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Chapter 12

Effectiveness of Forward Collision Warning Systems: a contribution from the cognitive analysis combining behavioural and electrophysiological measurements

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Abstract

This chapter discusses Forward Collision Warning Systems (FCWS), describing the characteristics and the functions of some of the systems currently on the market and presents an overview of behavioural studies evaluating the effectiveness of these systems on road and in simulators. Results are presented from recent studies using electroencephalography and the associated Event Related Potentials allowing, through the analysis of brain activity, a more in-depth understanding of the nature of the cognitive processes in the context of FCWS. These studies address three important questions:

1. Are FCWS as effective as they are expected to be when drivers are distracted?
2. What are the consequences of driving with a system that is not completely reliable?
3. Is there any behavioural adaptation to the FCWS over their use in time? Are the consequences of this adaptation positive or negative?

The chapter shows that FCWS provides potential benefits for road safety, but certain factors such as the attentional state of drivers but the reliability level of the system can mitigate its effectiveness.

12.1 Introduction

Advanced driver assistance systems (ADAS) have experienced a rapid development in recent years to optimise their potential benefits on road safety. It has been estimated that these systems contribute to reducing the number of casualties on the roads. Because of this, the European Commission has recently proposed the mandatory installation of some ADAS such as the lane departure warning system and the collision warning system in heavy vehicles from 1st November 2013 [1]. Nevertheless, light vehicles will be exempted at present because of the lower benefit-to-cost ratio compared to heavy vehicles.

Since ADAS have appeared on the market, research in the field of human factor has been promoted to investigate the impact of both the benefits of these systems on drivers' behaviour and their potential failures or limitations. Some of these systems warn drivers by an audible, visual or/and haptic signal when inappropriate behaviour is detected, either because an action is required but is not carried out or because the action carried out is not the right one. This chapter presents a review of the literature focused on a particular ADAS, the Forward Collision Warning System (FCWS). Nevertheless, some of the questions and discussions considered here could be applied to other warning systems.

FCWS are designed to reduce the number and/or to avoid rear-end collisions by providing warning to drivers. Traditional behavioural measures obtained in driving simulators and field operational tests are useful tools for evaluating the effectiveness of such systems, but they are not the only ones. Physiological data obtained through the event related potential technique can complement behavioural data. Reporting on data from these different methodological approaches, we discuss whether the system reaches one of its main objectives, i.e. to assist distracted drivers, and then how the system reliability affects the efficiency of the system and driver's acceptance. Finally, in the last section of this chapter certain studies examining the behavioural adaptation to the system are presented. Specifically, the effects on behaviour due to driving with the system over the time (from the introduction of the system to long term effects of ADAS use) and the consequences of driving without the system after a period of habituation to the system are discussed.

12.2 <u>The utility of FCWS</u>

As mentioned above, FCWS have been developed to warn drivers of potential rear-end collisions. Although the percentage of these collisions resulting in fatalities is relatively low compared to the percentage of injuries [2], these accidents are one of the most prevalent types of collision, disturbing traffic flow and representing an important economic cost for society. The environment (e.g. poor visibility, road type) and the vehicle (e.g. defective brakes) are some of the contributing factors to the rear-end collisions, in 5 - 11% and 12 - 20% of these accidents, respectively. However, the factor that most frequently contributes to rear-end collisions is the driver, accounting for between 75 - 93% of the cases. More precisely, inside the driver category, distraction has been involved in about 60% of the rear-end collisions [3, 4].

FCWS are based on sensors which continuously monitor certain parameters such as the relative speed, lateral position and distance between two vehicles. Although a wide variety of algorithms have been designed to calculate the moment for triggering the warning, most of them are based either on the time to collision between the obstacle and the following vehicle or on the minimum distance required to stop the vehicle safely [5]. When a certain threshold value is reached, predicting a potential risk of collision, the system provides a warning signal (e.g. visual, auditory, and/or tactile) to alert the driver.

The system, as well as providing assistance by warning the driver (Forward Collision Warning Systems), can also take an active part in the braking process by preparing and/or by applying partial or full braking automatically (Forward Collision Avoidance Systems). This active avoidance module could prevent or reduce the severity of the collision should the driver not react in time or not react at all. Moreover, the active avoidance system has become more relevant in preventing collisions since it has been demonstrated that most drivers do not apply enough force on the brake pedal [6] and that a high percentage of drivers only release the accelerator pedal or even do not react at all [7].

Driving simulators have been one of the most frequent tools used in the evaluation of FCWS and most research has shown positive effects of the system when drivers are undistracted. This benefit has been demonstrated, for example, by a reduction of the number of collisions [8], by faster braking reaction times following the detection of critical situations [9], and by the adoption of longer and safer headways [10]. Other studies such as Georgi et al. [11], have estimated the benefits of the system by developing models which apply the algorithm used by the system in real-life accidents. They categorized three different types of driver: lethargic drivers with the longest reaction times and lowest decelerations, realistic drivers as an intermediate level, and best drivers with the fastest reaction times and highest decelerations. According to their predictions, FCWS prevented 74% of collisions for best drivers, 38% for realistic drivers and 1% for lethargic drivers. In a more ecological context, using a field operational test, Najm et al. [7] assessed the impact of FCWS and advance cruise control

(ACC) systems for four weeks. 66 drivers drove without the system during the first week to obtain the baseline and with the system during the remaining three weeks. The results indicated that the exposure to conflicts (brake or steer at the last-second at a comfortable deceleration), near-crashes (brake or steer at the last-second at a hard deceleration), and severe near-crashes (minimum time to collision less or equal to 3s and maximum deceleration greater than 0.3g) in the last period of the test were reduced in about 20% compared to the first period. Based on different rear-end collision databases, these authors estimated that the system could prevent about 10% of these accidents. These studies show a range of benefit from these systems which fluctuates from 10% to 70% approximately [12]. This wide range could be explained by the different variables considered in these studies such as the type of system used and its limitations, the methodological approach chosen, the characteristics of drivers or the weather conditions. Moreover, it is necessary to consider other factors which can have a direct impact on the effectiveness of the system. In this chapter, the impact of the system according to the attentional state of drivers as well as the impact of the system as a function of its reliability level will be analysed. Furthermore, in order to shed light on this aspect, we are going to consider an alternative research method to the classical behavioural data such as the electroencephalography and the associated event related potentials.

12.3 A new approach for evaluating the effectiveness of FCWS

Different tools are available for investigating the effect of this kind of assistance system, from the most fundamental techniques such as simplified simulator experiments conducted in a laboratory, to more realistic contexts using driving simulators and to almost or real driving conditions such as field operational tests and naturalistic driving experiments. Among these studies we can highlight the classical trade-off between experimental control and ecological validity.

Given the difficulty in simulating rear-end collisions in real-life situations, most studies are employing driving simulators where different scenarios as well as the severity of collisions can easily be manipulated. Behavioural measures (e.g. reaction time, steering wheel angle, speed) are used most frequently by researchers in these studies. Not only behavioural data can be recorded in driving simulators. Often, these measures can be enhanced by other complementary techniques such as the analysis of information given by drivers (i.e. questionnaires, in-depth interviews) or the analysis of physiological measures (i.e.

electrooculography, galvanic skin response, heart rate, electroencephalography). Although physiological measures are still not very frequent in driving simulators, they provide complementary and additional information that in some cases is not observable in drivers' behavioural performance. In this part, we therefore will focus on the electroencephalography (EEG) and the associated Event Related Potential (ERP) techniques.

Electroencephalography is the study of the spontaneous electrical activity of the brain that can be recorded by electrodes placed on the scalp. Event Related Potentials are obtained from the electroencephalogram by filtering and averaging the activity time-locked to the stimulus of interest. The stimulus of interest is repeated a great number of time. The averaging allows reducing the random noise (i.e. movement artefacts), and so extracting the specific response to the target stimulus. As a result, a different succession of waves or components appears, depending on the type of stimulus presented and the nature of the task carried out. These components are usually designated by a letter (N or P) corresponding to the polarity of the component (Negative or Positive) and a number corresponding to its position in the chronology (i.e. P1, N1, N2, P2, P3) or the classical latency of the peak (i.e. N185 corresponds to a negative component peaking around 185 ms following the stimulus of interest) (see Figure 12.1).

"Figure 12.1 about here"

Figure 12.1 Example of a grand-average ERP showing a typical P3 component at parietal areas

This technique presents a high temporal resolution (on the order of milliseconds) which enables the identification of the different stages of information processing. The first stage of the neural processing chain can be identified even before the stimulus appears, reflecting the anticipation of a stimulus. For example, the contingent negative variation (CNV) is a slow negative wave appearing typically when two stimuli have been presented associated (Figure 12.2). Thus, when the first stimulus or warning always precedes the second or target stimulus, participants can expect the target stimulus and prepare their responses due to the appearance of the warning stimulus [13].

"Figure 12.2 about here"

Figure 12.2 Example of a grand-average ERP showing a typical CNV component at central areas

In the 200 ms following the stimulus presentation, ERP components such as P1 and N1 have been linked to sensory processes as well as to the discriminative processing and are mainly modulated by physical attributes of the stimuli [14]. After about 200 ms, the later ERP components such as N2/P3 are thought to reflect higher cognitive processes. The N2 component is elicited by tasks involving cognitive control, novelty stimuli, perceptual matching and response conflict, and the attention required for the processing [15]. The P3 component can be used as an indicator of the attentional resources allocation and working memory updating [16, 17]. In general, it is possible to identify differences between experimental conditions by analysing the differences in ERP in terms of peak amplitude and/or peak latency of the ERP components of interest. In a broader sense, differences in peak amplitude of the wave could indicate the different degree of attentional resources engaged in the processing of the stimulus, and differences in peak latency of the wave (earlier or later occurrence in time) could be related to the speed of stimulus information processing.

The implementation of the ERP technique in driving studies is not widespread due to some constraints, such as the high saccadic and motor movement sensitivity and the high number of trial repetitions required in order to reach an acceptable signal-to-noise ratio. Despite these constraints, there are a few ERP simulator studies which mainly investigate the negative effect of performing a concurrent cognitive task while driving [18, 19]. Nevertheless this technique has been implemented only recently in the study of advanced driver assistance systems and, specifically, in the study of FCWS [20].

12.4 Are FCWS effective for distracted drivers?

The major contributing factor to rear-end collisions is driver distraction or inattention. Therefore, if FCWS are expected to help distracted drivers in particular, the effectiveness of these systems should be evaluated according to the attentional state of the drivers, distracted or not.

Regan et al. [21] define driver inattention as ‘insufficient or no attention to activities critical for safe driving (p.5)’. Driver distraction, or driver-diverted attention, is a type of driver inattention where the attention to activities critical for safe driving is threatened by the diversion towards another competing activity. These competing activities can require cognitive, perceptual (i.e. visual, auditory), and/or motor resources, identifying the different distraction categories. Secondary visuo-motor tasks seem to produce the higher degree of interference with the driving task, although this could be mitigated by compensatory strategies. For example, visual concurrent tasks tend to impair lane keeping performance and increase the number of off-road glances but also induce speed reductions, whereas cognitive tasks generally provoke the opposite effect of visual concurrent tasks [22, 23].

Several reports have focused on the impact of FCWS on distracted drivers, but few studies have compared the distraction condition with the control situation (without any distraction); that is, assessing the impact of FCWS on distracted and also undistracted drivers. Data obtained in simulators show that distracted drivers also benefit from the warning systems by the reduction of the number of collisions [8], by faster braking reaction times in detecting critical situations [24], and/or by longer and safer headways [25]. Moreover, in some cases, the system even completely dissipates the negative effect of the secondary task [8, 26].

Electrophysiological studies have been recently conducted in driving contexts in order to assess the impact of secondary tasks. For example, Strayer and Drews [18] found that in a task where participants had to react to intermittent lead vehicle decelerations, the P3 amplitude was reduced and the P3 latency was delayed when they were engaged in phone conversations, suggesting a negative impact on the driving task when the memory load increased. Similarly, Rakauskas et al. [19] studied the impact of secondary tasks while driving and detecting unexpected sounds (oddball paradigm). They found that the P3 amplitude to novel sounds was especially reduced by a cognitive secondary task presented by cell-phone, showing that the processing of novel information is deteriorated by the dual task. In the context of FCWS, the ERP technique was introduced only recently by Bueno et al. [20]. These authors conducted an ERP study in a simplified driving simulator to evaluate the impact of a surrogate FCWS according to the attentional state of the participants, distracted or not by a secondary cognitive task. Participants were instructed to follow a lead motorcycle and they had to react by decelerating when the brake light (target) of the lead motorcycle was lit up. An auditory warning could forewarn participants that the motorcycle was going to brake soon. The results showed that the warning system reduced the reaction time when participants were undistracted but not when they were distracted. ERP data showed a benefit from the warning system at higher cognitive level (N2) suggesting that the warning could enhance the temporal expectancy regarding the target. However, and in parallel to behavioural data, this effect was only observed in simple task condition and not when participants were distracted. A possible explanation for this unexpected result could come from the experimental design. Indeed, an initial deceleration of the motorcycle occurred systematically before braking in all trials, whether or not the braking was preceded by the warning signal. Thus, participants may have used this motorcycle deceleration as an additional and better predictor of the brake light occurrence instead of the warning signal which was not always reliable. Therefore, in a recent study, Bueno et al [27] eliminated the predictive value of this motorcycle deceleration for the forthcoming brake light in order to increase the effectiveness of the FCWS under dual task conditions. The results indicated that participants were faster when they had available the warning signal compared to when no warning signal was given. At the electrophysiological level, this warning effect occurred at preparatory (increase of the amplitude of the CNV) and higher cognitive level (reduction of the peak latency of the P3). In addition, a strong negative impact of the secondary task was observed at behavioural and electrophysiological level with or without the system. This result suggests that the presence of the warning was not enough to compensate the negative effect of the dual task.

These last two studies have contributed to an increase in the knowledge about the processing of warning signals in driving. According to these results, it seems that the warning signal intervenes in motor preparation process (CNV) and higher cognitive processing (P3). These findings are also consistent with the findings of earlier non-driving studies showing warning signal operates in the stage of response selection [28] and that it could reduce the peak latency of the P3 [29].

Contrary to the positive effects on distracted drivers presented at the beginning of this section, the last two studies analysed here [20, 27] showed that the warning system was not always effective when drivers were distracted. Therefore, at present it is not clear whether these systems achieve their main purpose of mitigating the negative effects of the distraction. Although conclusions could not be drawn due to the limited number of studies evaluating the impact of the FCWS in distracted and undistracted drivers and their diverse methodology employed, there are some relevant questions to be considered.

Firstly, given that secondary tasks can differ in modality (visual, auditory, cognitive, etc.) and complexity level, the effectiveness of the system could vary depending on the type and difficulty of the secondary task. It could be possible that the dual task interferes with the warning signal when both warning and secondary task share the same modality. It is known that in dual task paradigms, the likelihood of interference produced when performing two tasks from the same modality (e.g. both tasks are auditory) is higher than when these tasks belong to different modalities (e.g. visual and auditory) [30]. As a result, the effectiveness of an auditory warning could see reduced if, for example, drivers are distracted by a secondary auditory task. Thus, auditory and visual-auditory warnings seem to be effective in helping drivers to detect potential collisions when they are distracted by a visual secondary task [8, 24, 26]. However, when the nature of the secondary task is auditory (i.e. phone conversations) and also when the complexity of the task increases (i.e. mental mathematics and categorisation questions), an auditory warning seems less effective than a tactile warning [31].

Secondly, from research using driving simulators [32] or ERP approach (but in non-driving related contexts [33]), multimodal warnings seem to be more effective that unimodal warnings. Indeed, receiving redundant warnings from two different modalities could be advantageous in the case of distraction or in the case of warning failures.

Finally, the difficulty level of the secondary task could also undermine the effectiveness of the warning system. It is known that the amount of attentional resources available is considerably reduced by the presence of another competitive task [30, 34]. When secondary tasks are highly demanding on a cognitive level, it might be possible that participants need to invest a lot of attentional resources to dealing with both tasks at the same time. Consequently, it is possible that the warning signal cannot be completely processed given the lack of attentional resources available, as could have occurred in the study of Bueno et al. [20]. In another study conducted in our laboratory, we investigated the impact of the difficulty of the secondary task on the effectiveness of the warning system. In this study in a driving simulator, only behavioural measures were recorded. The results showed an increase in the reaction time (RT) when participants were distracted by a high difficulty cognitive secondary task, but also when they were distracted by a low difficulty secondary task. However, when the warning system was available, RTs were shorter than the baseline (no warning, no distraction) only in the condition of low difficulty distraction, suggesting that the benefit from the system, at least partly, depends on the drivers' attentional resources available (manuscript in preparation).

This result could support the hypothesis that warning signals are not treated automatically and need attentional resources to be processed.

12.5 Does the reliability of the system affect its effectiveness?

Besides drivers' attentional state, the effectiveness and acceptance of the system and driver behaviour may also be affected by the reliability level of the system. Indeed, depending on the type of algorithm and scan sensor, the system may malfunction, producing false alerts and/or misses of critical events. False alerts refer to the situations in which an alert is issued in the absence of any potential collision, for example, when there are highly reflective objects. Nuisance alerts can be defined as alerts triggered in an appropriate situation but perceived by drivers as inappropriate because of their frequency, timing, intensity or modality [35]. Nuisance alerts can also be considered as alerts triggered in an inappropriate situation but whose origin could be justified by the presence of a potential threat (i.e. an alert triggered by a stationary vehicle placed out of or near the driver’s line) [36]. Misses occur when an alert is not triggered despite the situation requiring it. Such failures are due to the fact that the capacity to detect obstacles could be limited in situations such as bad weather, detecting two-wheeled vehicles, pedestrians, stationary obstacles or very slow-moving vehicles, swerving vehicles or vehicles in bends, abrupt accelerating or decelerating. Because of these limitations, no FCWS currently works perfectly.

Real data about the false alert and miss rates are not frequent in the literature, but the existing data suggests that this rate is still far from acceptable. As already mentioned, Najm et al. [7] collated data from drivers who drove with a vehicle fitted with Advance Cruise Control and FCWS during one month. Their results showed that 44% of the alerts were false alerts and only 56% of all warnings were triggered by in-path targets (whether all of these alerts were necessary or not is unknown). McLaughlin et al. [37] evaluated the algorithm used in the previous study using real-crash data and compared it with two other algorithms. Their results showed a benefit from the first system of about 60%. However, this algorithm also accounted with the higher warning frequency, 87 alerts per 161 km driven, compared to the two other algorithms, 83 and 8 alerts per 161 km driven, respectively. Taking into account the recommendation that no more than one nuisance alert per 322 km would be an acceptable rate [38], the data presented above is not very encouraging.

Drivers' trust in the warning system could be considerably undermined if the number of nuisance or false alerts is too high, because these alerts are irritating and distractive [39]. As a result, the acceptance of the warning could be reduced and, therefore, it is likely that users ignore or react inadequately to further warnings, whether or not they are valid [40]. Moreover, concerning behavioural changes in drivers' performance, false alerts seem to lengthen the braking reaction time [41] and to induce unnecessary deceleration responses [39]; however, a higher false alerts rate could be associated with increases in the speed since drivers would tend to ignore the warning [42]. Misses are also critical for the acceptance and trust in the system and drivers' performance could be affected by longer reaction times, even longer than driving with no system at all [41]. In addition, the speed could decrease with the increase of the misses which has been interpreted as a reduction of drivers' trust on the system [43].

Besides the rate of false alerts and misses, hit alerts (alerts delivered when a potential collision is imminent) could also be considered as ineffective depending on the timing in which the alert is triggered. In general, early alerts are more effective and account with a higher acceptance level by drivers than late alerts, but if they are prompted too early, they can be considered as nuisance or false alerts [44].

However not all false alerts and misses have negative effects. For example, nuisance alerts can improve the knowledge that drivers have about the way the system functions [36]. In addition, if a system never triggers a false alert, drivers could fail to react adequately when the first hit alert occurs [45]. On the other hand, if a system almost never fails to detect a potential collision, drivers may over-rely on it and become vulnerable or not react adequately, when, for example, driving another unequipped vehicle [45]. It is complicated to assess which level of false alerts/misses is acceptable, given that the probability of experiencing a rear-end collision is quite low, and the efforts for finding out the cut-off point have not been very conclusive as yet [38, 40].

Other studies have investigated the reliability of the system focusing on the percentage of true alerts without specifying the rate of false alerts or misses. In general, higher levels of reliability result in better performance, but the point where the system becomes useless remains uncertain. Bliss and Acton [46] noted that participants responded more frequently to the warning and manoeuvred more appropriately in avoiding collisions when the warning was 100% reliable. Nevertheless, Maltz and Shinar [39] and Ben-Yaacov et al. [10] did not find any differences between systems reliable at 60, 80-85, and 90-95%. Subsequently, Wickens and Dixon [47] carried out a meta-analysis of twenty two studies and concluded that a reliability level of 70% could be the criterion from which a system can be considered as an aid in avoiding rear-end collisions.

Finally, it should be noted that failures of the system could have different effects depending on certain driver characteristics such as age, driving experience [36], or attentional state. For example, an alert triggered too early could be considered as a nuisance alert for an undistracted driver but it could be a hit alert for a distracted driver. Abe et al. [25] discovered that drivers rated alerts as less unnecessary when they were distracted by a secondary visual task than when they were undistracted. Thus, it seems that distracted drivers try to compensate their lack of attentional resources by the aid of the system. Maltz and Shinar [48] did not find any differences in distracted groups with regard the percentage of the time spent in a danger or safe zone according to the reliability of the system (high, medium, and low reliability or 1, 4, and 8 errors per minute, respectively). Nevertheless, the analysis of drivers' performance in case the system failed to deliver an alert showed a higher rate of deceleration responses in the danger zone by the low reliability group compared to the medium and high reliability groups and control group. This result could suggest that even when distracted, drivers can adopt a safe behaviour when the system frequently fails in detecting the hazard; however, when the system is highly reliable, drivers did not compensate the error of the system. As in the Malt and Shinar study [48], Bueno et al. [20] analysed the reliability level of an FCWS (100% or 70% reliable) in drivers distracted by a secondary cognitive task but they also analysed this in undistracted drivers. Behavioural data showed that reliable and unreliable systems only reduced RT when drivers were undistracted but not when they were distracted. However, the analysis of the electrical activity of the brain revealed a slightly different pattern of results. ERP data showed a reduction in the amplitude and the latency of the N2 by the reliable system in simple task condition; whereas the unreliable system reduced the latency of the P3 in dual task condition. These results could be interpreted as an increase of the expectancy of the target in the first case and a diminution of the time required for processing the target at higher cognitive level, in the second case. In parallel to Maltz and Shinar's study [48] but with all due caution, it could be speculated that less reliable systems are more effective than more reliable systems in dual task situations. Nevertheless, further research is needed to shed light on these phenomena.

As it has been discussed here, the cut-off between a reliable and an unreliable system does not seem to be determined exclusively by the characteristics of the system (level of reliability, type of warning signal, etc.) but also by some driver characteristics such as the attentional state.

12.6 Behavioural adaptation to the system

The last factor addressed in this chapter is the behavioural adaptation defined as "those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change (p.23)" [49]. Given its repercussion for road safety, the behavioural adaptation to the assistance system has a market negative connotation, although a wider vision could be adopted by considering all relevant changes associated to the introduction of the assistance system [50].
To our knowledge, there are no studies evaluating the behavioural adaptation to the FCWS using ERP data; therefore, only behavioural studies will be considered in this section.

As previously discussed, the introduction of an FCWS can produce different effects on drivers' behaviour. Some of them are positive, such as faster reaction times and the reduction of collisions. However, undesirable behavioural changes can also appear, sometimes as a consequence of the interaction with other factors such as the attentional state of the driver or the reliability level of the system. For example, drivers could engage in more secondary tasks or even assume more risky behaviours by delegating the danger monitoring task to the system (compensatory effects). This could have unintended consequences such as an increase in the brake reaction time in the case of a real collision or in the case of the system failing to warn drivers. Concerning the failures of the system, false alerts could increase the driving speed and reaction times and a reduced miss rate could lead to over-relying on the system.
In general, FCWS have been analysed in short-term studies and, in most of the cases, the effect of introducing the system could not have been assessed in experimental studies because the order effects were eliminated by the counterbalancing. Therefore, at present it is not fully understood how drivers adapt their behaviour to the system in the first-time uses (learning and appropriation phase), nor after a prolonged use during a long period of time (integration phase) [51]. Moreover, other factors could have an influence on the adaptation to the system, such as traffic conditions, driver characteristics and some attitudes and personality traits like driving style, sensation seeking, and the locus of control (internal or external responsibility

attribution for the outcome of events). Jamson et al. [51] conducted a driver simulator study to analyse the benefits of an FCWS taking into account the driver style, with higher or lower sensation seekers. Their results showed a positive effect of the system compared to the baseline; however, the driver style had little or no impact.

To our knowledge, only one study has been carried out showing the behavioural effect of an FCWS in the long term in a field operation test [10]. In this study, participants had to drive in real traffic conditions with the system (2^{nd} trial) and without it (1^{st} and 3^{rd} trials, and 4^{th} trial six months later). Safer time headway was observed immediately after exposure to the system (3^{rd} trial). Interestingly, this effect was also observed six months later when participants were exposed again to the same drive without the warning assistance. We have also analysed the behavioural effect of an FCWS in the short term in a driving simulator study. Participants were required to drive without the system during the first session (baseline). Then, the system was introduced in the second, third, and fourth sessions in order to evaluate the immediate effect of introducing an FCWS and the behavioural adaptation to the system in the short term. Finally, participants drove without the system during the fifth l session to analyse the consequences of switching off the system after a short period of habituation. The results showed that the introduction of the system drastically reduced the reaction time during the second session compared with the control group who drove without any assistance. During the integration phase (sessions two and three), reaction times were also faster for the system group than for the control group. Finally, results showed longer reaction times during the last session (with the system switched off), with an increase especially noticeable for the system groups. This last result may provide evidence for the disruptive effect of driving without the warning system, for example, by a system breakdown, once the driver is accustomed to driving with the system. Nevertheless, the control group showed a progressive increment of the reaction time along the five sessions which could be interpreted as a practice and/or fatigue effect. Therefore, it was not possible to conclude whether the longer reaction times for the system groups were completely explained by the absence of the system. As there are not many studies in this respect, further research would be necessary to investigate the effects of driving with or without the system after the integration phase.

Although the number of studies and the situations evaluated are not sufficient to draw final conclusions, it is interesting to observe that among these studies no negative behavioural adaptation effects were evidenced. It could be possible that compensatory effects when driving with an FCWS are more difficult to reproduce than when driving with other systems. Rear-end collisions are relatively infrequent situations compared to, for example, monitoring excessive speed or lane departure. Moreover, given the safety risk involved in these collisions, it could be more difficult for drivers to rely completely on the system. Certainly the reliability level can have a strong impact on the behavioural adaptation to the system. However it has been demonstrated that unreliable systems can also be useful in terms of assistance for drivers.

Psychology of learning could enable interpretation of why unreliable systems can be effective. The association between the warning (stimulus 1) and the hazard (stimulus 2) is produced in very different contexts (i.e. high traffic flow, good or bad weather conditions, secondary tasks, etc.). Moreover, drivers learn that the causal relation between the two stimuli is not perfect. Indeed, as discussed earlier, the perfect system does not exist. Therefore, the presence of false alerts and misses produces an intermittent reinforcement of the warning and, consequently, more resistance to extinction [52]. Nevertheless, given the limited number of studies in this regard, further research would be necessary in order to determine the positive and negative effects of FCWS used in the short and long term.

12.7 Conclusions

This chapter aimed at reviewing literature assessing the effectiveness of FCWS. Although it has been shown that the system provides potential benefits for road safety, certain factors such as the attentional state of drivers and the reliability level of the system can mitigate its effectiveness. Further research seems necessary to clarify whether the system helps distracted drivers by manipulating the difficulty level of the secondary tasks and the type of warnings. If, as it has been hypothesised here, the processing of the warning information is not an automated task and needs some attentional resources, it is possible that a training program could optimise drivers’ performance when driving with the system.

The reliability of the system is likely to be one of the most critical factors for the acceptance of the system by drivers. Although failures of the system can have a positive impact for road safety, it is necessary to find a good balance to avoid drivers deciding not to use it. Probably one of the most negative effects of behavioural adaptation could be over-reliance. The studies presented in this chapter did not show evidence of this phenomenon in drivers; however, currently there are only a few studies and, therefore, more research assessing behavioural adaptation after short and long-term use needs to be conducted.

Finally, ERP studies have shown to be promising in the analysis of the effectiveness of FCWS. Until now, FCWS had been mainly studied by recording measures of driver performance and, eventually, by analysing the visual behaviour of drivers. The ERP technique permits to elucidation and dissociation of the different stages of the information processing, some of which are not observable in open behaviour. Thus, the results showed in the studies presented above revealed that the warning signal could operate at preparatory (CNV) and higher cognitive stages (P3).

Throughout this chapter, it has been shown that the effectiveness of the FCWS and its acceptance by drivers depend on numerous factors. On the one hand, factors that directly affect the effectiveness of the system can come from the system itself. For instance, the moment for triggering the warning, the reliability level of the system or the modality of the warning (visual, auditory) are critical elements to take into consideration. But even the “best” of the systems in terms of technical parameters could not be appropriated for certain drivers. It has been demonstrated that the effectiveness of the system could vary according to the attentional state of the driver. The different driving style, age, experience or health status of drivers should also be considered in order to insure that specific populations, for example, older drivers, could benefit as expected from these systems. Moreover, one of the issues evidenced in some of the studies above presented has been the large inter-individual variability observed among the same type of drivers. Therefore, we strongly recommend developing adaptive FCWS which take such characteristics into account.

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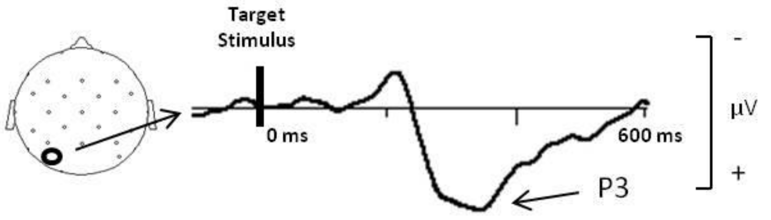

Figure 12.1 Example of a grand-average ERP showing a typical P3 component at parietal areas

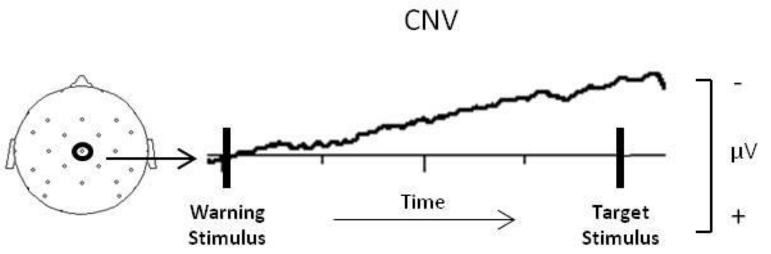

Figure 12.2 Example of a grand-average ERP showing a typical CNV component at central areas