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Systematic Review

How to Counteract Driver Fatigue during Conditional Automated Driving—A Systematic Review

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Abstract: This paper summarizes the research on countermeasures against driver fatigue based on a comprehensive systematic literature review. Driver fatigue, induced by task monotony during conditional automated driving (CAD, SAE Level 3), can increase the risk of road accidents. There are several measures that counteract driver fatigue and aim to reduce the risk caused by a fatigued driver in the context of CAD. Twelve selected articles focusing on driver fatigue countermeasures in CAD were analyzed. The findings and conclusions are presented, focusing on the countermeasures themselves and their implementation. The countermeasures were critically discussed, especially regarding effectiveness and applicability. They seem to be effective in counteracting driver fatigue. However, the measures are not easily compared because they were studied in various experimental settings and various driver fatigue measurements were used. Different countermeasures have proven to be effective in reducing fatigue during CAD. For this reason, further investigation is needed to gain further insights into their applications, advantages, and disadvantages. Further studies will be conducted to verify the best solution regarding their effectiveness and applicability.

Keywords: driver fatigue; conditional automated driving; countermeasures; non-driving-related activities; driving-related strategies

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1. Introduction

Fatigue driving, as part of the "fatal five" (drink and drug driving, distraction and inattention, speeding, failure to wear a seat belt, and driver fatigue), is one of the most common causes leading to traffic crashes [1]. It has been estimated that fatigue is the leading cause of 30 percent of crashes [2–7]. Johns [8] defined fatigue as "weariness resulting from bodily or mental exertion", which is synonymous with "tiredness". The fatigue model by May and Baldwin [9] distinguishes between two different forms of fatigue, namely, sleep-related and task-related fatigue. Circadian rhythms, sleep deprivation, and sleep restriction can cause sleep-related fatigue. For example, a lack of sleep can lead to impairments in driving performance which in turn increases crash risk [10,11]. Task-related fatigue differentiates in turn between active and passive fatigue. Active fatigue is caused by increased task load (e.g., high traffic density, poor visibility, or engaging in non-driving-related activities) [9,12]. Passive fatigue occurs during highly monotonous tasks with underload conditions [12], such as conditional automated driving (CAD).

According to the current state of development, conditional automated vehicles (SAE Level 3) [13] will soon be widely available on the market. CAD transforms the role of the driver from an active operator to a passenger [12]. The driver no longer needs to monitor the system permanently and can engage in non-driving-related activities (NDRAs). However, at this level of automation, the driver will still be needed as a fallback option and is required to take over the driving task with sufficient lead time when the function detects system limits [13]. The performance of the transition from automated driving to manual driving can be affected by different factors, such as driver fatigue [14]. Driver fatigue influences the takeover performance and quality [15,16]. Goncalves et al. [17] came to the conclusion that the takeover performance of a fatigued driver is poorer than that of a driver who is not fatigued. For example, Vogelpohl et al. [18] and Wu et al. [19] found that reaction time is impaired by passive fatigue. Once the driver has reached a certain fatigue level, it is questionable whether the driver can take over the controls at system limits appropriately [20] and safely perform vehicle control afterward [21,22].

With the introduction of automated driving and the shift from active-related to passive-related fatigue, new investigations must be pursued. Passive-related fatigue is also a critical safety problem during manual driving. Therefore, so far, drivers often use self-initiated measures during manual driving, such as playing music, rolling down the window, setting the temperature, or caffeine consumption, to counteract fatigue [23–25]. A comprehensive overview of countermeasures against driver fatigue during manual driving is given by Nazari et al. [26] and Bayne et al. [27]. For example, Schmidt [28] found in her studies that cool and fresh air is subjectively perceived to reduce fatigue. Furthermore, besides opening the window, turning on the radio/music is the most common self-applied countermeasure against driver fatigue [29,30]. According to Gershon et al. [25], the most common and effective measures against driver fatigue are a conversation with a passenger, listening to the radio, and opening the window. However, it was ascertained that the effects of previously studied countermeasures are very temporary (10–20 min) [24]. With the consideration of CAD, new opportunities emerge to counter driver fatigue, in contrast to manual driving, for example engagement in non-driving-related activities (NDRAs). NDRAs can be performed during CAD and serve to prevent the development of driver fatigue. For example, in addition to turning on the music, karaoke can be sung, which can increase the effectiveness of fatigue reduction. Moreover, drivers can perform these non-driving-related activities for a longer period of time during CAD [31]. Another possibility to counter driver fatigue is support through driving-related strategies. Driving-related strategies are countermeasures that serve to minimize the risk caused by a fatigued driver, for example handling over the driving task. This type of countermeasure has been introduced by Weinbeer et al. [32] as a system-based strategy. These countermeasures are intended to eliminate the problem of passive-related fatigue.

Because of the serious consequences of fatigued driving, various studies have investigated potential measures to counter driver fatigue during CAD. To the best of the authors' knowledge, there is a lack of a comprehensive overview of these studies to date. Based on an extensive literature review, this paper gives a review of the status quo of countermeasures against passive driver fatigue during CAD. Moreover, this literature analysis discusses these measures in the context of CAD regarding their effectiveness, feasibility, and applicability.

2. Search Strategy and Selection Criteria

The literature review was conducted in March 2023 via the search engine for scientific literature, Google Scholar. In addition, we also searched for articles in the literature manager ResearchGate and in the library of the Chair of Ergonomics. The searching process followed the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; see Supplementary Material Table S1 for the checklist) [33]. The selection process is depicted in Figure 1.

For the selection of potential articles, different combinations of the keywords "driver fatigue", "drowsiness", "countermeasures", and "conditional automated driving" were applied. In this review, no distinction was assumed between drowsiness and fatigue since several studies do not distinguish between these driver states. The review included only articles published in the last 10 years (≥2012) and those written in English. Articles that investigated countermeasures in manual driving were excluded from this review.

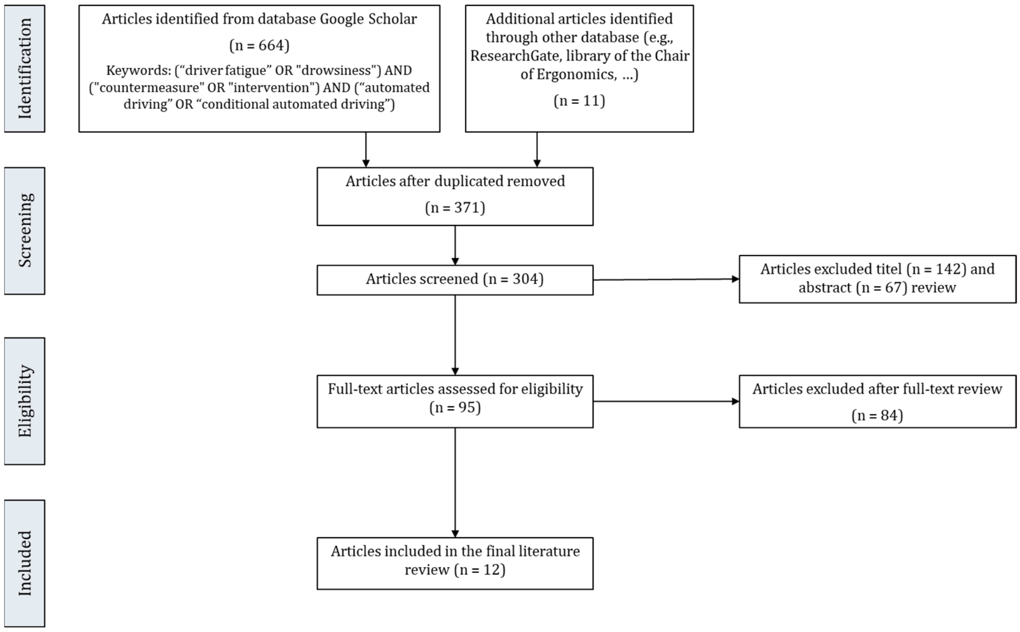

Figure 1. Selection process of the literature review in accordance with PRISMA statement guidelines [33].

The first step in the review process resulted in 675 articles. After articles were identified in other libraries or databases, 304 duplicates were removed. After analyzing titles and abstracts, only articles related to studies investigating countermeasures in CAD were included in the review. This led to the further exclusion of 209 articles. After reviewing the remaining 95 articles, 84 articles were excluded due to a lack of relevance to this review. These articles mainly did not focus on countermeasures in CAD, but on manual driving. Schneider et al. [34], for example, investigated the effects of a seat-integrated mobilization system on passive fatigue, Bier et al. [24] focused on the effects of driving games, and Wang et al. [35] explored a haptic guidance steering system. Although these studies showed effective opportunities to prevent driver fatigue, they are not wholly applicable in CAD.

3. Results

The final selection includes twelve articles detailing NDRAs and driving-related strategies as countermeasures against driver fatigue. Moreover, the articles are considered in more detail in terms of the type of countermeasures and the time condition of use, i.e., the time aspect of their implementation. In addition, the findings are summarized in the respective tables.

3.1. Types of Countermeasures

As this literature review shows, there are several approaches to dealing with driver fatigue. Ten articles were identified that cover different NDRAs as possible countermeasures against driver fatigue during CAD and two focused on driving-related strategies. Table 1 provides an overview of these studies.

A simulator study by Mahajan et al. [36] examined the effectiveness of speech-based assistants during CAD to counter the effects of passive fatigue. Mahajan et al. [36] used a speech-based assistant with natural language interactions and compared it to driving without a conversation with a speech-based assistant. The assistant initiated a conversation every 3 min by asking a question or providing information, e.g., event reminders (calendar), entertainment, or road traffic feedback. The conversation included follow-up questions that depended on the driver's response to the speech-based assistant. The authors showed lower subjective fatigue ratings on the Karolinska Sleepiness Scale (KSS) created by Åkerstedt and Gillberg [37] and higher pupil diameter, indicating higher alertness in the drive with a speech-based assistant. Thus, fatigue symptoms were reduced with assistants, but cognitive workload was higher when driving with a speech-based assistant [36]. Moreover, no drivers nodded off when driving with a speech-based assistant, while six nodded off when driving without one. While no significant difference in mean takeover time was found between the two groups, drivers who interacted with a speech-based assistant had their hands on the wheel and feet on the pedals in less time.

Neubauer et al. [38] assessed the effects of a trivia game and a hands-free cell phone conversation on driver fatigue during CAD. These two tasks were compared to the effects of a baseline ride. During the trivia game, the participants selected a question from one of five categories (e.g., food, sports, movies, current events, and general knowledge) [39]. Moreover, the participants drove either manually, in partial automation mode, or in fully automated mode. During partially automated driving, braking and speed are controlled, and during fully automated driving, the steering, braking, and speed of the vehicle are controlled. In this study, the variability in lateral position and response time to an emergency event were measured, as well as the driver's subjective stress and fatigue state by using the Dundee Stress State Questionnaire. The cell phone conversation and game of trivia appeared equally effective in counteracting fatigue. Furthermore, task engagement was higher and distress was lower during the trivia game and the cell phone conversation compared to the baseline. Both cell phone use and the trivia game led to better vehicle control; however, no faster response time to subsequent events was found. According to the authors, these two tasks may help counteract driver fatigue.

Saxby et al. [40] also investigated the influence of cell phone conversations on driver fatigue. The participants drove either manually or in fully automated mode for 30 min. The authors assumed that during the fully automated drive, passive fatigue was induced. The manual drive served as the control. This was confirmed in the results by a significant decrease in task engagement. In addition, some participants experienced a cell phone conversation and others did not. The cell phone conversation was guided by the experimenter and consisted of open-ended questions regarding a close-call experience. These 30 min served to induce fatigue and were measured with the Dundee Stress State Questionnaire. A five-minute manual drive followed, which was the same for all participants. During this time, standard deviation of lane position (SDLP), response times to an unexpected event, and the number of crashes were measured. The results revealed that there was no significant difference in task engagement between the two cell phone conditions. However, participants engaging in a cell phone conversation had significantly a lower SDLP, meaning they maintained a better lane position, than participants engaging in no cell phone conversation. Furthermore, participants driving in fully automated mode had significantly delayed braking reaction times. Overall, the study showed that a cell phone conversation improved SDLP, but did not counteract fatigue.

Furthermore, Schömig et al. [41] studied driver fatigue effects of (1) driving with a conditional automated system, (2) driving with a conditional automated system and additionally performing a quiz task, and (3) driving manually throughout the whole drive. The task of the quiz was to select the correct answer from several options to a question displayed on a touch screen. Driver fatigue was assessed by the detection algorithm from Hargutt [42]. The results showed that manual driving and driving with a conditional automated system without a quiz increased fatigue levels. Driving with a conditional automated system and additionally performing a quiz task had no major effect on driver fatigue. This led to the conclusion that an NDRA, i.e., a quiz, has the potential to significantly decrease driver fatigue during CAD.

Moreover, Jarosch et al. [43] used the same quiz task as Schömig et al. [41] to investigate the effects of two different NDRAs on drivers' fatigue and takeover performance during CAD. They compared the quiz task, representing an activating task, with a monotonous monitoring task in which the participants had to touch the screen when a "p" was displayed among different letters ("P", "q", "p", and "d"). Driver fatigue, assessed with the self-reported KSS and PERCLOS (percentage of eyelid closure), increased during the monotonous monitoring task, but not during the quiz task. No difference was found in the takeover time and the driving-related parameters (longitudinal and lateral acceleration, steering angle, steering angle velocity, and standard deviation of lateral position).

Miller et al. [44] also investigated the effects of different NDRAs on drivers' fatigue during CAD. Participants had to monitor the automated driving system, read, or watch a video. Fatigue was measured by visual coding of driver behavior and eye closure. In addition, reaction time and minimum headway were assessed during a critical scenario. The results revealed that reading or watching a video can counteract driver fatigue compared to monitoring the automated driving system. There was no significant difference in reaction time or minimum headway distance between the conditions.

Pan et al. [12] examined watching a movie and watching a movie combined with a road screen monitoring task regarding driver fatigue and takeover performance. These two tasks were compared to an environment monitoring task. During the road screen monitoring task, the participants were instructed to monitor the road screen for about 2 min "when the vehicle was approaching certain areas where the automated system would reach their operation limit (e.g., pedestrian, road intersections)" [10]. Participants watching a movie and watching a movie combined with a road screen monitoring task were significantly more fatigued, measured with the KSS and PERCLOS, than participants performing the environment monitoring task. Takeover performance was worse for the participants with the environment monitoring task than with the two other tasks. There was no significant difference between these two tasks regarding driver fatigue; however, there was a significant difference regarding takeover performance. This study showed that watching a movie combined with a road screen monitoring task can help to prevent driver fatigue.

Feldhütter et al. [20] investigated whether free choice NDRAs can prevent driver fatigue. Participants were asked to provide their personal items for the study, or they had several opportunities for NDRAs in the test car. The effects of free choice NDRAs were compared to the effects of doing nothing during the study. Fatigue (PERCLOS and blink frequency) and takeover performance (securing behavior before changing lanes, takeover time, maximum longitudinal and lateral acceleration, and minimum time-to-collision) were measured. Twenty-five percent of the participants doing nothing showed strong evidence of fatigue or falling asleep. There was no significant difference between the two conditions regarding blink frequency. PERCLOS could only be analyzed for the participants who did nothing during the experiment. Nevertheless, a significant effect was found for time, indicating that driver fatigue increased over time. However, evaluating the PERCLOS values descriptively, participants who performed free choice NDRAs reached a questionable fatigue level [20]. This indicates that free choice NDRAs cannot counter high levels of fatigue during CAD [20]. There was no significant difference in the takeover performance between the two groups except for longitudinal acceleration, which was significantly higher when performing NDRAs.

In a further experiment by Feldhütter [45], the game Tetris was selected as the NDRA and compared to a baseline with no NDRA. The KSS, PERCLOS, and the expert rating by Wiegand et al. [46] were used to measure driver fatigue. A significant difference was found on the KSS, indicating that playing Tetris led to a lower fatigue level than no NDRA. This was confirmed by the analysis of PERCLOS and the expert rating by Wiegand et al. [36]. Moreover, takeover performance was assessed by takeover time, time-to-collision, and maximum lateral and longitudinal acceleration, though no significant differences were found between Tetris and no NDRA. According to the authors, their studies showed that Tetris was more effective in preventing driver fatigue than the free choice NDRAs.

In a real-world driving study by Weinbeer et al. [31], the effects of different NDRAs on driver fatigue were investigated. A relaxation task (listening to relaxation music) that each participant experienced at the beginning of the study served as a baseline. This was compared with a dictation task, where the participants had to type different words for a limited period, and with a sports activity task, where the participants used a Handytrim fitness device. Fatigue, measured with the KSS, significantly increased during the relaxation task of the study. There was no significant difference between the dictation and sports activity task regarding driver fatigue. Moreover, participants performing the dictation task or sports activity task did not reach level 7 on the KSS.

In a further study by Weinbeer et al. [32], driver-state-related strategies and system-based strategies (which are named in this paper as driving-related strategies) were examined to counter driver fatigue (see Weinbeer et al. [32] for a detailed description of the countermeasures). The participants gave their subjective assessment of these strategies on a five-point Likert Scale (1—not at all and 5—extremely), measuring acceptance and effectiveness (most reactivating). According to the subjective assessment, the driver-state-related options "upright seat position", "interior lighting", and "targeted offer of non-driving-related tasks (NDRTs)" received the best rating regarding effectiveness. "Reduction in maximum speed", "no further lane changes", and "move to the slow lane" received the best ratings regarding the effectiveness of the system-based strategies. These system-based strategies refer to actions initiated by the system, which means for example that the system reduces the speed to increase the time available for a takeover [32]. Regarding acceptance, the option "the vehicle offers a specific selection of NDRTs" was the most accepted of the driver-state-related options. The participants also indicated that this option was the most effective. The system-based strategy "no further lane changes and a move to the slow lane" was followed by the strategies "rest area and break" as well as "reduction in maximum speed".

As Weinbeer et al. [31] investigated in their study, another opportunity to counter driver fatigue is to involve driving-related strategies. Bourrelly et al. [47] investigated how different durations of automated driving impact takeover performance and driver state in a driving simulator study. The journey was divided into three parts, a short automated phase (10 min), a long automated phase (60 min), and again a short automated phase (10 min), ending with a takeover scenario after each phase. During the automated phases, the drivers watched a self-selected film on the control screen behind the steering wheel. Furthermore, a distinction was made between two takeover scenarios. The participants experienced either an accident situation or a no-car condition. In the accident situation, two cars had crashed in the right lane, so the driver had to move to the left lane to avoid them. The results showed a significant effect on driver fatigue in the long automated phase compared to the two short phases. There was no significant effect between the two short automated phases. The results revealed a significant effect on the time taken regarding hands on the steering wheel, feet on the pedals, and deactivation. This indicates that the participants reacted faster to the takeover after the short automated phases compared to the long automated phase. In general, the study showed that the duration of the automated phase affected takeover performance and fatigue development.

Table 1. Overview of different countermeasures regarding sample size, measurements, main results, and conclusion.

Article	Countermeasures	Sample Size	Measurement	Main Results	Conclusion
Bourelly et al. [47]	Phases of automated driving	30	Driver fatigue: 5-level Likert scale Driving performance: Reaction times and car trajectories Takeover performance: Takeover time and quality	Poorer takeover performance (longer reaction time and sharper avoidance maneuver) and increased fatigue in the long automated phase compared to the short automated phases.	Short automated phases led to significantly lower fatigue levels and better takeover performance compared to long automated phases.
Feldhütter et al. [20]	Free choice NDRA	42	Driver fatigue: PERCLOS and blink frequency Takeover performance: Securing behavior before changing lanes, takeover time, maximum longitudinal and lateral acceleration, and minimum time-to-collision	Descriptively, participants who performed free choice NDRAs reached a questionable fatigue level according to PERCLOS. There was no significant difference between the two conditions regarding blink frequency. There was no significant difference in the takeover performance between the two groups except for longitudinal acceleration, which was significantly higher when performing NDRAs.	Participants achieved a high fatigue level despite free choice NDRAs. However, this had no effect on driving performance.
Feldhütter [45]	Tetris	40	Driver fatigue: PERCLOS, KSS, and expert rating—protocol proposed by Wiegand et al. [36] Takeover performance: Takeover time, time-to-collision, acceleration, initial response, final response, mirror check, and crashes	There was a significant difference between the two conditions on the KSS, expert rating, and PERCLOS. No significant effects were found on the takeover performance parameters.	Tetris resulted in a low fatigue level that did not increase significantly over time, in contrast to the drive without the game.
Jarosch et al. [43]	Quiz	73	Driver Fatigue: PERCLOS and KSS Takeover performance: Center-of-road fixation time, hands-on time, first braking reaction, first steering maneuver, first braking maneuver, and maximum longitudinal and lateral acceleration	KSS and PERCLOS increased during the monotonous monitoring task, but not during the quiz task. No difference was found for the takeover performance parameters.	The monitoring task resulted in a significantly higher fatigue level and a significant increase over time compared to the activating quiz task. The quiz prevented participants from experiencing high levels of fatigue.

Table 1. *Cont.*

Article	Countermeasures	Sample Size	Measurement	Main Results	Conclusion
Mahajan et al. [36]	Speech-based assistant	24	Alertness and workload: KSS, pupil diameter, eye blink frequency, eye blink duration, and NASA-TLX Takeover performance: Takeover time Engagement in conversation: Participation ratio	Lower KSS ratings and higher pupil diameters were observed in the drive with a speech-based assistant. There was a higher cognitive workload in the drive with a speech-based assistant. No drivers nodded off when driving with a speech-based assistant, whereas six nodded off in the drive without one. No significant difference was found in takeover time.	Using a speech-based assistant counteracted driver fatigue.
Miller et al. [44]	Monitor the automated driving system, read, or watch a video	48	Driver fatigue: Visual coding of driver behavior Driving performance: Minimum headway distance and collision avoidance reaction time	Participants supervising the system showed significantly greater incidence of fatigue compared to participants reading or watching videos. There was no significant difference in reaction time or minimum headway distance between the conditions.	Reading or watching videos were effective in counteracting driver fatigue compared to supervising the CAD system.
Neubauer et al. [38]	Trivia game and a hands-free cell phone conversation	180	Driver fatigue: Dundee Stress State Questionnaire Driving performance: Vehicle control and reaction time to a sudden event	Task engagement was higher and distress was lower during the trivia game and the cell phone conversation compared to the baseline. Both the cell phone use and the trivia game led to better vehicle control; however, no faster response time to subsequent events was found.	A cell phone conversation or a game of trivia appear to be equally effective. Both tasks led to a higher task engagement compared to a supervising task.
Pan et al. [12]	Monitor the automated driving system, watch a video, and/or a road screen monitoring task	63	Driver fatigue: Stationary Gaze Entropy (SGE), PERCLOS, heart rate, respiration measures, and KSS Takeover performance: Saccade latency, braking reaction time, steering reaction time, interval between saccade latency and braking reaction time, interval between saccade latency and steering reaction time, maximum braking pedal input, maximum steering velocity, and minimum time to crash	There was a significant difference regarding KSS and PERCLOS between the two tasks and the monitoring task. Takeover performance was significantly worse during the monitoring task than during the other two tasks. However, takeover performance was best in the participant group watching a movie combined with a road screen monitoring task.	Watching a movie combined with a road screen monitoring task helped to prevent driver fatigue without impairing the takeover performance.
Saxby et al. [40]	Cell phone conversations	160	Driver State: Dundee Stress State Questionnaire, Driver Fatigue Questionnaire, and Driver Stress Inventory Driving performance: SDLP, reaction times to unexpected events, and crashes	No significant difference in task engagement between the two cell phone conditions was found. Participants engaging in a cell phone conversation had significantly lower SDLP than participants engaging in no cell phone conversation. Participants driving in fully automated mode had significantly delayed braking reaction times.	The cell phone conversation did not counteract driver fatigue. However, the cell phone conversation improved SDLP.

Table 1. *Cont.*

Article	Countermeasures	Sample Size	Measurement	Main Results	Conclusion
Schömig et al. [41]	Quiz	16	Driver fatigue: Drowsiness detection algorithm from Hargutt [32] Takeover performance: Takeover time	KSS and PERCLOS increased during the monotonous monitoring task, but not during the quiz task. No difference was found for the takeover time and the driving-related parameters.	A quiz task has the potential to counteract driver fatigue. However, this had no effect on the driving performance.
Weinbeer et al. [32]	Driver-state-related strategies and system-based strategies	31	Subjective assessment: Acceptance and effectiveness (most reactivating)	"Upright seat position", "interior lighting", and "targeted offer of NDRTs" received the best rating regarding effectiveness. "Reduction in maximum speed", "no further lane changes", and "move to the slow lane" received the best ratings regarding the effectiveness of the system-based strategies.	This subjective assessment provided the first indicator as to how to counteract driver fatigue from a user's perspective. These countermeasures have to be evaluated objectively.
Weinbeer et al. [31]	Dictation, a sport activity, and a relaxation task	71	Driver fatigue: KSS Takeover performance: Hands-on time and takeover time	No participant of the dictation or sports activity group exceeded level 7 on the KSS. Fatigue did not significantly influence hands-on time and takeover time.	Dictation and a sports activity had a positive effect on driver fatigue.

3.2. Time Condition of Use

In addition to the countermeasures themselves, this literature focuses on how they were implemented in the studies. A special focus is placed on the start time and on the duration of the countermeasures. A summary of the results is shown in Table 2. Most studies used measures to prevent and avoid driver fatigue. For this reason, most of the studies used the application of the measures directly after the start [12,20,38,43–45]. Bourrelly et al. [47], Mahajan et al. [36], Saxby et al. [40], and Weinbeer et al. [31] started the application after a certain time (after 5 vs. 10 vs. 18.5 vs. 30 min). Schömig et al. [41] investigated the effectiveness of the countermeasures only after a certain level of fatigue was reached to find out whether driver fatigue could be prevented, and alertness restored. The duration of countermeasure application differs between studies, ranging from 5 min to 60 min.

Table 2. Summary of the start time and the duration of the countermeasures.

Article	Countermeasure	Start Time of the Countermeasure	Duration of the Countermeasure
Bourrelly et al. [47]	Driving-related strategies	After 10 min	60 min
Feldhütter et al. [20]	NDRA	From the start	60 min
Feldhütter [45]	NDRA	From the start	60 min
Jarosch et al. [43]	NDRA	From the start	30 min
Mahajan et al. [36]	NDRA	After 5 min	30 min
Miller et al. [44]	NDRA	From the start	8.5 min
Neubauer et al. [38]	NDRA	From the start	10 min
Pan et al. [12]	NDRA	From the start	60 min
Saxby et al. [40]	NDRA	After 30 min	4.5 min
Schömig et al. [41]	NDRA	At certain drowsiness level	15 min
Weinbeer et al. [32]	Driving-related strategies	Evaluating through subjective assessment after test drive	
Weinbeer et al. [31]	NDRA	After 18.5 min	8.5 min

4. Discussion

This review is intended to provide an initial overview of various countermeasures against driver fatigue during CAD by analyzing eleven selected articles. The results of this systematic review showed that different countermeasures reducing driver fatigue were assessed, such as gamification, interaction with a speech-based assistant, or handing over vehicle control back to the driver. Most of the countermeasures addressed in this research showed a positive effect on driver fatigue. As an opportunity to counter driver fatigue, driving-related strategies were considered in this review [47]. The authors revealed in their study that short automated phases exerted a greater effect in terms of fatigue and takeover performance compared to long automated phases. They recommended that more takeovers should be used to prevent driver fatigue and improve the driver's takeover performance [47]. Furthermore, the subjective assessment by Weinbeer et al. [32] provided the first indications of which measures are the most effective against fatigue and the most accepted from the user's perspective. System-based strategies such as "reduction in maximum speed", "no further lane changes", and "move to the slow lane" have proven to be the most effective. Among driver-state strategies, offering NDRAs was most frequently mentioned as a countermeasure against driver fatigue. However, it cannot be inferred whether an objective measurement of fatigue would confirm these findings. For this reason, further research is needed to investigate and objectify the effectiveness of these driving-related strategies regarding driver fatigue.

In addition to driving-related strategies, the application of NDRAs as countermeasures is promising. Great potential is, for example, seen in reading, watching a video, dictation, and a sports activity in terms of fatigue [31,44]. Miller et al. [44] reported that reading or watching a movie can counteract driver fatigue compared to supervising an automated system. However, this did not affect takeover performance. Pan et al. [12] went one step further and recommended combining "watching a movie" with a road screen monitoring task in order to reduce driver fatigue and improve takeover performance. Weinbeer et al. [31] confirmed that participants performing a dictation task or a sports activity did not exceed level 7 on the KSS. Furthermore, talking to a speech-based assistant led to lower driver fatigue compared to doing nothing during CAD [36]. Moreover, the analyzed studies showed that playing games during CAD (Tetris, a quiz, or a trivia game) had a positive effect on driver fatigue [38,41,43,45]. May and Baldwin [9] have already recommended using interactive games to prevent driver fatigue. The recommendation was confirmed by a study by Feldhütter [45]. They revealed that the game Tetris led to a significantly lower mean fatigue level than without the game. Furthermore, fatigue did not increase significantly during the game and remained at a low level. Jarosch et al. [43] and Schömig et al. [41] confirmed a beneficial effect of games on driver fatigue. Schömig et al. [41] showed in their study that during CAD with a quiz task, fatigue did not increase significantly compared to driving with CAD systems without an NDRA. Furthermore, the same activating quiz task led to a significantly lower fatigue level than a monitoring task. Moreover, Neubauer et al. [38] showed that both a trivia game and a cell phone conversation led to lower driver fatigue than doing nothing during CAD. This is in line with previous studies which confirmed that a cell phone conversation can have a positive effect on driver fatigue during manual driving [27,48]. However, Saxby et al. [40] cannot support the counteracting effect of cell phone conversations on driver fatigue. The authors revealed no significant difference in task engagement between a cell phone conversation and no conversation during automated driving. SDLP seemed to be improved by this conversation. The same type of conversation was used in both studies, namely, questions about close-call experiences. A lack of effect could have been due to the method used to measure fatigue. This was already stated by Matthews et al. [49].

The mentioned studies can only be compared to a certain extent because different measurement methods and experimental settings were applied. The studies used different methods and metrics to measure fatigue, and the effectiveness of the countermeasures and are therefore challenging to compare. Several studies used self-report measures, for example the KSS [31,36,43,45] or the Dundee Stress State Questionnaire [38,40]. Another common measurement was eye activity measures, for example PERCLOS [20,43,45]. As already stated by Bier et al. [50], there is no uniform and consistent method to measure driver fatigue. However, it is important to use standardized metrics to draw comparisons between experiments and to provide transparency to other researchers. A uniform method to measure the effectiveness of such countermeasures in terms of fatigue is needed to compare such studies and provide a conclusion on which countermeasure proves to be the most effective. For this reason, no meta-analysis was conducted.

Moreover, this review raises the question regarding at what point in time such countermeasures should be applied to counteract driver fatigue and minimize the risk of a crash caused by a fatigued driver. These presented studies used different time points to investigate this, ranging from "the start of the drive" to "start after 30 min". Thus, there are different time points to apply countermeasures. This wide variation in different time points reinforces the issue that these studies are difficult to compare and that no statement can be made as to which time conditions of use are most effective. Furthermore, it must be examined whether such measures should be applied for the entire driving time and if these could annoy the driver. In the future, it is important to find a balance between "the driver is annoyed by a measure" and "counteracting fatigue". Schömig et al. [41] have already chosen the approach of only "intervening" when a certain fatigue level has been reached. This ensures that the driver does not even reach a critical level of fatigue and does not have to devote himself to NDRAs right from the start. Further studies must therefore be carried out to find out when the best time is to interfere. Not only is there variation in the time point when the countermeasures should be started in the studies, but also in how long these measures should be applied. This review shows that the studies used an application time between 4.5 and 60 min. Although different start times and durations were used, all studies showed that the use of such countermeasures was effective in counteracting driver fatigue compared to no countermeasures. Additionally, there should be a further focus on the time condition of use depending on the different types of countermeasures. Since driving-related strategies have not yet been extensively investigated, no recommendation can be derived from previous studies. However, for NDRAs as a countermeasure, our recommendation is to apply these countermeasures if driver fatigue already exists. Countermeasures can be effective regarding driver fatigue reduction and the likelihood that drivers will use these measures without being annoyed by them is then higher. This is therefore the more realistic and effective scenario. Furthermore, NDRAs should be performed for as long as possible. If the NDRA ends, the driver again experiences a passive, monotonous situation, which can again lead to increasing fatigue. However, NDRAs should be chosen in such a way that they do not lead to boredom and fatigue despite the NDRA.

Previous research has mainly used standardized tasks to counteract driver fatigue. In practice, however, the question arises whether such tasks have a positive effect when they force the user to execute this task. Feldhütter et al. [20] have already addressed this issue and studied the effectiveness of free choice NDRAs in the development of driver fatigue. The results revealed that free choice NDRAs cannot completely counteract high fatigue levels during CAD. However, due to technical issues, there were missing data on PERCLOS values. Thus, driver fatigue could not be evaluated comprehensively and should be studied again in detail. Moreover, Feldhütter [45] concluded that free choice NDRAs did not counter driver fatigue as effectively as the game Tetris. The results suggested that participants were more motivated to play the game than to engage in free choice NDRAs [44]. However, it has not yet been finally clarified whether free choice tasks lead to a better effect than standardized, predefined tasks. Feldhütter [45] noted that the development of fatigue depends on the motivation of the individual, notably whether they want to engage in an NDRA during CAD. Thus, free-choice NDRAs will be evaluated in a further study to investigate their effectiveness regarding driver fatigue.

To date, most interactive technologies, such as demanding NDRAs, have caused driver distraction [35]. Previous studies have confirmed that higher cognitive load occurs during drives where the driver has a conversation with both a speech-based assistant and a real person [18,36]. If the driver experiences great distraction at the time when they need to take over, there might be a lack of situational awareness, which in turn may result in poor takeover performance [12,17–19]. This could negate the positive effect of counteracting fatigue. Future measures need to ensure that the driver is not underchallenged, resulting in fatigue, and also that the driver is not overloaded with NDRAs, resulting in being overstrained in case of a needed takeover.

Driving-related strategies have the advantage that they are independent of motivation and they do not depend on individuality. However, there is a lack of sufficient research on driving-related strategies, hindering our understanding of their effectiveness in counteracting fatigue in an all-encompassing way. However, this kind of measure has great potential to avoid certain disadvantages of other strategies, such as distraction, motivation, and individual fatigue development. Hence, further driving-related strategies will be investigated as potential countermeasures against driver fatigue. Driving-related strategies could also be of assistance during the manual drive after CAD.

Moreover, this work indicates that most previous measures have proven effective in counteracting drive fatigue. Most of the analyzed studies focused on the development of driver fatigue, but also on takeover performance during the transition from CAD to manual driving. Feldhütter [45] revealed no difference in effects on takeover time, time-to-collision, and maximum lateral and longitudinal acceleration between the use of the Tetris game and no game. Furthermore, no effect on takeover performance could be found in the studies by Jarosch et al. [43], Mahajan et al. [36], Miller et al. [44], Schömig et al. [41], and Weinbeer et al. [31]. The results of the study by Feldhütter et al. [20] revealed no significant effects for securing behavior before changing lanes, takeover time, maximum lateral acceleration, and minimum time-to-collision; however, there was a significant difference in maximum longitudinal acceleration. Neubauer et al. [38] and Saxby et al. [40] showed significant effects on lateral control, namely that performing an NDRA during CAD led to a lower SDLP in the transition. Moreover, Bourrelly et al. [47] found significant differences in takeover quality and the avoidance of maneuvers between the short and long automated phases. While most of the presented studies showed that a measure could counteract fatigue compared to CAD without action, not all of them also revealed more positive behavior during the takeover from CAD to manual driving. The studies examined takeover behavior in critical, urgent situations. In the future, non-critical takeover situations should also be examined. A focus should be placed on the influence of fatigue on these non-critical takeovers. We recommend investigating the countermeasures regarding three aspects. First, driver fatigue development per se should be measured. Furthermore, takeover performance as well as driving performance after the takeover should be examined in order to ensure effectiveness for a long-term period.

Overall, this review recommends that countermeasures against driver fatigue in the context of CAD should address different requirements. Firstly, such countermeasures should have the main objective of reducing driver fatigue in order to ensure safe driving. The countermeasures should be present in future vehicles with automated driving systems to ensure that CAD is safe. The countermeasures should therefore be selected in such a way that they are most effective in terms of reducing fatigue and increasing road safety. Furthermore, the aim of such countermeasures should be that beyond CAD and the takeover, they are also effective regarding driver fatigue in a subsequent manual drive. However, the aim is not only to reduce fatigue, but also to have a positive effect on driving performance when driving manually after the takeover. Moreover, as studies have already shown, such countermeasures should be voluntary and therefore intrinsically motivated in order to promote their effectiveness. Furthermore, the measures should not be too demanding and also not exhausting. In other words, underload and overload should be avoided.

This advice is intended to help researchers investigate promising countermeasures against driver fatigue regarding their applicability and effectiveness in the context of CAD. It is also intended to help automotive manufacturers apply effective countermeasures in CAD to ensure the safe introduction of automated vehicles.

5. Conclusions and Outlook

There is currently a lack of sufficient research and investigation on driver fatigue countermeasures in CAD. Ensuring road safety with the introduction of conditional automated vehicles entails several challenges and requires extensive consideration of how to counteract driver fatigue. Therefore, this literature review analyzed twelve articles investigating the application of different countermeasures to address driver fatigue. Altogether, there are different options to counter driver fatigue, ranging from a speech-based assistant to a game or quiz. In general, the measures can be divided into two different types. One option is to counter driver fatigue and keep the driver awake by applying NDRAs during CAD. Another option is to abort CAD and to indicate a break. Most of the studies have shown that these measures are effective in counteracting driver fatigue. This review indicated that the studies that have examined countermeasures to date are difficult to compare. It is not possible to conclusively answer how a fatigued driver should be dealt with and which countermeasures should be used. Moreover, the review has shown that it has not yet been clarified which measures should be applied at what time and for how long to achieve the greatest effectiveness. The presented literature review gives a first outlook on how driver fatigue during CAD can be reduced by countermeasures in the future. However, new studies must be conducted to evaluate various countermeasures in the context of CAD in more detail and in a comparable setting. In further studies, different countermeasures, such as free-choice NDRAs and driving-related strategies, will be investigated and compared regarding their effectiveness against driver fatigue. Therefore, the countermeasures should be applied when the drivers reach a certain fatigue level during CAD so as to only intervene when the drivers are already fatigued. Future studies should be used to find out whether the driver becomes more alert again with these measures and whether the driver can be supported by driving-related strategies to drive more safely. Such countermeasures have great potential to introduce CAD safely and responsibly into road traffic.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/futuretransp4010015/s1. Table S1: PRISMA checklist.

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References

1. Salmon, P.M.; Read, G.J.M.; Beanland, V.; Thompson, J.; Filtness, A.J.; Hulme, A.; McClure, R.; Johnston, I. Bad behaviour or societal failure? Perceptions of the factors contributing to drivers' engagement in the fatal five driving behaviours. *Appl. Ergon.* **2019**, *74*, 162–171. [CrossRef] [PubMed]
2. Bowman, D.S.; Schaudt, W.A.; Hanowski, R.J. Advances in Drowsy Driver Assistance Systems Through Data Fusion. In *Handbook of Intelligent Vehicles*; Eskandarian, A., Ed.; Springer: London, UK, 2012; Volume 2, pp. 895–909. [CrossRef]
3. Folkard, S. Black times: Temporal determinants of transport safety. *Accid. Anal. Prev.* **1997**, *29*, 417–430. [CrossRef] [PubMed]
4. Kecklund, G.; Akerstedt, T. Sleepiness in long distance truck driving: An ambulatory EEG study of night driving. *Ergonomics* **1993**, *36*, 1007–1017. [CrossRef]
5. Lenné, M.G.; Triggs, T.J.; Redman, J.R. Time of day variations in driving performance. *Accid. Anal. Prev.* **1997**, *29*, 431–437. [CrossRef] [PubMed]
6. Lyznicki, J.M.; Doege, T.C.; Davis, R.M.; Williams, M.A. Sleepiness, driving, and motor vehicle crashes. *JAMA* **1998**, *279*, 1908–1913. [CrossRef] [PubMed]
7. National Transportation Safety Board. *Safety Study: Fatigue, Alcohol, Other Drugs, and Medical Factors in Fatal-to-the-Driver Heavy Truck Crashes*; NTSB Publications: Miami, FL, USA, 1990; Volume 1. Available online: https://www.ntsb.gov/safety/safety-studies/Documents/SS9001.pdf (accessed on 1 January 2020).
8. Johns, M. *Drowsy Driving and the Law*; Tasmania Law Reform Institute: Sandy Bay, Australia, 2007; Volume 12.
9. May, J.F.; Baldwin, C.L. Driver fatigue: The importance of identifying causal factors of fatigue when considering detection and countermeasure technologies. *Transp. Res. Part F Traffic Psychol. Behav.* **2009**, *12*, 218–224. [CrossRef]
10. May, J.F. Chapter 21—Driver Fatigue. In *Handbook of Traffic Psychology*; Porter, B.E., Ed.; Academic Press: Cambridge, MA, USA, 2011; pp. 287–297. [CrossRef]
11. Zeller, R.; Williamson, A.; Friswell, R. The effect of sleep-need and time-on-task on driver fatigue. *Transp. Res. Part F Traffic Psychol. Behav.* **2020**, *74*, 15–29. [CrossRef]
12. Pan, H.; He, H.; Wang, Y.; Cheng, Y.; Dai, Z. The impact of non-driving related tasks on the development of driver sleepiness and takeover performances in prolonged automated driving. *J. Saf. Res.* **2023**, *86*, 148–163. [CrossRef]
13. On-Road Automated Driving (ORAD) committee. *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (Surface Vehicle Recommended Practice J3016)*; SAE International: Warrendale, PA, USA, 2021. [CrossRef]
14. Guo, H.; Zhang, Y.; Cai, S.; Chen, X. Effects of Level 3 Automated Vehicle Drivers' Fatigue on Their Take-Over Behaviour: A Literature Review. *J. Adv. Transp.* **2021**, *2021*, 8632685. [CrossRef]
15. Saxby, D.J.; Matthews, G.; Hitchcock, E.M.; Warm, J.S.; Funke, G.J.; Gantzer, T. Effect of Active and Passive Fatigue on Performance Using a Driving Simulator. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, New York, NY, USA, 22–26 September 2008; Volume 52, pp. 1751–1755. [CrossRef]
16. Saxby, D.J.; Matthews, G.; Warm, J.S.; Hitchcock, E.M.; Neubauer, C. Active and passive fatigue in simulated driving: Discriminating styles of workload regulation and their safety impacts. *J. Exp. Psychol. Appl.* **2013**, *19*, 287–300. [CrossRef]

17. Gonçalves, J.; Happee, R.; Bengler, K. Drowsiness in Conditional Automation: Proneness, Diagnosis and Driving Performance 466 Effects. In Proceedings of the 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), Rio de Janeiro, Brazil, 1–4 November 2016; pp. 873–878.
18. Vogelpohl, T.; Kühn, M.; Hummel, T.; Vollrath, M. Asleep at the automated wheel-Sleepiness and fatigue during highly automated driving. *Accid. Anal. Prev.* **2019**, *126*, 70–84. [CrossRef]
19. Wu, Y.; Kihara, K.; Hasegawa, K.; Takeda, Y.; Sato, T.; Akamatsu, M.; Kitazaki, S. Age-related differences in effects of non-driving related tasks on takeover performance in automated driving. *J. Saf. Res.* **2020**, *72*, 231–238. [CrossRef] [PubMed]
20. Feldhütter, A.F.; Hecht, T.; Kalb, L.; Bengler, K. Effect of prolonged periods of conditionally automated driving on the development of fatigue: With and without non-driving-related activities. *Cogn. Technol. Work.* **2019**, *21*, 33–40. [CrossRef]
21. Calvi, A.; D'Amico, F.; Ferrante, C.; Ciampoli, L.B. A driving simulator study to assess driver performance during a car-following maneuver after switching from automated control to manual control. *Transp. Res. Part F Traffic Psychol. Behav.* **2020**, *70*, 58–67. [CrossRef]
22. Choi, D.; Sato, T.; Ando, T.; Abe, T.; Akamatsu, M.; Kitazaki, S. Effects of cognitive and visual loads on driving performance after take-over request (TOR) in automated driving. *Appl. Ergon.* **2020**, *85*, 103074. [CrossRef]
23. Atchley, P.; Chan, M.; Gregersen, S. A Strategically Timed Verbal Task Improves Performance and Neurophysiological Alertness During Fatiguing Drives. *Hum. Factors* **2014**, *56*, 453–462. [CrossRef]
24. Bier, L.; Emele, M.; Gut, K.; Kulenovic, J.; Rzany, D.; Peter, M.; Abendroth, B. Preventing the risks of monotony related fatigue while driving through gamification. *Eur. Transp. Res. Rev.* **2019**, *11*, 44. [CrossRef]
25. Gershon, P.; Shinar, D.; Oron-Gilad, T.; Parmet, Y.; Ronen, A. Usage and perceived effectiveness of fatigue countermeasures for professional and nonprofessional drivers. *Accid. Anal. Prev.* **2011**, *43*, 797–803. [CrossRef]
26. Nazari, S.S.H.; Moradi, A.; Rahmani, K. A systematic review of the effect of various interventions on reducing fatigue and sleepiness while driving. *Chin. J. Traumatol.* **2017**, *20*, 249–258. [CrossRef]
27. Bayne, A.; Trivedi, N.; Liotta, M.; Siegfried, A.; Gaspar, J.; Carney, C. *Countermeasures to Reduce Drowsy Driving: Results of a Literature Review and Discussions with Experts*; Technical Report; AAA Foundation for Traffic Safety: Washington, DC, USA, 2022.
28. Schmidt, E. *Effects of Thermal Stimulation during Passive Driver Fatigue*; Springer Fachmedien Wiesbaden: Wiesbaden, Germany, 2020. [CrossRef]
29. Anund, A.; Kecklund, G.; Peters, B.; Åkerstedt, T. Driver sleepiness and individual differences in preferences for countermeasures. *J. Sleep Res.* **2008**, *17*, 16–22. [CrossRef]
30. Stutts, J.C.; Wilkins, J.W.; Scott Osberg, J.; Vaughn, B.V. Driver risk factors for sleep-related crashes. *Accid. Anal. Prev.* **2003**, *35*, 321–331. [CrossRef]
31. Weinbeer, V.; Muhr, T.; Bengler, K. Automated Driving: The Potential of Non-driving-Related Tasks to Manage Driver Drowsiness. In Proceedings of the 20th Congress of the International Ergonomics Association (IEA) 2018, Florence, Italy, 26–30 August 2019; Springer: Cham, Switzerland, 2019; pp. 179–188. [CrossRef]
32. Weinbeer, V.; Bill, J.S.; Baur, C.; Bengler, K. Automated driving: Subjective assessment of different strategies to manage drowsiness. In Proceedings of the Human Factors and Ergonomics Society Europe Chapter Annual Meeting, Rome, Italy, 28–30 September 2017.
33. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, n71. [CrossRef]
34. Schneider, L.; Frings, K.; Rothe, S.; Schrauf, M.; Jaitner, T. Effects of a seat-integrated mobilization system during passive driver fatigue. *Accid. Anal. Prev.* **2021**, *150*, 105883. [CrossRef]
35. Wang, Z.; Zheng, R.; Kaizuka, T.; Shimono, K.; Nakan, K. The Effect of a Haptic Guidance Steering System on Fatigue-Related Driver Behavior. *IEEE Trans. Hum.-Mach. Syst.* **2017**, *47*, 741–748. [CrossRef]
36. Mahajan, K.; Large, D.R.; Burnett, G.; Velaga, N.R. Exploring the effectiveness of a digital voice assistant to maintain driver alertness in partially automated vehicles. *Traffic Inj. Prev.* **2021**, *22*, 378–383. [CrossRef] [PubMed]
37. Akerstedt, T.; Gillberg, M. Subjective and objective sleepiness in the active individual. *Int. J. Neurosci.* **1990**, *52*, 29–37. [CrossRef] [PubMed]
38. Neubauer, C.; Matthews, G.; Saxby, D. Fatigue in the Automated Vehicle: Do Games and Conversation Distract or Energize the Driver? In Proceedings of the 58th Human Factors and Ergonomics Society Annual Meeting, Chicago, IL, USA, 27–31 October 2014; Volume 58, pp. 2053–2057. [CrossRef]
39. Gershon, P.; Ronen, A.; Oron-Gilad, T.; Shinar, D. The effects of an interactive cognitive task (ICT) in suppressing fatigue symptoms in driving. *Transp. Res. Part F Traffic Psychol. Behav.* **2019**, *12*, 21–28. [CrossRef]
40. Saxby, D.J.; Matthews, G.; Neubauer, C. The relationship between cell phone use and management of driver fatigue: It's complicated. *J. Saf. Res.* **2017**, *61*, 129–140. [CrossRef] [PubMed]
41. Schömig, N.; Hargutt, V.; Neukum, A.; Petermann-Stock, I.; Othersen, I. The Interaction Between Highly Automated Driving and the Development of Drowsiness. *Procedia Manuf.* **2015**, *3*, 6652–6659. [CrossRef]
42. Hargutt, V. *Das Lidschlussverhalten als Indikator für Aufmerksamkeits- und Müdigkeitsprozesse bei Arbeitshandlungen*; VDI Gesellschaft Fahrzeug- und Verkehrstechnik (Hrsg.); Reihe 17: Biotechnik/Medizintechnik (VDI-Fortschritt-Bericht, Nr. 233); VDI-Verlag: Düsseldorf, Germany, 2013.

43. Jarosch, O.; Kuhnt, M.; Paradies, S.; Bengler, K. It's Out of Our Hands Now! Effects of Non-Driving Related Tasks During Highly Automated Driving on Drivers' Fatigue. In Proceedings of the 9th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Manchester, UK, 26–29 June 2017. [CrossRef]
44. Miller, D.; Sun, A.; Johns, M.; Ive, H.; Sirkin, D.; Aich, S.; Ju, W. Distraction Becomes Engagement in Automated Driving. In Proceedings of the 59th Human Factors and Ergonomics Society Annual Meeting, Los Angeles, CA, USA, 26–30 October 2015; Volume 59, pp. 1676–1680. [CrossRef]
45. Feldhütter, A.F. Effect of Fatigue on Take-Over Performance in Conditionally Automated Driving. Ph.D. Thesis, Technical University of Munich, Munich, Germany, 2021.
46. Wiegand, D.; McClafferty, J.; McDonald, S.E.; Hanowski, R.J. *Development and Evaluation of a Naturalistic Observer Rating of Drowsiness Protocol: Final Report*; National Surface Transportation Safety Center for Excellence: Blacksburg, VA, USA, 2009.
47. Bourrelly, A.; Jacobé de Naurois, C.; Zran, A.; Rampillon, F.; Vercher, J.L.; Bourdin, C. Long automated driving phase affects take-over performance. *IET Intell. Transp. Syst.* **2019**, *13*, 1249–1255. [CrossRef]
48. Anderson, C.; Horne, J.A. Driving drowsy also worsens driver distraction. *Sleep Med.* **2013**, *14*, 466–468. [CrossRef] [PubMed]
49. Matthews, G.; Neubauer, C.; Saxby, D.J.; Wohleber, R.W.; Lin, J. Dangerous intersections? A review of studies of fatigue and distraction in the automated vehicle. *Accid. Anal. Prev.* **2018**, *126*, 85–94. [CrossRef] [PubMed]
50. Bier, L.; Wolf, P.; Hilsenbek, H.; Abendroth, B. How to measure monotony-related fatigue? A systematic review of fatigue measurement methods for use on driving tests. *Theor. Issues Ergon. Sci.* **2020**, *21*, 22–55. [CrossRef]