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Distracted by familiarity: Implications of 'autopilot' as a default cognitive mode

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ABSTRACT

Most trips are made, and most travel is done on roads and paths well-known. To provide insight in the cognitive processes involved in visual information processing of familiar traffic environments this paper considers a series of four consecutive empirical studies. The aim of this paper is 1) to discuss the implications of these insights on research methodologies used to measure driver attention and distraction and 2) to provide recommendations for policymaking, road design and vehicle design. This line of work consists of three studies on car driver behaviour (two driving simulator studies and a video-based study) and an observational study on pedestrian behaviour. The recurring theme in the results of these studies is that the progressive exposure to the same traffic environment enables participants to automatise their behavioural performance in traffic up to the point that it could be executed at skill-based level. As a result, attention is easily diverted away from traffic participation, while participating in traffic. Participants could act without thinking about it, so they didn't always even remember what they had done. People get used to familiar traffic environments so much that they don't have to think about walking or driving with much conscious focus. Hence, when studying road user behaviour and particularly driver distraction, it is crucial to mimic these natural circumstances as closely as possible. It is therefore proposed that within driver distraction research, route familiarity should be regarded as a context that enables distraction. What is more, is that the results point in the direction of a *familiarity paradox*: deviating from what is very familiar likely results in involuntary distraction, but being very familiar may lead to underload resulting in (voluntarily) diverting attention elsewhere.

1. Introduction

It is well-known in traffic research that driving along an unfamiliar route, in an unfamiliar vehicle or under unfamiliar weather conditions may be very demanding. For example, for foreign tourists in Amsterdam riding a bicycle for the first time. In fact, this kind of unfamiliar tasks may demand so much attention that it becomes a distraction, diverting attention away from activities critical for safely moving through traffic. Becoming familiar with a new task, such as driving a new route, is a gradual process ranging between the extremes of 'not familiar at all' till 'very familiar' (e.g. Fitts & Posner, 1967; Harms, Burdett & Charlton, 2021). While a task not familiar at all may demand a lot of attention, the opposite is true for very familiar tasks (e.g. Fitts & Posner, 1967; Rasmussen, 1983). Performance of very familiar tasks is characterised as seemingly effortless, requiring very little to no attention. The construct of

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familiarity can also be applied to negotiating one's surroundings, a key activity when participating in traffic. A recent systematic review on the role of route familiarity in traffic participants' behaviour revealed familiarity to have large effects on how people attend to and process the environment (Harms, Burdett & Charlton, 2021). Under conditions of high familiarity with an area, drivers' subjective task difficulty reduced and they displayed a general tendency to decrease cognitive control, with their brains slipping into 'autopilot'. At the same time drivers became increasingly prone to displaying non-driving related behaviours: mind wandering increased, the time spent looking at objects not related to traffic increased, as did their engagement in secondary tasks such as (smart) phone usage, music listening, talking and singing (similar to findings for route-familiar pedestrians). Moreover, many studies have shown that the probability of crash risk and violations increases when driving on familiar roads (Burdett et al., 2017; Burdett et al., 2018; Chen et al., 2005; Chevalier et al., 2016; Horvath et al., 2012; Intini et al., 2017; Payyanadan et al., 2019; Rosenbloom et al., 2007; Wen & Xue, 2019). High familiarity with an area seems to create a context that contributes to the occurrence of distraction in traffic.

Within transport research, distraction has been commonly understood as 'diversion of attention away from activities critical for safe driving toward a competing activity, which may result in insufficient or no attention to activities critical for safe driving' (Regan, Hallett & Gordon, 2011). Typically research on distracted driving addressed distractions in the road environment, such as billboards and electronic message signs (Beijer, Smiley, & Eizenman, 2004; Chattington, Reed, Basacik, Flint, & Parkes, 2009; Crundall, Van Loon, & Underwood, 2006; Decker et al., 2015; Holahan, Culler, & Wilcox, 1978; Kaber et al., 2015; Megías et al., 2011; Metz & Krüger, 2014; Pankok, Kaber, Rasdorf, & Hummer, 2015; SWOV, 2012; Young et al., 2009). In more recent years distracted driving research expanded its focus towards in-vehicle distractions, such as mobile phone use (e.g., Nicolls, Truelove, & Stefanidis, 2022; Oviedo-Trespalacios et al., 2016), infotainment systems (e.g., Imberger et al., 2020) and vehicle automation (e.g., Cunningham & Regan, 2018). Altogether our understanding of driver distraction has greatly improved. However despite the huge body of research on driver distraction, to the author's knowledge familiarity has not yet been considered as a context for driver distraction research. This, while increased familiarity with a traffic environment is associated with an increase of attention being diverted away from processing this environment. Better understanding the relation between route familiarity and driver distraction is especially important against a backdrop of recent road safety campaigns, which urge traffic participants to continuously attend the road, such as FIA's current global #3500LIVES campaign (FIA, 2022). This campaign outlines their 15 Golden Rules, of which one is simply requesting traffic participants to 'always pay attention'. It can be questioned whether it is even feasible for traffic participants to pay attention all the time, given that 1) most trips are made, and most travel is done on roads and paths well-known, and 2) route familiarity negatively impacts attention for the road (Harms, Burdett & Charlton, 2021).

The current paper represents a first attempt to bring research on distraction and route familiarity together by exploring route familiarity as a context that enables distraction. To set the scene this paper first addresses the process of skill development, which is a process underlying familiarity. Next a series of four consecutive empirical studies on visual awareness using route familiarity as a context are considered. This to provide insight in the cognitive processes involved in visual information processing of familiar traffic environments. These studies were performed as part of the author's PhD thesis (Harms, 2021). Next the results of this series are discussed as one whole. This is followed by a discussion on how familiarity as a context relates to existing research methodologies used to measure driver attention and distraction. The paper ends with example applications of familiarity as a context for distraction and attention in traffic, and recommendations for policymaking, road design and vehicle design.

2. The process of skill development

Becoming increasingly familiar with a new task, or in other words 'skill development', is a process described e.g. by Fitts and Posner (1967) and Rasmussen (1983). The central idea is that with repeated exposure humans reach an increasing level of familiarity. Fitts and Posner (1967) discerned three sequential stages: the cognitive, associative, and autonomous stages. In their model, control shifts from an initial, explicit control into more procedural forms of control. In the final, autonomous, stage further practice hones performance into an automatised routine. The final stage of skill acquisition described by Fitts and Posner bears strong similarities with the skill-based level in Rasmussen's threefold task hierarchy Rasmussen (1983).

Rasmussen (1983) proposed that depending on the level of experience, human beings perform tasks at a skill-based, rule-based, or knowledge-based level. Rasmussen distinguished between these levels based on how much mental effort and control, thus attention, is needed. Knowledge-based level performance requires most attention, skill-based level performance requires the least. When experience with a task and/or situation increases, execution of a task shifts from (controlled) knowledge-based to (automatised) rule- and skill-based performance. When tasks or situations are partly new, one can rely on previous experiences by selecting and testing of the most suitable mental models and adapt them to create a new model to fit the new environment. Examples of rule-based level performance are driving in an unfamiliar, foreign city or being a novice driver. Driving a car or – in the latter case – the concept of participating in traffic, are not new. Though the specific situation or task at hand (being a driver instead of e.g. a pedestrian) is. When one can rely on previous experiences by using the accompanying mental models, performance may be at skill-based level. At this level performance is mostly effortlessly and subconsciously. Thus, processing of task-related information may require very little attention. Examples of this are navigating from home to work, and stopping at, or crossing, a familiar intersection. Acts repeatedly practised, become skilled behaviour that can be performed without much cognitive deliberation.

For people to be able to act appropriately in a given situation, they must know what is going on around them, a state of mind also referred to as situation awareness (Endsley, 1995). Part of achieving situation awareness is selecting and integrating elements of the traffic environment into meaningful pieces of information. The amount of effort necessary for this cognitive process depends on the individual's level of experience with the task at hand and with the particular situation (Rasmussen, 1983). With practice, humans gain expertise and skill so they are not overwhelmed with stimuli anymore.

A more recent angle on the development of automaticity in relation to sensory input, comes from predictive processing theory (Clark, 2016). Following predictive processing, the brain makes continuous predictions of what will be seen and tries to minimise deviation between the prediction and actual sensory input. The brain is thought to actively minimise this deviation by updating the prediction based on sensory input, or/and moving (parts of) the body to bring about the predicted sensory input. For example by looking in a particular direction. Predictions are based on statistical models. By gradually tuning a generative model to repeated sensory input, a person is becoming increasingly familiar with, for example, a particular environment. Frequent exposure to the same stimuli or situations leads to less complex models and thus more accurate predictions. When deviation between the prediction and the sensory input is near to non-existent, little to no effort is required to adjust the prediction (Engström et al, 2018).

Although the theoretical models have their differences, the common theme is that with repeated exposure humans require less effort to process and act upon their surroundings. This line of thought is reflected in the results of the aforementioned systematic review on route familiarity (Harms, Burdett & Charlton, 2021). This review showed that route familiarity was typically reported to reduce the amount of cognitive control used to process the immediate environment compared to unfamiliar situations. Instead, attention was diverted away from the task of participating in traffic.

3. Method and results of a series of four studies

To provide insight in the cognitive processes involved in visual information processing of familiar traffic environments a series of four consecutive empirical studies on visual awareness are considered. In all four, peer-reviewed studies route familiarity was used as a contextual factor for human behaviour in traffic. Participants were either familiarised with a specific route by repeated exposure during the experiment (Studies 1–3) or they rated themselves as familiar with the area (Study 4). In all studies something in the environment had changed and the recurring theme was whether participants were aware of this altered situation. The change was always related to participants' task in traffic. In Studies 1 and 2 the change concerned the speed limit, in Study 3 it concerned a critical detour message, and in Study 4 it concerned an obstacle on the pavement. For the experimental studies (Studies 1 – 3) participants were requested to behave as they normally would in traffic and for the observational study (Study 4) participants did so by nature. This chapter deals with the method and most important results in light of the current paper. These are described in brief per empirical study. An overview of the studies is provided in Table 1. Although all four studies have been published in peer-reviewed journals, for the purpose of readability of the current paper their goal, method and results are summarised in this chapter.

3.1. Study 1

Goal. The aim of this study was to provide insight in whether drivers notice when electronic speed limits change into another speed limit along a familiar route. A prerequisite for purposeful speed limit compliance in the first place. The study has been described in more detail in Harms and Brookhuis (2016).

Method. To simulate regular driving conditions, twenty-four participants were familiarised with a particular route by driving the same route in a driving simulator nineteen times on five separate days. Part of the route consisted of a motorway where electronic speed limit signs were regularly displayed above every driving lane (see Fig. 1). At the 19th drive, speed limits changed from 80 km/h to 100 km/h on the last four out of eight consecutive signs. Both driving speed as well as verbal reports and recall and recognition surveys were used to measure change detection. In this study, 'change awareness' is defined by at least two measures indicating a participant has seen the change, including at least one measure representing a conscious awareness of the change (so a verbal report or survey response). Additionally participants performed a stimulus detection task during the drives, for which they had to report any time they noticed a red Volvo truck. The truck appeared a random number of times per drive and at irregular intervals in the opposing

Table 1
An overview of the four studies.

Study no.	Traffic mode	Type of study	*n*	Main results
#1	Driving	Driving simulator	24	• Participants failed to see that the speed limit on consecutive electronic road signs had changed. Instead they 'saw' the speed limit they expected to see and adhered to it. • Quick proficiency with a repeated stimulus detection task showed increased automaticity in visual information processing.
#2	Driving	Video-based	255	• When using repeated videos instead of repeated drives in a driving simulator, all participants were able to see that the speed limit on consecutive electronic road signs had changed. • Using motion in electronic road signs to attract attention in fact distracted participants. It diverted attention away from processing the information contained in the signs.
#3	Driving	Driving simulator	32	• Repeated exposure to messages on an electronic road sign suppressed the need for severe speed reduction to process the sign's new content compared to drivers unfamiliar with the sign displaying any messages. • Several drivers familiar with an electronic road sign displaying ads, failed to recall when this sign displayed a critical route instruction (recalling an advertisement instead). This, despite they had just complied with this route instruction by taking the exit.
#4	Walking	Observation	234	• All participants avoided walking into a signboard on the pavement, yet more than half of them (53.8 %) was unaware of the signboard. They were 'acting without awareness'.

Fig. 1. Example of a gantry with a variable speed limit in real-life (left) and in the driving simulator (right).

traffic stream during the first 19 drives (excluding the motorway section equipped with gantries, so the task would not interfere with change perception concerning the electronic speed signs).

Results. The main outcome of the study was that after passing all signs, one expects 6.25 % of the participants still to be unaware that the speed limit had increased (based on chance), while the results showed most participants had failed to notice the speed limit change (58.3 %). Instead, they 'saw' what they expected to see: a speed limit of 80 km/h.

The outcome of 'having seen the change' is the result of apprehension of the change on at least one of the four electronic signs. As per sign there is a 0.5 chance of apprehension (50 %), it is expected that at the end of the experiment 6.25 % of the participants have failed to see what changed (as $(0.5)^4 = 0.0625$). Based on chance, the remaining 93.75 % is expected to have seen the new speed limit. A binomial test compared this percentage with the actual results. It showed that only 41.7 % of the participants being aware of the speed limit change by the end of the experiment, is significantly less than what may be expected, $p < 0.001$. Both change-aware as well as change-unaware drivers became quickly proficient with the truck detection task after repeated practice. Correct truck detections started at 69 % (drive 1), but by drive 5 the average detection rate was already at 95 % and fluctuated between 93 % and 99 % for the remaining drives. The main result of the study is visualised in Table 2.

3.2. Study 2

Goal. A follow-up study aimed to assess various countermeasures to improve drivers' ability to detect changes in electronic speed limits along familiar roads. A description of the study in more detail can found in Harms and Brookhuis (2017).

Method. Using a video-based study, 255 participants were familiarised with a motorway by viewing it 13 times before the speed limit changed. Countermeasures included 1) leaving electronic signs blank prior to a speed limit change and adding motion signals by

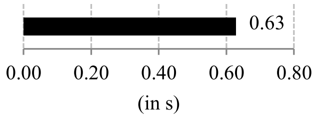
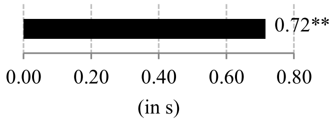
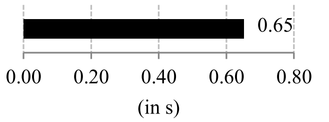
Table 2
Main result of study 1: after familiarising themselves with the electronic speed limit signs displaying a speed limit of 80 km/h on eight consecutive gantries (drive 1 – 18), more than half of the participants failed to perceive that in drive 19 the speed limit on the electronic signs had changed from 80 km/t to 100 km/h. Instead they saw what they expected to see: a speed limit of 80 km/h.

Gantry #	1	2	3	4	5	6	7	8
Drive 1–18	80	80	80	80	80	80	80	80
Drive 19	80	80	80	80	100	100	100	100
Participants' report of the speed limit in drive 19					80 58.3 % ✗ 100 41.7 %* ✓ * Less than based on chance, $p < 0.001$. Based on chance, 93.75 % is expected to have seen the new speed limit			

means of 2) flashing amber lights or 3) a ‘wave’. The suggestion that the depicted speed limit was moving in a wave-like manner was obtained by constantly moving a blacked out row of pixels from the top to the bottom of the sign and vice versa. The study consisted of a 2x3 design, mixing the type of speed sign preceding the change (Blank and Active) with three types of change indicators (Regular, Flash and Wave), as depicted in Table 3. Participants were instructed to press the space bar when detecting a change. Both change detection accuracy as well as response time were measured.

Results. Contrary to expectations, the main result of the study was that the countermeasures to improve change detection did not have the desired result (see Table 3). Leaving signs blank prior to the change instead of displaying speed limits continuously did not alter change detection accuracy. It solely reduced response time for participants who accurately detected the change ($F(1,239) = 9.30$, $p = 0.003$). What is more, the usage of motion signals – which were meant to enhance change detection – instead eroded detection of the changed speed limit. Whilst all participants were able to detect the change when depicted in the regular way (i.e., without motion signals), post hoc tests using the Bonferroni correction showed that the decreased detection accuracy was statistically significant for Flash, with α 0.05, $p = 0.042$, 95 % CI[0.002, 0.161]. For Wave it was not, $p = 0.090$, 95 % CI[-0.008, 0.152]. On top of that, in the Flash condition participants also took longer to detect the change, as confirmed by post hoc tests using the Bonferroni correction comparing Flash vs Regular, $p = 0.002$, 95 % CI[0.026, 0.147], and Flash vs Wave, $p = 0.005$, 95 % CI[0.020, 0.143]. Response time between the Regular and Wave conditions did not vary significantly. This suggests that using motion signals, in particular flashers, to attract attention to electronic signs in fact distracts people, diverting attention away from processing the information contained in the

Table 3
Main result of study 2: after participants familiarised themselves with the prevailing speed limit by viewing a video of the same road repeatedly, none of the countermeasures to improve detection of the speed limit change (occurring in drive 14) had the desired result. The countermeasures were tested in a 2x3 design, mixing the type of speed sign preceding the change (Blank and Active) with three types of change indicators (Regular, Flash and Wave). Both change detection accuracy and response time (RT) were measured. Particularly the flashing amber lights (Flash) eroded both detection accuracy as well as response time. Statistical significance is indicated as follows: *** sig. with α of 0.01, ** sig. with α of 0.05, and * sig. with α of 0.10.

Drive 1–13	Drive 14 (speed limit change)	Change detection accuracy in drive 14	Mean normalised response time (RT) in drive 14, for those who detect the change
 Active or	 Regular	100 %	
 Blank	 Flash change + flashing amber lights	91.9 % **	
	 Wave change + ‘wave’	92.8 % *	
Effect on change detection in drive 14: • No main effect on detection accuracy, only an interaction effect *** • Main and interaction effect on RT (both ***)	Effect on change detection in drive 14: • Main and interaction effect on detection accuracy (respectively ** and ***) • Main and interaction effect on RT (both ***)		

signs. As this study was executed using videos, perception might deviate from that in a more naturalistic environment.

3.3. Study 3

Goal. The third study attempted to disclose possible negative effects that repeatedly displaying traffic-irrelevant messages on overhead electronic road signs may have on the perception of, and subsequent compliance with, traffic-relevant messages for route-familiar drivers. A more detailed account on this study can be found in Harms, Dijksterhuis and colleagues (2019).

Method. To ensure the focus lied on familiarisation and expectations instead of on driver distraction due to the electronic signs themselves, the traffic-irrelevant messages were designed to meet the same design principles as regular, relevant, electronic road sign messages (Kroon et al., 2016; Rijkswaterstaat, 2012). By meeting aforementioned guidelines, it was assumed that the amount of distraction induced by the design of the traffic-irrelevant messages would not to exceed the level of distraction that is accepted for traffic management messages. In a driving simulator, thirty-two participants were all familiarised with the same route by driving nine times along a motorway equipped with an overhead electronic road sign. Participants were divided between a control group and an experimental group (the advertisements group). For the advertisements group, up to drive 8, the electronic road sign displayed various advertisements. Whereas for the control group it was blank. In the 9th drive, the electronic road sign displayed a critical detour message for all participants (see Fig. 2). An overview of the study is provided in Table 4. Both route choice as well as verbal reports and recall and recognition surveys were used to measure detection.

Results. One of the main outcomes of the study was that the critical route instruction – informing drivers to take the nearest exit – resulted in compliant driver behaviour in both the advertisements group as well as the control group. With 75 % of the control group and 81 % of the advertisements group taking the exit, a Fisher's Exact Test showed that compliance did not differ significantly between both groups, $p = 0.500$, and that effect size was low, $\Phi = 0.076$. However, whereas the advertisements group reduced speed marginally to increase the time to process the critical route instruction on the electronic road sign, the control group, on the contrary, displayed a relatively sharp, statistically significant, speed reduction (see Fig. 3). In the control group, every participant who managed to take the exit also correctly recalled the critical route information. Surprisingly, in the advertisements group 31 % (n = 4) of those who had complied with the critical route instruction subsequently failed to recall this message (recalling an advertisement instead). This recall performance differed from the control group (one-sided Fisher's Exact Test = 0.057) with large effect size, $\Phi = 0.419$. Table 4 provides a visualisation of the main result of the study.

3.4. Study 4

Goal. In the previous studies cases were found of participants complying with visual input from the road environment, yet failing to recall this input. Therefore this concluding, observational study addressed acting without awareness while executing a highly automated task, i.e. walking. The study aimed to assess 1) whether pedestrians are sufficiently aware of their surroundings to successfully negotiate obstacles in a city, and 2) whether various common walking practices - such as secondary task engagement, mind wandering, and taking familiar routes - affect awareness of obstacles and, or, avoidance behaviour. Further details regarding this study can be found in Harms, van Dijken and colleagues (2019).

Method. To this end, an obstacle, i.e. a signboard was placed on a pavement in the city centre of Utrecht, the Netherlands (see Fig. 4). The behavioural measure consisted of the distance to the signboard before pedestrians moved to avoid it. After passing, participants were interviewed to obtain thought samples (i.e., what they were thinking), self-reported route familiarity, a confirmation of secondary task engagement and to assess awareness through recall and recognition of the signboard and its text. Recall consisted of mentioning the signboard and its text as part of the thought samples, as part of describing the area they had just passed or as part of the answer whether they had passed a sign on the pavement and if so, what had been visible on the sign. All while facing away from the signboard. Recognition concerned participants' response after turning around and viewing the blank backside of the signboard they had just passed and – if not volunteered by then – being told the message on the signboard. This to also access degraded awareness

Fig. 2. Example of an overhead electronic road sign in real-life (left) and in the driving simulator (right), informing drivers they have to deviate from their route. Translations of the texts are "A27 to Breda is closed. [Bridge] Malfunction. Breda follow Rotterdam" (left) and "A31 closed after Bergdorp. Accident. Oostdorp follow Bergdorp" (right).

Table 4
Main result of study 3: after familiarising themselves with the overhead electronic road signs displaying either a blank sign (control group) or a selection of ads (advertisements group), the critical route instruction displayed on this road sign in drive 9 – informing drivers to take the nearest exit – resulted in compliant driver behaviour in both groups. While the control group sharply decreased speed when approaching the critical route instruction, this was not the case for the advertisements (ads) group. Despite of taking the exit, some participants in the ads group failed to recall seeing the route instruction, recalling seeing an advertisement instead. During drive 2–8, the ads group were shown ads in this order: A_1, A_2, A_1, A_3, A_2, A_1, A_2. Drive 1 was a practice drive on the same route, in which the overhead electronic road sign was left blank for both groups. The four varieties of the overhead electronic road sign message read: A_1, the ad of a nation-wide supermarket chain ("It is the 'hamster weeks' again at Albert Heijn"), A_2, the ad of a nation-wide chemist's chain ("DA, that is the chemist's, the friendly specialist. DA"), A_3, the road safety slogan ("Wear a seatbelt, in the backseat as well. This is how you get home"), and the critical route instruction ("A31 closed after Bergdorp. Accident. Oostdorp follow Bergdorp").

Group	Drive 2–8	Drive 9	Exit behaviour in drive 9	Recall of the critical route instruction after correctly taking the exit
Ads	Het zijn weer hamsterweken bij Albert Heijn A_1, ad advertisement of a nation-wide supermarket chain DA, dat is de drogist, de vriendelijke specialist. DA A_2, ad of a nation-wide chemist's chain Gordel om, ook achterin Daar kun je mee thuiskomen A_3, road safety slogan	A31 na Bergdorp dicht ongeval Oostdorp volg Bergdorp The critical route instruction	81 % takes exit + Marginal speed reduction to increase the time to process the critical route instruction	A31 na Bergdorp dicht ongeval Oostdorp volg Bergdorp 69% ✓ DA, dat is de drogist, de vriendelijke specialist. DA or Het zijn weer hamsterweken bij Albert Heijn or Gordel om, ook achterin Daar kun je mee thuiskomen 31 % ✗
Control	Blank sign	A31 na Bergdorp dicht ongeval Oostdorp volg Bergdorp The critical route instruction	75 % takes exit + Relatively sharp, statistically significant, speed reduction to increase the time to process the critical route instruction *% taking the exit: no significant difference*	A31 na Bergdorp dicht ongeval Oostdorp volg Bergdorp 100% ✓ *Recall differs statistically significantly*

(Overgaard & Sandberg, 2012). Participants behavioural and cognitive reactions towards the signboard have been merged to define four distinct levels of awareness: 1) *full awareness*, the highest level of awareness at which participants displayed a rich conscious experience and representation of the signboard, consistent with their ability to avoid and recall it; 2) *partial awareness*, to account for degraded conscious experiences and representations, based on participants' ability to avoid the signboard and to eventually recognise it after failing recall; 3) *acting without awareness*, a level at which participants were unable to report passing the signboard while having managed to evade it; 4) *no awareness, no acting*, a level at which participants bumped into the signboard.

In this study 234 pedestrians participated. Route familiarity was assessed by using a 10-point scale on which participants rated their familiarity with the area. This scale was derived from Charlton and Starkey (2018) and ranged from 1, "this street is completely new to me, I have never walked here before" to 10, "I know this street very well, I walk here regularly". Of the participants 56.4 % were identified as "route familiar" and 18.8 % as "route unfamiliar", scoring respectively 8 – 10 and 1 – 3 on the route-familiarity scale.

Results. The study's main outcome is that more than half of the participants (53.8 %) was unaware of the signboard, still none of them had bumped into it. Only 32.9 % was *fully aware* of the signboard (both avoiding the signboard and mentioning the signboard and its text in recall), which is less than recalling the signboard by chance, a binomial test showed, $p < 0.001$ (see Fig. 5). Mind wandering, being engaged in secondary tasks such as talking with a companion or using a mobile phone, and being familiar with the route, did not affect awareness nor avoidance behaviour.

Despite prior expectations, route familiarity did not affect awareness or avoidance behaviour, nor did it relate to overt secondary task engagement or mind wandering. This may suggest that – contrary to driving – walking is in fact so ubiquitous that route familiarity does not facilitate further automaticity. Instead, walking is already executed as a largely, highly automated procedure requiring very little to no attention.

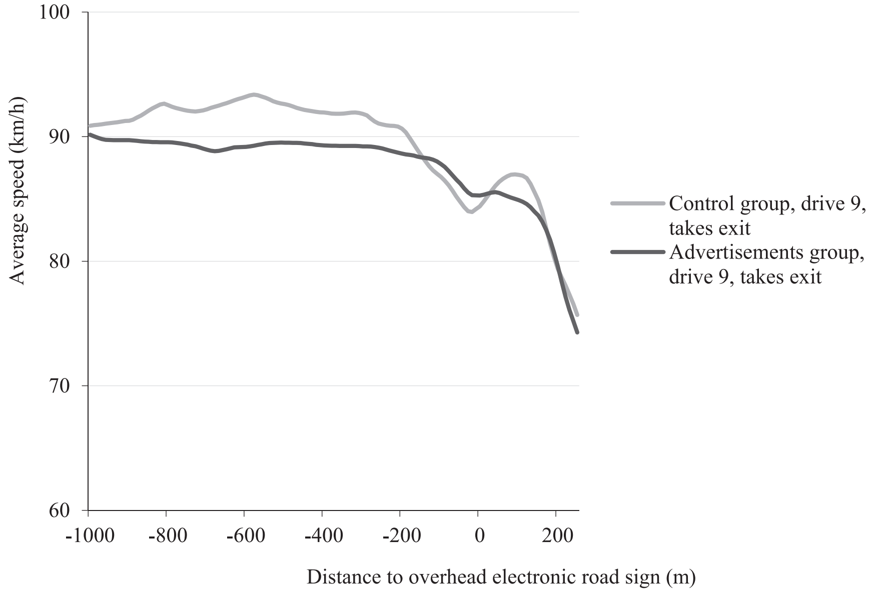


Fig. 3. Average driving speed in drive 9 near the overhead electronic road sign, exclusively for participants eventually taking the exit (differentiating between control group and advertisements group). The overhead electronic road sign displaying route information is the point of reference, hence differentiating between the distance before passing the overhead electronic road sign (-1000 to 0 m) and the distance between the overhead electronic road sign and the exit (0 to 273 m). For the control group, the speed difference between 200 m and 150 m, 150 m to 100 m and 100 m to 50 m preceding the road sign shows participants' statistically significant decrease in driving speed ($t = 3.13$, $df = 15$, $p = 0.007$; $t = 4.13$, $df = 15$, $p = 0.001$; $t = 2.84$, $df = 15$, $p = 0.012$, respectively, using a paired samples T-test). This decrease discontinued from 50 m to the moment of passing the road sign ($t = 0.90$, $df = 15$, ns). The advertisement group on the contrary did not significantly decrease speed between 200 m and 150 m, and 150 m to 100 m preceding the road sign ($t = 2.09$, $df = 15$, ns; and $t = 1.25$, $df = 15$, ns). These participants decreased speed 100 m to 50 m and 50 m until passing the road sign ($t = 4.24$, $df = 15$, $p = 0.001$; and $t = 2.23$, $df = 15$, $p = 0.041$).

Fig. 4. The signboard reads "Welcome to St.-Jacobsstreet" (in Dutch: "Welkom in de St.-Jacobsstraat"). One observer was positioned on the pavement across the road (not visible in the picture) while the other was located adjacent to the first lamp post visible in the picture.

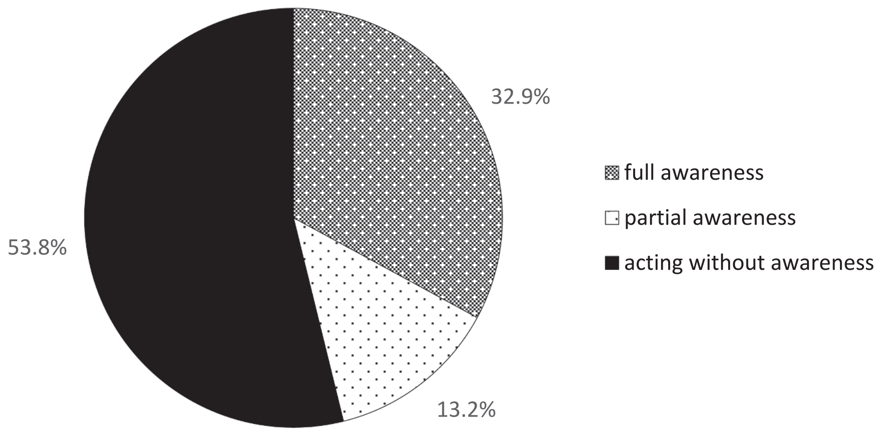


Fig. 5. Main result of study 4: all participants avoided walking into a signboard placed on the pavement, yet more than half of them (53.8 %) was unaware of the signboard. They were 'acting without awareness'. The level of awareness for the signboard is based on walking behaviour (avoidance of the signboard) and ability to report the signboard during recall or recognition. The amount of participants being fully aware of the signboard is significantly lower than recalling the signboard by chance ($p < 0.001$), while tallying full and partial awareness did not differ from chance level at all ($p = 0.266$).

4. Discussion considering all four studies together

4.1. Skill-based behaviour: Automaticity in visual information processing

Route familiarity typically reduces the amount of cognitive control drivers use to process the immediate environment they are passing through. As a result of repeated exposure one may enter a cognitive mode also described as 'being on autopilot' while still actively participating in traffic (Harms, Burdett & Charlton, 2021). In 1983, Rasmussen already noted that at skill-based level 'the total performance is smooth and integrated, and sense input is not selected or observed: the senses are only directed towards the aspects of the environment needed subconsciously to update and orient the internal map. The man looks rather than sees.' (p. 259). The current studies suggests that this is also applicable for the concept of route familiarity. We postulate that repeated practice with the same environment results in the ability to negotiate a familiar environment at skill-based level. This automaticity is reflected in both visual information processing itself (Studies 1–4), as well as in the amount of cognitive control that is required to process visual information (Harms, Burdett & Charlton, 2021). The experiences that resulted from practice, in turn resulted in expectations about which visual information to be present, leading to increased automaticity in visual information processing. An example of this is the proficiency that participants displayed after repeated practice with a stimulus detection task (Study 1). Due to increased automaticity, the required effort to process visual information decreases. Increased automaticity with reading the electronic road sign participants were repeatedly exposed to, as described in Study 3, enabled them to anticipate on a new text more easily. Participants without practice with reading the sign decelerated more severely to process it – a form of self-regulation to mitigate attentional overload (De Waard, 1996) – than those who were accustomed to seeing texts on the sign. In Study 2, the repeated exposure to the same speed limit signs resulted in an increase of participants' ability to memorise the correct speed limit. In some cases, increased automaticity in visual information processing also led to reports of what one expected to see; which was the case with the failure to report the change in electronic speed limits (Study 1), the failure to report the critical route instruction (Study 3) and the failure to report the signboard (Study 4).

4.2. Disengagement: Monitoring rather than attending

Interestingly, the failure to report an instruction or object that should guide behaviour does not necessarily equal the failure to act. In Study 3, all participants who reported they had seen an advertisement on the electronic road sign instead of the critical route instruction, had changed their driving behaviour; they took the first exit, in accordance with the critical route instruction. A similar result was obtained in a study by Fisher (1992) on the recall of pictorial road signs and speed limits rather than written messages. Fisher found that 41 % ($n = 11$) of drivers who reduced their speed after passing a pedestrian warning sign and subsequent speed limit sign, were unable to recall these signs only moments after passing them. In a similar vein, Charlton (2007) found curve warning signs were quite effective for reducing drivers' speeds; while in a previous study (2006) he had found that many drivers failed to detect and recognise these signs. Study 1 also reported on a participant who complied with a sudden speed limit increase without any recollection of the new speed limit (this one participant equalled 14 % of those who adhered to the new speed limit). However, since it was only one participant this finding was initially regarded as an anomaly we could not explain. By now, the findings show that the phenomenon to act on information that cannot be reported is not exclusive for drivers. In fact, it is applicable to pedestrians too (Study 4). All participants who failed to report having passed the signboard (53.8 %) had changed their walking trajectory in order to avoid bumping into it. A similar result was also obtained by Hyman and colleagues (2014).

Considered together, these studies display a pattern of traffic participants unable to report about information present in their surroundings while they changed their behaviour in accordance with this information. This is a novel finding in traffic psychology research. When the inability to report equals unawareness – similar to e.g. Sandberg, Timmermans, Overgaard and Cleeremans (2010) and Spering and Carrasco (2015) – this behaviour may be regarded as acting without awareness. This mode of performance enables traffic participants to process visual information to the extent that they may behave accordingly, although they are unable to access the processed information to report it. This means that the lack of a verbal report to confirm an object's presence does not necessarily mean that the object has not been taken into account. It may also suggest that the processing of visual information, of which one is not aware, is likely to be highly automated. Further proof for this hypothesis has been provided by the finding that participants were able to engage in other tasks, such as conversing, listening to music, using their mobile phone and mind wandering (Study 4). This form of highly automated processing of visual information may be regarded as a monitoring process, bearing strong similarities with the tandem model for visual information processing as proposed by Charlton and Starkey (2011; 2013), Clark's predictive processing theory (2016) and the mental disengagement from traffic participation, also referred to as being on autopilot, as described for driving, cycling, and walking (Charlton & Starkey, 2011; 2018; Middleton, 2009; Van Duppen & Spierings, 2013; Wunderlich, 2008). Due to its high degree of automaticity, this monitoring process strongly relies on previous experiences and expectations. It may increase the chance that changes in the traffic environment may be missed, which occurred for example in Study 1, but it does not mean that all changes will necessarily not be processed or acted upon. In fact, continuous variability in objects in the traffic environment may become part of a subconscious monitoring process, as long as they have been sufficiently practised.

4.3. Study limitations

One might argue that the most apparent limitation of the studies is the fact that was focussed on route familiarity only, while in general other factors in traffic also vary in their degree of familiarity. For example, the degree of familiarity with the vehicle, with specific traffic situations, with specific road users (e.g. cyclists), or even the weather. Specifically in Study 1 – 3, not only the route was kept the same during the repeated drives, all other circumstances have also been kept either the same or somewhat similar. Some small variations have been introduced, e.g. in fellow traffic participants, to keep the experience as realistic as possible. Keeping circumstances similar between the repeated drives of these experiments did serve a purpose. It was done to control the number of factors that may influence driver behaviour. In real life, apart from being familiar with a route, other factors and one's familiarity with them, will likely also affect behaviour.

Another limitation when interpreting the results, is the design of the advertisements used in Study 3. In the Netherlands commercial advertisements are not allowed to feature on electronic road signs. Therefore the advertisements used in Study 3 have been devised for the sole purpose of the study. To avoid that the advertisements would be distracting, they were designed following the same guidelines as regular, traffic-related messages on electronic road signs (Kroon et al., 2016; Rijkswaterstaat, 2012). In other words, they were explicitly designed not to exceed the level of driver distraction that is acceptable for traffic management messages and road safety slogans. This may contradict with the main aim of commercial advertisements: attracting attention. Care should also be taken when interpreting the results of Study 3 in relation to displaying advertisements on electronic road signs, due to the length of the familiarisation process. Although results indicated familiarisation, this process took 1.5 h instead of months or years. Controlling exposure to electronic road signs over a longer period is only feasible in a longitudinal field study. In conclusion, further research is required before road authorities should allow deployment of commercial advertisements on electronic road signs.

Studies 1 and 2 both targeted detecting changes in electronic speed limit signs, under conditions of repeated exposure to the same environment. In study 1 only 41.7 % of the participants noticed the changed speed limit. Study 2 used similar road sign conditions (i.e., repeatedly displaying the same speed limit followed by a new speed limit). However, in contrast to Study 1, in Study 2 all participants were able to detect the changed speed limit. The main difference between both studies is 'passively' watching videos (Study 2) versus active driving in a driving simulator (Study 1). It appears that despite repeated exposure to the same driving environment, using videos does not sufficiently mimic driving to reproduce effects of familiarity on change detection.

Table 5
Overview of the main practical implications for research methodologies.

#1. Study context	While unfamiliarity likely results in involuntary distraction, being very familiar may lead to underload resulting in (voluntarily) diverting attention elsewhere. Given both the impact and the prevalence of route familiarity in everyday driving, route familiarity should be considered as a more integral context for experimental, naturalistic and observational research in transport psychology.
#2. Measuring awareness of visual information	To get an understanding of the visual information that has been processed to the extent of awareness, a variety of seemingly similar though (semi) mutually exclusive verbal report measures need to be used. This, as different methods appeal to a different manner of retrieving the visual information that has been processed. E.g., while recall appears to mostly tap into richer experiences and representations, recognition may also touch upon more degraded levels of awareness.
#3. Measuring perception of visual information	To distinguish between what is seen and what is not seen one should account for *acting without awareness* – a cognitive mode in which visual stimuli guide behaviour without the participant being able to report on this stimuli. Hence it is insufficient to rely solely on verbal reports. To assess (the results of) visual information processing they need to be combined with behavioural measures.

5. Implications for research methodologies

The findings of the four studies provide guidance for setting up future studies to measure driver attention and distraction in a more ecologically valid manner. In this chapter the implications for research methodologies are discussed. Table 5 provides an overview of the main practical implications.

5.1. Research methodology: Cognitive measures for visual information processing

One of the challenges regarding the study of visual information processing is how to measure the results of this process. This is a prerequisite to know what is really seen, or in other words, what visual information has been processed. The simplest, and arguably most common method to assess what has been seen is to ask (e.g. Al-Gadhi et al., 1994; Johansson & Rumar, 1966; Johansson & Backlund, 1970; Luoma, 1991). Researchers may use methods such as recall and recognition. When using recall, the participant has been presented with a visual stimulus which has disappeared, and which needs to be retrieved from memory. For recognition, the participant is presented with the reappearing target stimulus, generally together with some distractor stimulus, and the task is to recognise the target stimulus. The methods of recall and recognition, however, likely yield different results. Not because different information has been processed, but because both methods appeal to a different manner of retrieving the visual information that has been processed. This has been clearly demonstrated for traffic participants in Studies 1, 3 and 4. Hence the two methods cannot substitute each other, since differences in outcome between the two measures may be explained by differences in retrieval from memory. They may also be explained in terms of different levels of awareness. Recall appears to mostly tap into richer experiences and representations, which may be more easily accessible and retrieved, whereas recognition may also touch upon more degraded levels of awareness. Contrary to recall, a recognition question may serve as a prompt (Tulving & Pearlstone, 1966), enabling participants to retrieve and confirm stimuli that have been present, whether it concerns the actual message in the electronic road sign (Study 3) or the presence of a signboard (Study 4). As a result of degraded awareness some participants may hold only very vague experiences, which they thereupon might not share with the observer (Overgaard & Sandberg, 2012). The method of recognition, providing participants with a prompt, is known to make it easier for them to report these experiences after all. Another method to prompt participants to report even the faintest experiences or representations is to encourage them to guess (Overgaard & Sandberg, 2012). This method has also been used in the current studies. The downside of this method is that participants might also provide a correct answer by chance, rather than as a result of visual information processing. Regardless, for all these methods applies that as a single method, none of them is capable of providing a full overview of the output of visual information processing. Hence, to get an understanding of the visual information that has been processed to the extent of awareness, a variety of seemingly similar though (semi) mutually exclusive verbal report measures need to be used.

5.2. Research methodology: Behavioural measures for visual information processing

To distinguish between what is seen and what is not seen it is insufficient to rely solely on verbal reports. This has been clearly demonstrated by the cognitive mode of acting without awareness. Visual stimuli may guide behaviour without the participant being able to report on this stimulus, as shown by Fisher (1992) and in Studies 3 and 4. This means that the presence of said stimuli have in fact been sufficiently processed in order for the participants to be able to successfully incorporate them in their behaviour, e.g. by negotiating the obstacle, by taking the correct exit or by complying with the actual speed limit. The ability of people to act without awareness underlines the importance of behavioural measures when assessing (the results of) visual information processing. For measuring visual information processing, not all behavioural measures are equally suitable. Behaviours that require a discrete choice are to be preferred, such as obstacle avoidance or taking an exit. Speed on the other hand is continuous behaviour, making it more difficult to determine if and when information has been processed. Another complicating factor with speed is that in a driving simulator there is little incentive to stick to the speed limit. In Study 1 the speed limit was increased after eighteen trials for this reason, but the behavioural parameter was not very informative regarding the visual information that had been processed. Additionally, even using discrete-choice behaviour will not provide an exhaustive measure for visual information processing. This has anecdotally been pointed out by the participant in Study 3 who had failed to take the exit, and yet, at the end of the trial triumphantly exclaimed 'the road wasn't closed at all!'.

In conclusion, it remains difficult if not impossible to exhaustively assess whether visual information has been processed. Nevertheless, to optimise measurements of visual information processing – extending from full awareness, via partial awareness to acting without awareness – it is advised to combine various cognitive and behavioural measures (preferably discrete-choice behaviour).

6. Conclusions

Being familiar with a road scene, and consequently being seemingly inattentive, is the default mode of how we behave in traffic. This behavioural mode is supported by increased automaticity in behaviour, also referred to as skilled behaviour, having many perks. It is swift, energy efficient and allows us to perform multiple tasks at once. These are all components that are potentially very beneficial in traffic, however, it also has drawbacks. Errors are lurking, as shown by the increased likelihood of crash risk and violations (Harms, Burdett & Charlton, 2021). What is more, is that for skill level errors it is very difficult to realise our mistakes. Hence making it harder to correct them (Reason, 1990). In other words, it is harder to realise our mistakes when our brain is on 'autopilot' and attention is diverted away from traffic-related activities toward a competing activity. At the same time, there appears to be a *familiarity paradox*: being very familiar may lead to underload resulting in (voluntarily) diverting attention elsewhere, while deviating from what is very familiar may result in involuntary distraction. The question is how to navigate between these extremes.

For road authorities and policymakers, it is a given that many of their road users will be familiar with the roads they are driving on. Hence, it is important to realise that not all information presented on or near the road will be processed by traffic participants. Not because traffic participants do not wish to comply with the rules, but simply because of the energy efficient way their human information processing system processes, i.e. filters, information present. In familiar environments, people will typically see what they expect to see. Changes to familiar environments may go unnoticed. This means traffic participants may be disobeying the rules, but not deliberately at all. To mitigate this, traffic information on signage should be supported by the actual traffic environment. For example merely changing a fixed speed limit sign from 50 km/h to 30 km/h without changing the road layout accordingly is asking for non-compliance.

Especially in familiar environments, human performance is mostly executed on a skill-based, low-attention automated level. Therefore, road authorities should take this into account and aim to design for automaticity. A very useful approach is the concept of self-explaining roads (Theeuwes & Godthelp, 1995; Theeuwes, 2021). Self-explaining design thrives on automaticity and corresponding expectations. By design, traffic participants learn what to expect and how to behave on a particular road type. Repeated exposure to the design not only hones automaticity for a single road, it also expands to familiarising traffic participants up to a certain level with roads they have not yet encountered before.

However, as the traffic environment is dynamic by nature, changes are immanent. When bringing changes to the attention of the driver, the frequency of occurrence of said changes plays a role. Preferably, rare changes are avoided, as these are difficult to incorporate in one's scheme of what to expect in an otherwise familiar environment. For changes which are rare, such as changing priority at an intersection (Martens, 2007), road authorities are advised to provide additional means to attract attention and emphasise what has changed. Prudence is warranted when deploying flashers or other motion-based traffic signals to highlight changes. Indeed motion may attract traffic participants' attention, though it might not necessarily focus attention to any additional message one wants to convey. For example adding flashers to a changed speed sign in Study 2, resulted in attracting drivers' attention, making them aware that 'something was going on'. However at the same time, for part of the drivers, the attention-grabbing motion signal masked the fact that the speed limit had changed. This means that flashers should typically only be deployed when they can convey the message themselves. For example, when alerting road users that something will happen and they should be alert and reduce speed (without requiring compliance with an exact speed limit). Another strategy for road authorities to avoid rare changes in familiar environments, is to make the changes less rare. An example of this is avoiding settings for a signalised intersection which by default provides right of way when approaching, with the exception of some rare conditions which result in a red light instead. Road authorities should aim to design the traffic system in such a way that it enables changes to occur with a frequency high enough to become part of traffic participants' monitoring system. Thus making it easier for traffic participants to actually perceive the change and display the right behaviour.

For vehicle design and policymaking, the observation that humans very familiar with a particular area have a habit of drifting into a cognitive autopilot mode is very relevant as well. It underlines the importance of driver monitoring systems, or occupant status monitoring, to be able to recognise cognitive inattentiveness. One of the open questions for future research, is 1) how to distinguish between an alert driver capable of an immediate response and a driver whom has mentally shifted into an autopilot mode, unable to respond swiftly and adequately to unexpected events; and 2) how to communicate this to the driver in an appropriate way. Perhaps the car can even accommodate and increase situation awareness for drivers on 'cognitive autopilot'?

With the rise of increasingly advanced driver assistance systems (ADAS), drivers display a tendency of diverting attention away from the driving task (Nordhoff et al., 2023). Similar to familiar environments, ADAS which decrease engagement with the driving task lower the amount of attention allocated to the driving task. Hence it can be questioned if driving on familiar roads may enhance this effect of disengagement with the driving task. When studying the effects of ADAS on driver attentiveness it is relevant to take into account the context of driving in a familiar environment. Moreover, research could provide guidance for policymakers to draft more accurate regulations regarding driver attentiveness. For example in the regulation for ALKS (United Nations, 2021) – which is an automated driving system (ADS) –, driver attentiveness has now been defined solely based on gaze direction and driver head movement. The regulation states that a driver is to be deemed attentive when gazing primarily at the road ahead, or at the rear-view mirrors, or when head movement is primarily directed towards the driving task. Based on the current understanding of route familiarity and distraction this definition provides insufficient protection against cognitive inattentiveness.

Ultimately, the broader concept of familiarity may also be applied to familiarity with driving a car itself. An emerging trend in automotive is to replace physical knobs and buttons by a touch screen. Recently, Swedish car journalists have shown that this introduction of the touchscreen as a large centre console in the car has fuelled diversity between vehicle dashboards (Diits Vikström, 2022). Their study across twelve different cars indicated it was difficult for drivers to find specific controls when they were located in unexpected locations, in multi-level touch screen menus. Deviating from familiar patterns while controlling the vehicle, may result in skill-based errors which require attention to correct. These types of errors can be mitigated by achieving a certain level of standardisation across different brands of vehicles. Particularly when targeting regularly used controls and time-critical controls. This, to reduce the number of involuntary distractions while driving.

Recent work presented by Oviedo Trespalicous (2022) focussed on variety in driver support systems (ADAS). They found that the vehicle behaviour of a single ADAS type may very well differ between car brands. What is more, is that different approaches by car manufacturers to seemingly similar types of ADAS, have resulted in drivers being confused over the behaviour of their vehicle. The introduction of new technologies in vehicles appears to have increased the variety between vehicles of different brands. In other words, being familiar with one vehicle might not be helpful understanding how to operate the vehicle of another brand. Similar to road design, both the design of vehicle driving behaviour as well as the design of vehicle interfaces may benefit from a framework for self-explaining design, leading to a level of standardisation across vehicle brands.

For general traffic research, the ecological validity of studies in traffic psychology could improve dramatically when testing participants in their habitat, their natural environment, i.e. a familiar environment, as participating in traffic in a familiar context is the default. Hence, research should either mimic the everyday context by controlled, repeated exposure, or confine to traffic behaviour in the natural habitat.

As part of the systematic literature review on route familiarity (Harms, Burdett & Charlton, 2021), it was found that increased route familiarity is associated with a decrease in cognitive control, with drivers drifting into *autopilot*, with attention being diverted away from the driving task and with reduced task difficulty. Task difficulty has even been reported to drop to the point that driving a familiar route resulted in boredom. However, no mentions were found that increased route familiarity also resulted in (task-induced) fatigue, drowsiness or sleepiness. This is interesting, as literature has shown that boring, highly monotonous drives may increase the risk of driver drowsiness (e.g. Mishler & Chen, 2023; Thiffault, 2011; Thiffault & Bergeron, 2003). Further research is warranted to understand whether driving along familiar routes may result in fatigue or drowsiness behind the wheel.

When studying traffic participants, it is important to include behavioural measures next to self-report measures, to control for acting without awareness. Acting upon information without having become aware of it, is possible when performance can be executed at skill-based level; a level of automaticity which is enabled by progressive exposure to the same traffic environment. This level of automaticity also contributes to attention being diverted away from traffic participation while participating in traffic. It is therefore proposed that within driver distraction research route familiarity should be regarded as a context that enables distraction.

Acting without awareness is not limited to driving. It appears to be a universal cognitive state for human beings when they are up and awake. This is the heart of automaticity and the base of our sheer existence which may also suggest that mobility is not so much a task itself. In fact, it points in the direction that to the general commuter – who is accountable for most journeys (Mucelli Rezende Oliveira et al., 2016) – transport is nothing more than a means to get from A to B, to proceed with their life. Hence, when studying road user behaviour and particularly driver distraction, it is crucial to mimic these natural circumstances as closely as possible.

CRediT authorship contribution statement

Ilse M. Harms: Conceptualization, Investigation, Formal analysis, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [At the time of research, Ilse Harms was employed at Rijkswaterstaat (the national Dutch road authority), Connecting Mobility (joint program of the Dutch road authority and the corresponding ministry) and the Dutch Ministry of Infrastructure and Water management consecutively, while carrying out her PhD research at the University of Groningen].

Data availability

Data will be made available on request.

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