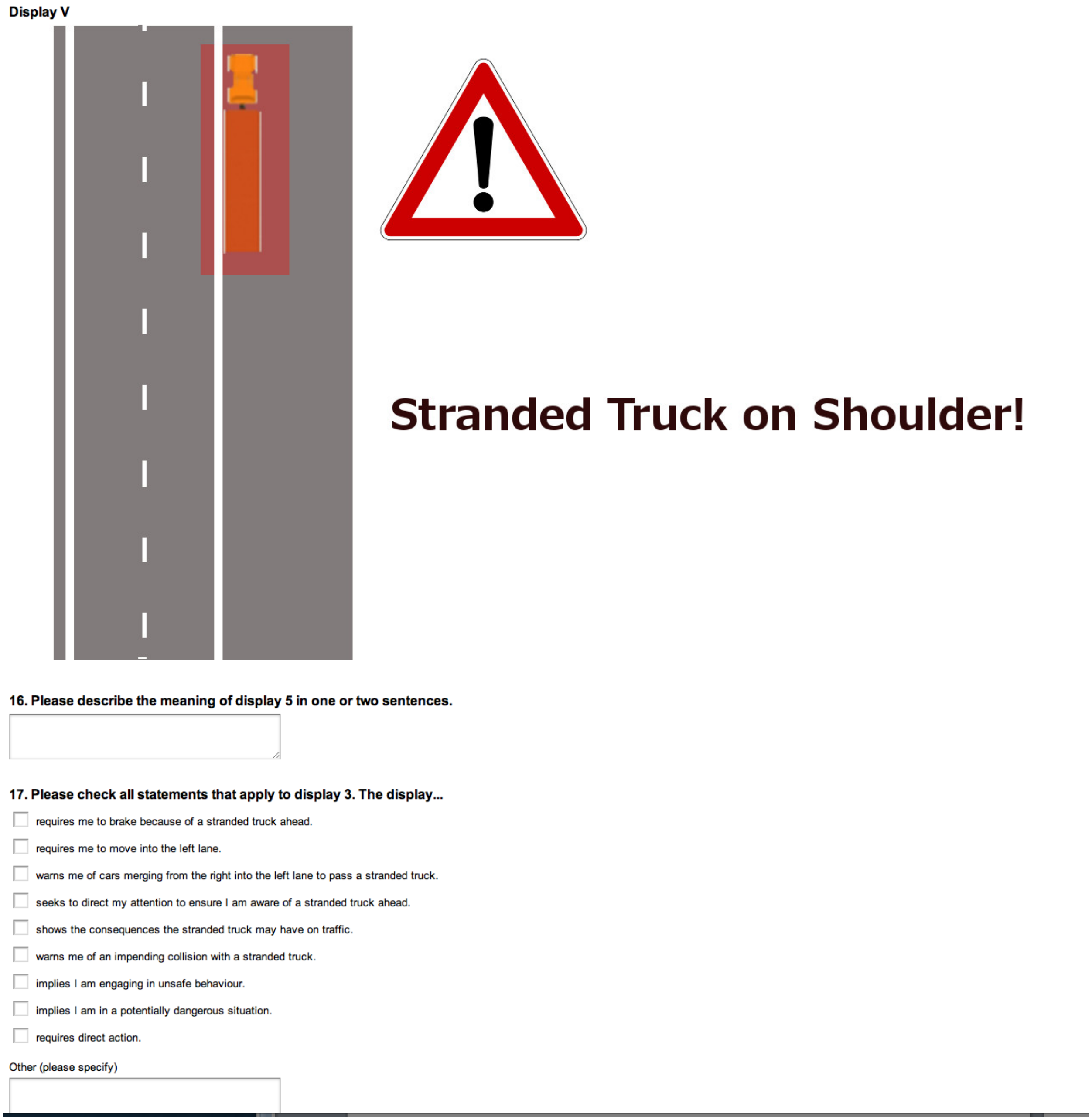


14. Please describe the meaning of display 4 in one or two sentences.

15. Please check all statements that apply to display 4. The display...

☐ requires me to brake because of a slow truck ahead.
☐ requires me to brake because of a car ahead.
☐ requires me to move into the left lane.
☐ warns me of cars merging from the right into the left lane to pass a slow truck.
☐ seeks to direct my attention to ensure I am aware of a slow truck ahead.
☐ shows the consequences the slow truck may have on traffic.
☐ warns me of an impending collision with a slow truck ahead.
☐ warns me of an impending collision with a car ahead.
☐ implies I am engaging in unsafe behaviour.
☐ implies I am in a potentially dangerous situation.
☐ requires direct action.

Other (please specify)



Display V

Stranded Truck on Shoulder!

16. Please describe the meaning of display 5 in one or two sentences.

17. Please check all statements that apply to display 3. The display...

☐ requires me to brake because of a stranded truck ahead.

☐ requires me to move into the left lane.

☐ warns me of cars merging from the right into the left lane to pass a stranded truck.

☐ seeks to direct my attention to ensure I am aware of a stranded truck ahead.

☐ shows the consequences the stranded truck may have on traffic.

☐ warns me of an impending collision with a stranded truck.

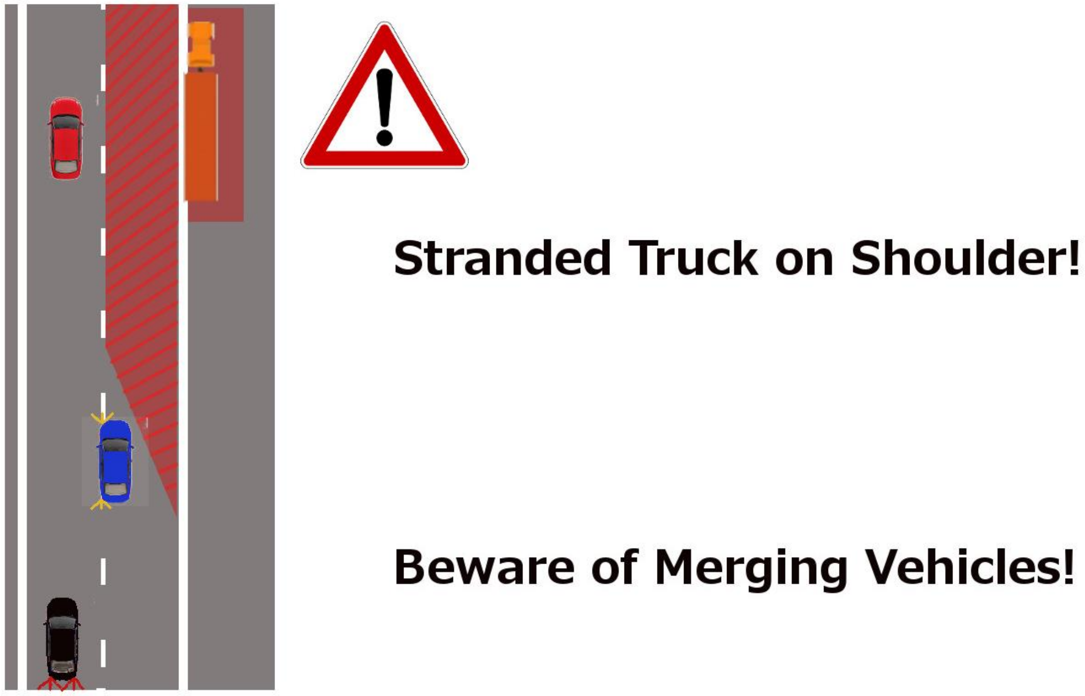
☐ implies I am engaging in unsafe behaviour.

☐ implies I am in a potentially dangerous situation.

☐ requires direct action.

Other (please specify)

Display VI



18. Please describe the meaning of display 6 in one or two sentences.

19. Please check all statements that apply to display 3. The display...

- ☐ requires me to brake because of a stranded truck ahead.
- ☐ requires me to move into the left lane.
- ☐ warns me of cars merging from the right into the left lane to pass a stranded truck ahead.
- ☐ seeks to direct my attention to ensure I am aware of a stranded truck ahead.
- ☐ shows the consequences the stranded truck may have on traffic.
- ☐ warns me of an impending collision with a stranded truck ahead.
- ☐ warns me of an impending collision with cars ahead.
- ☐ implies I am engaging in unsafe behaviour.
- ☐ implies I am in a potentially dangerous situation.
- ☐ requires direct action.

Other (please specify)