

## Article

# Distraction in the Driving Simulator: An Event-Related Potential (ERP) Study with Young, Middle-Aged, and Older Drivers

Melanie Karthaus \*, Edmund Wascher  and Stephan Getzmann

Leibniz Research Centre for Working Environment and Human Factors at the TU Dortmund,  
D-44139 Dortmund, Germany; wascher@ifado.de (E.W.); getzmann@ifado.de (S.G.)

\* Correspondence: karthaus@ifado.de



**Citation:** Karthaus, M.; Wascher, E.; Getzmann, S. Distraction in the Driving Simulator: An Event-Related Potential (ERP) Study with Young, Middle-Aged, and Older Drivers. *Safety* **2021**, *7*, 36.  
<https://doi.org/10.3390/safety7020036>

Academic Editor: Raphael Grzebieta

Received: 11 March 2021

Accepted: 29 April 2021

Published: 11 May 2021

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

**Abstract:** Distraction is a major causal factor of road crashes, and very young and older drivers seem to be particularly susceptible to distracting stimuli; however, the possibilities of exploring the causes for increased distractibility of these groups in real traffic seem to be limited. Experiments in a driving simulator are a good choice to eliminate the risk for crashes and to present highly standardized stimulus combinations. In the present study, 72 subjects from four age groups completed a driving task that required occasional responses to the brake lights of a car in front. In addition, in certain experimental conditions, subjects had to respond to distracting visual or auditory stimuli. In addition to behavioral data, electrophysiological correlates of stimulus processing were derived from the electroencephalogram (EEG). In the two older groups, braking response times increased even in a simple task condition when visual distraction stimuli occurred. In more complex task conditions braking response times increased with acoustic and visual distractors in the middle-aged group as well. In these complex task conditions braking error rates, especially the missing of braking reaction in favor of the distracting task, increased under visual distraction with increasing age. Associated with this, a reduced P3b component in the event-related potential indicated an unfavorable allocation of mental resources. The study demonstrates the potential of driving simulators for studying effects of distraction, but also their limitations with respect to the interpretability of the results.

**Keywords:** driving; distraction; older drivers; driving simulator; EEG

## 1. Introduction

Distraction is one of the greatest risk factors for road crashes. According to the National Highway Traffic Safety Administration (NHTSA), in 2018, 8% of all fatal crashes and 14% of all police-known traffic crashes in the USA were caused by distraction [1]. In view of the difficulty to identify distraction-related crashes and according to a study showing that drivers may be distracted for more than half the driving time [2], it can be assumed that the actual number of distraction-related crashes is even much higher.

Attention to irrelevant distracting stimuli and the pursuit of distracting activities can affect driving behavior in different ways, resulting in, for example, poor lane keeping [3], misjudgments in distance [4], overlooking driving-related stimuli [5], or longer brake response times [6]. All of these negative effects can increase the risk of a crash, especially if the distraction occurs in complex traffic environments, such as intersections or multi-lane roads or in critical situations that require a quick and focused response from the driver.

Investigating distraction while driving in real traffic is difficult because traffic situations are usually unpredictable and uncontrollable. As a result, the test conditions (e.g., traffic density, weather conditions) under which individual test subjects have to perform a driving task are often not easily comparable. Moreover, the systematic investigation of distraction while driving in real traffic could be extremely dangerous—both for the test subjects and other road users and is, therefore in many cases, ethically unacceptable. The

use of driving simulator offers a good and, above all, safe alternative offering several advantages; it allows for a targeted and controlled measurement of distraction in various (including critical) situations, which can be repeated as often as needed regardless of external conditions and is completely safe for everyone involved.

What kind of distraction affects driving performance most is not clearly understood yet. With regard to relatively simple distraction stimuli, specific stimulus characteristics seem to be important; in general, visual stimuli seem to be particularly distracting, quite in line with the model of multiple resources [7,8]. This model assumes that a negative impact on performance results from a conflict of resources when processing very similar stimuli or performing similar actions. Since most environmental stimuli in the driving context are visual, this resource conflict should be greatest when processing additional visual stimuli, for example, relative to auditory stimuli. The greater distracting effect of visual stimuli has been confirmed in various studies (e.g., [9]), and was found even when the visual stimuli were in the driver's direct field of view did not require averting the gaze from the road [10,11]. In some studies, great distraction effects were also observed with auditory stimuli (e.g., [12]), but here the distracting stimuli were rather complex (like speech stimuli) and required more cognitive resources to be processed. In principle, the more complex the distraction stimulus and the more demanding the distracting activity, the greater the distracting effect (e.g., [13,14]). This applies not only to external stimuli (e.g., digital billboards) or social distraction (e.g., communication with other passengers), but also to in-vehicle stimuli, such as in-car messages or other in-vehicle information system (IVIS) interactions, which can have, under certain conditions, a more distracting than supportive effect [15].

In order to adequately deal with distraction, inhibition is required. Inhibition is one of the executive functions that are neurophysiologically associated with the prefrontal cortex and are therefore subject to age-related changes [16]. Although not all inhibitory processes seem to require the same level of executive control [17], studies showed that healthy older people [18] and patients with frontal lobe lesions [19] are more prone to distraction. Given that the selective suppression of irrelevant stimuli requires a high level of executive control, the increased distractibility of older people could be related to decreased activity and coherence in the corresponding frontoparietal network, as the results of an fMRI study by Campbell, Grady, and Hasher et al. [20] suggests.

Whenever a distracting stimulus is perceived (or even anticipated, cf. [10,11]), it attracts attention, which is no longer available for processing a task-relevant stimulus, for example, a warning signal in a critical traffic situation. On the neurophysiological level, the P3b is of great interest here, a prominent event-related potential (ERP) obtained from the electroencephalogram (EEG). The P3b is most pronounced over parietal areas of the cortex and typically occurs at about 300 to 900 ms after a task-relevant stimulus. It is associated with mental resource allocation and the controlled processing of stimuli [21], and is also a correlate of inhibition processes (see [22]). In the driving context, for example, inhibition deficits associated with declines in the cognitive processing of distraction stimuli are reflected in a smaller P3b amplitude [10]. In fact, previous EEG studies on the P3b indicated that older adults are apparently less able to differentiate between relevant and irrelevant stimuli, thus investing too much attentional resources in (distracting) irrelevant stimuli [23]. This could explain why older adults, when distracted, show poorer tracking [24], longer braking times [25], and more braking errors [11] than younger adults. This is especially true for visual stimuli that occur in complex driving situations [10], quite in line with the model of multiple resources [7,8].

Some authors attributed a large part of the age-related performance losses to inhibition deficits [26], but this idea is increasingly being questioned by other authors [27]. They postulated a two-factor model [28] or even a three-factor model [29], according to which inhibition is not an uniform construct but instead consists of various facets, each of which can be susceptible to age-related changes to varying degrees: (a) the suppression of irrelevant stimuli (resistance of distractor interference), (b) the inhibition of previously

initiated reactions (prepotent-response inhibition), and (c) the suppression of information that was relevant in the past, but now is no longer relevant for the task at hand (resistance to proactive interference).

It can be assumed that additional task requirements go hand in hand with an increased strain on attention and mental resources. Increased task demands can be associated with both a reaction to the distraction stimulus and a suppression of such a reaction. When analyzing various laboratory tasks that are typically used to study inhibition, Rey-Mermet et al. [28] only found performance impairments of older people in tasks associated with the inhibition of prepotent responses. In tasks dealing with resistance to distracter interference, older adults sometimes performed even better than younger adults. However, other studies on age effects of the various facets of inhibition provided inconsistent findings (e.g., [30]). Likewise, in a previous study we found that inhibition of distracting stimuli as well as suppressing a reaction to irrelevant stimuli seemed to be more challenging for older than younger adults [10].

In the driving context, there are various distraction stimuli that are irrelevant to the traffic situation, but may—under specific circumstances—require a reaction, such as the ringing of the mobile phone, which prompts you to accept the call. Whether such a response might better be performed or not, critically depends on the current traffic situation. In view of the significantly increased risk of crashes in complex or unforeseen traffic situations, additional (potentially distracting) activities in these situations should be avoided. This applies in particular to older people who show the above-mentioned impairments in driving behavior when distracted. Indeed, there is some evidence that older drivers tend to forego additional, distracting activities even when they are in a complex traffic situation. For example, Charlton et al. [31] investigated the behavior of older drivers (65–83 years) at various intersection passages. They found that the proportion of time in which drivers were engaged in distracting activities varied with the context, and decreased with increasing complexity of the intersection, vehicle status (moving vs. stationary), and traffic density. However, it is to note that this study focused on overt behavior, that is, measuring how long the test subjects took their eyes off the road and their hands off the steering wheel during the distracting activity. It is still an open question how flexibly drivers of different age (can) adapt their driving behavior under distraction when critical events occur, requiring a braking response, for example. On a more general level, this raises the question to what extent age-related changes affect the meta-ability to focus attention on potentially distracting stimuli and to withdraw attention when the situation requires it.

The present study addressed this issue and investigated how acoustic and visual distraction stimuli affect the braking behavior of different age groups. A rather simple driving task in a reduced visual environment and with low traffic density was therefore designed, while the demands of cognitive resources required by a secondary task were systematically varied. Of particular interest was, whether and how flexibly different age groups managed to deal with distraction, i.e., appropriately adapted their attentional resources on a given traffic situation. In order to map age-related differences over wide age range, four age groups were tested, comprising young, middle-aged, young-old, and old-old drivers. The simulated driving task employed already in previous studies was used [10,11], in which the participants were instructed to respond to critical, driving-related events (braking reaction), while driving a vehicle. This critical event occurred either alone or simultaneously with a (visual or auditory) distraction stimulus, which required responses of different complexity.

In the simplest condition, all distraction stimuli should be ignored (“perception-only task”). This task served as a baseline condition, which, in terms of the model by Rey-Mermet & Gade [27], should reflect resistance to distractor interference. To investigate the inhibition of prepotent responses, participants had to perform a second task condition (“inhibition task”), in which they had to respond to the distracting stimuli in some cases; similar to real driving situations, the reaction to a distracting stimulus should only be performed, if it did not occur in a critical situation (here: together with the brake light).

Otherwise, the response had to be suppressed. This task was significantly more complex than the perception-only task, because the participants had only to respond to an additional stimulus in some cases, that is, they had to quickly and flexibly decide whether to respond or not. As we know, performance in such dual-task situations is usually impaired, especially in the elderly (e.g., [10,11,32]). In a third condition (“response task”), they had to respond to all distraction stimuli, regardless of whether the distraction stimulus occurred alone or in combination with the brake light. This condition was intended to attribute possible effects to inhibition of prepotent responses; for this purpose, a similar dual task with comparable requirements and complexity was needed in which no response had to be suppressed.

Taken together, on the basis of the literature and the findings from our previous studies, the following hypotheses were tested in the present study:

1. In simple tasks, additional distraction stimuli show little or no effect on braking behavior in all age groups.
2. Brake reaction times (RTs) and brake errors increase with increasing complexity, especially with visual distraction stimuli and in the two older groups.
3. In tasks in which a response to the distraction stimulus was required under certain conditions (and had to be suppressed in other conditions), brake RTs and error rates are highest, especially with visual distraction stimuli and in the two older groups.

In order to better understand the neurophysiological mechanisms underlying behavioral differences and, in particular, the potential role of mental processing resources, the EEG was recorded and analyzed with a focus on the P3b component. Here, it was expected that

4. The P3b, as a neurophysiological correlate of controlled stimulus processing, should be smaller in complex task conditions with additional distracting stimuli, especially in the older groups.

## 2. Materials and Methods

### 2.1. Participants

A total of 72 adults out of 4 age groups took part in the experiment: 18 young (18–25 years;  $M = 21.5$ ,  $SD = 2.3$ ), 18 middle-aged (31–40 years;  $M = 35.7$ ,  $SD = 2.6$ ), 18 young-old (55–65 years;  $M = 59.6$ ,  $SD = 3.2$ ), and 18 old-old (70–80 years;  $M = 75.1$ ,  $SD = 2.8$ ) active drivers (50% female in each group). The younger subjects were recruited in the universities in the area and via social media, the subjects from the two older groups via flyers that were displayed in the institute and at events for senior citizens.

All test persons reported normal or corrected vision and hearing. None of the subjects claimed to have suffered from a neurological or psychiatric illness or took drugs that affect the central nervous system. None of the subjects met the criteria for dementia [33] and all achieved significantly more than 17 points (young:  $M = 27.3$ , middle-aged:  $M = 26.9$ , young-old:  $M = 27.4$ , old-old:  $M = 25.4$ ) in the Montreal Cognitive Assessment (MoCA; [34]).

Also, the four age groups did not differ significantly in their annual mileage (young:  $M = 10,210$  km, middle-aged:  $M = 15,611$  km, young-old:  $M = 11,889$ , old-old:  $M = 9353$  km;  $F(3, 70) = 2.09$ ;  $p = 0.109$ ). Therefore, possible differences in driving behavior in the test drive cannot be traced back to differences in the current routine and/or driving practice of the age groups.

The subjects received 40 € for their participation in the experiment and gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the local Ethics Committee of the Leibniz Research Centre for Working Environment and Human Factors.

### 2.2. Task and Procedure

Before starting the driving simulation, the participants answered many questions about their driving history, their driving routines and experiences, and what they think about car driving. Additionally, the MoCA [34] was conducted to ensure that no participant

had significant cognitive deficits. Then the driving simulation took place in a static driving simulator (ST Sim, St Software B.V. Groningen, The Netherlands).

The participants follow another car at a distance of about 15 m at a constant speed (31 mph; 50 km/h) on a two-lane road. The straight route leads through a low-stimulus environment (grassland). Participants were instructed to keep their vehicle as precisely as possible in their (right) lane. To ensure that the subjects use the steering wheel despite the straight road design, their car was pushed to the left or right to different degrees, similar to a crosswind, which they were supposed to compensate by counter-steering. Both the direction and the strength of this simulated crosswind varied according to an unpredictable pattern, which consisted of several different superimposed and phase-delayed sine waves (1/25.6, 1/17, 1/12.8, 1/10.2, 1/8.6, 1/7.2, 1/6.4, and 1/5.6 Hz, see also [10,11,35]).

The brake lights of the car in front flashed up at irregular intervals, each lasting 500 ms. As soon as the brake lights flashed up, subjects were instructed to press their brake pedal as quickly as possible. Additionally, various distraction stimuli (duration: 500 ms) were presented. These were 18 country names and 18 German city names. They were presented either acoustically by a female voice via two broad-band loudspeakers (sound-pressure level 75 dB (A)) or visually on a 10.4 × 14 cm (4.73 by 6.36° visual angle) sign presented on the monitor, just below the car in front (see Figure 1).

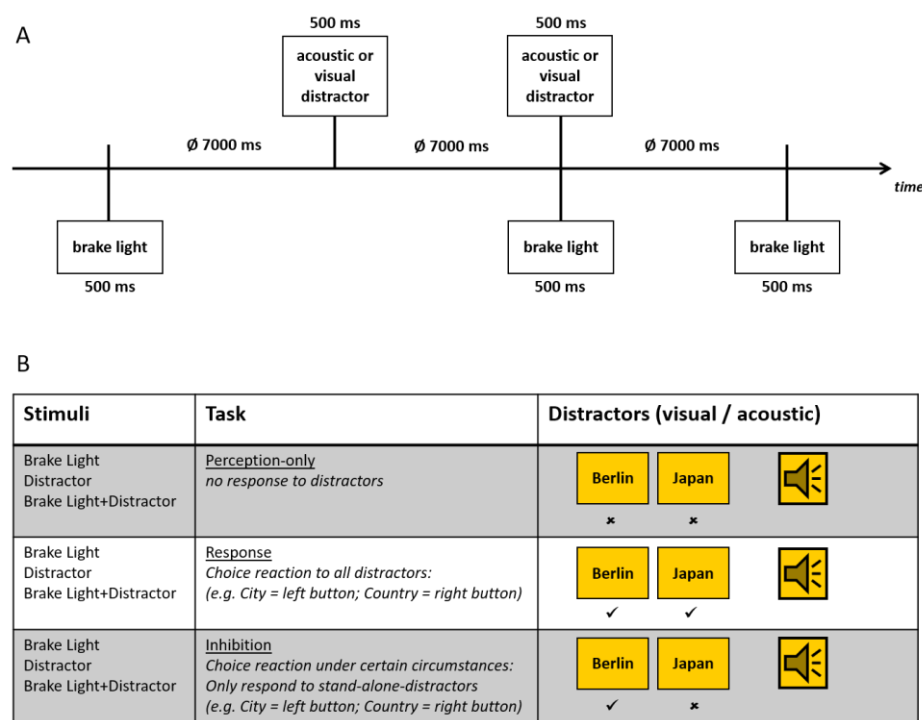


**Figure 1.** Screenshot of driving simulator task with flashing up brake lights of the leading car and visual distractor.

Both the brake lights and the acoustic and visual distraction stimuli could occur either alone or in combination. The inter-trial interval varied between 6 and 8 s (mean: 7 s; see Figure 2A).

Depending on the instruction, the participants should (a) ignore the distraction stimuli completely (perception-only task), or (b) react to each distraction stimulus by pressing a left button (as response to a country name) or right button (as response to a city name or vice versa) on the steering wheel (response task). In the third task, participants should (c) only react to the distraction stimulus in the described way if it occurred alone, but should ignore it when it was presented in combination with the brake light (inhibition task, see Figure 2B for an overview of the tasks). In any case, according to the instructions, the driving task (steering and braking), as in real life, had a higher priority than the secondary task (responding to distraction stimuli).





**Figure 2.** (A) Schematic representation of the time sequence of the brake light and secondary stimuli during driving simulation (B) overview of the three different tasks with their instructions and the required (non-)reaction to the visual/acoustic distraction stimuli.

In each of the three task conditions, the same 48 stimuli and stimulus conditions were presented in a pseudo-randomized order. That is, the brake lights flashed up 48 times alone and 48 times in combination with the distractor (24 times with the visual and 24 times with the acoustic distractor). Each of the three task conditions was presented in two separate blocks. Before each block, the participants received precise instructions for the task that followed. The order of the blocks was counterbalanced across the subjects. In sum, the entire driving simulation lasted 84 min (without breaks).

Before the experimental test blocks started, there was a short exercise (approx. 5 min) in which the participants could familiarize themselves with the driving simulator. A subsequent test ensured that the participants could correctly categorize the words presented in the test blocks as city or country names.

### 2.3. Data Recording

EEG was recorded by using a “BioSemi active 2” system (BioSemi, Amsterdam The Netherlands) with 32 scalp electrodes at positions of the extended international 10–20 system. In addition, two electrodes were placed on the left and right mastoids. The EEG was recorded with a sampling rate of 2048 Hz and an amplifier bandpass 0.5–25.0 Hz. Electrode impedance was kept below 10 k $\Omega$ . Additionally, an electrooculogram (EOG) with six additional electrodes that were positioned around both eyes was applied, to record horizontal and vertical eye positions.

### 2.4. Data Analysis

#### 2.4.1. Behavioral Data

To evaluate braking behavior, both the braking RTs and the braking error rates were analyzed. The time between the onset of the flashing brake lights and the actuation of the brake pedal was determined as braking RT. Responses made within a time window between 100 and 2500 ms, following a stimulus were considered as valid responses, whereas later responses were rated as omission errors. The braking error rate describes the proportion

of all incorrect reactions in trials that required a braking reaction. All RT analyses only contained correct responses.

To investigate whether a simultaneously presented additional acoustic or visual stimulus had an effect of the braking response (RTs and error rates) in the different task conditions and age groups, two  $3 \times 3 \times 4$  ANOVAs with the within-subject factors Task (perception-only, response, inhibition) and Stimulus (single brake light, brake light + acoustic stimulus, brake light + visual stimulus) and the between-subject factor Age (young, middle-aged, young-old, old-old) were computed.

#### 2.4.2. EEG Data

The raw data were digitally band-pass filtered (0.5 to 25 Hz; slopes 48 dB/octave) before re-referenced to the average of the mastoid electrodes. They were corrected for ocular artifacts by the Gratton, Coles, and Donchin procedure [36]. All individual epochs with a maximum-minimum difference higher than 200  $\mu$ V or with a maximum voltage step of 80  $\mu$ V per sampling point, were excluded from further analyses by the automatic artifact rejection function in the BrainVision Analyzer software (Version 2.1; Brain Products, Gilching, Germany). The peak of P3b was defined as a maximum positivity ( $\pm 5$  ms) at the electrode Pz, which occurred in a time window of 300 to 900 ms after the stimulus onset. Only trials with correct reaction were included in the analysis. These trials were corrected using the time interval 100 ms before the stimulus onset as baseline and finally averaged individually for each participant.

In order to account for the fundamental neurophysiological differences in the processing of single stimuli and stimulus combinations of different modality, EEG data were analyzed separately for the different stimulus types (single brake light vs. brake light + additional acoustic stimulus vs. brake light + additional visual stimulus). Thus, separate ANOVAs were conducted for the three stimulus combinations with the within-subject factor Task (perception-only vs. response vs. inhibition) and the between-subject factor Age (young vs. middle-aged vs. young-old vs. old-old).

In all analyses, Levene's test was used to test the homogeneity of variance. To correct for violations of sphericity the Greenhouse–Geisser adjustment was used. We computed partial  $\eta^2$  as effect size to rank and interpret the practical significance of statistically significant results more accurately.  $p$ -values of post-hoc tests were FDR-corrected.

### 3. Results

Means and standard deviations of braking RTs, error rates, and P3b-amplitudes are presented in Table 1.

#### 3.1. Braking Response Times

There were main effects of Age ( $F(3, 68) = 9.47, p < 0.001, \eta^2 = 0.29$ ), Task ( $F(2, 136) = 182.81, p < 0.001, \eta^2 = 0.73$ ) and Stimulus ( $F(2, 136) = 105.73, p < 0.001, \eta^2 = 0.61$ ), which were qualified by interactions of Task  $\times$  Age ( $F(6, 136) = 5.37, p < 0.001, \eta^2 = 0.19$ ), Stimulus  $\times$  Age ( $F(6, 136) = 7.85, p < 0.001, \eta^2 = 0.26$ ) and Task  $\times$  Stimulus ( $F(4, 272) = 59.98, p < 0.001, \eta^2 = 0.47$ ). The three-way interaction Task  $\times$  Stimulus  $\times$  Age slightly failed to reach statistical significance ( $F(12, 272) = 1.89, p = 0.053, \eta^2 = 0.08$ ).

Post-hoc tests revealed different effects of additional distracting stimuli depending on task complexity: In the perception-only task there was a decrease of braking RTs in trials with acoustic and visual distracting stimuli in the two younger groups (young:  $-29$  ms/ $-22$  ms (acoustic/visual); middle-aged:  $-33$  ms/ $-22$  ms; all  $p < 0.005$ ), but an increase of braking RTs in trials with visual stimuli in the two elderly groups (young-old:  $+27$  ms, old-old:  $+43$  ms; both  $p < 0.003$ ; see Figure 3, Perception-only).

In the response task all age groups showed longer braking RTs in trials with additional distractor stimuli, independent from stimulus modality (young:  $+106$  ms/ $+78$  ms (acoustic/visual), middle-aged:  $+144$  ms/ $+145$  ms, young-old:  $+204$  ms/ $+195$  ms, old-old:  $+295$  ms/ $+285$  ms; all  $p < 0.001$ ; see Figure 3, Response).

The same effect was observed in the middle-aged and young-old group in the inhibition task (middle-aged: +89 ms/+94 ms (acoustic/visual); young-old: +160 ms/ + 162 ms; all  $p < 0.001$ ), while the braking RTs of the young and oldest group differed significantly between acoustic and visual distractor stimuli: In the young group, braking RTs increased from single brake light to brake light with visual distraction and to acoustic distraction (visual: +57 ms, acoustic: +103 ms; both  $p \leq 0.001$ ), whereas the braking RTs of the old-old group increased from single brake light to brake light with acoustic to brake light with visual distraction (acoustic: +175 ms, visual: +206 ms; both  $p < 0.001$ ; see Figure 3, Inhibition).

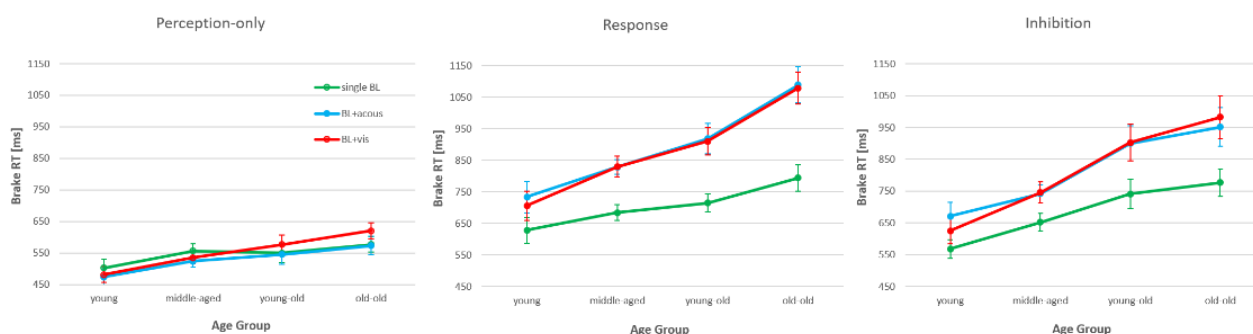
**Table 1.** Means (M) and standard deviations (SD) of braking RTs, error rates, and P3b-amplitudes of the four age groups in the perception-only, response and inhibition task, presented separately for single brake lights (Single BL), brake lights with additional acoustic stimuli (BL + acous), and brake lights with additional visual stimuli (BL + vis).

		Young		Middle-Aged		Young-Old		Old-Old	
		M	SD	M	SD	M	SD	M	SD
Task									
Perception-only	Braking RT [ms]								
	Single BL	502.79	115.25	556.61	96.11	549.57	127.05	577.10	104.91
	BL + acous	473.81	110.85	523.57	78.74	544.87	126.96	573.26	122.92
	BL + vis	480.81	106.01	534.94	80.53	576.38	126.22	620.44	111.07
	Brake error rate [%]								
	Single BL	1.62	3.47	3.82	8.28	1.04	1.79	3.59	6.10
	BL + acous	0.69	1.24	1.85	4.22	0.46	0.89	2.43	4.70
	BL + vis	1.39	2.58	3.01	8.73	3.01	5.90	12.62	12.26
	P3b-amplitude [ $\mu$ V]								
	Single BL	13.11	5.39	14.01	6.62	13.86	4.51	11.44	4.76
	BL + acous	14.31	5.48	14.00	5.97	13.73	4.29	11.00	4.28
	BL + vis	13.93	4.58	13.15	6.06	12.07	5.22	9.31	3.52
Response	Braking RT [ms]								
	Single BL	628.18	170.55	684.07	104.88	714.73	118.33	793.79	178.08
	BL + acous	734.10	212.72	828.43	98.81	918.24	204.06	1089.08	244.37
	BL + vis	705.95	193.26	829.45	139.98	910.03	185.41	1078.30	215.06
	Brake error rate [%]								
	Single BL	4.75	6.46	5.32	7.19	1.85	1.58	6.83	10.18
	BL + acous	5.56	9.51	7.06	8.96	4.17	4.40	13.89	16.31
	BL + vis	8.22	9.52	11.69	12.26	23.96	18.96	38.43	24.94
	P3b-amplitude [ $\mu$ V]								
	Single BL	14.12	4.30	13.36	5.91	10.46	4.67	9.87	4.67
	BL + acous	12.47	3.97	14.31	6.23	9.94	4.65	9.09	5.37
	BL + vis	11.40	4.59	10.15	6.32	5.86	3.82	6.43	4.75



Table 1. Cont.

		Young		Middle-Aged		Young-Old		Old-Old	
		M	SD	M	SD	M	SD	M	SD
Task									
Inhibition	Braking RT [ms]								
	Single BL	567.95	124.29	652.32	117.20	740.68	196.17	776.85	181.14
	BL + acous	671.15	183.07	741.61	121.03	900.42	233.11	951.60	257.98
	BL + vis	624.85	170.65	746.05	143.88	903.10	248.48	982.55	284.71
	Brake error rate [%]								
	Single BL	1.85	3.42	4.98	12.48	1.85	2.25	3.24	4.06
	BL + acous	5.21	8.19	3.94	7.18	3.47	3.57	11.34	17.77
	BL + vis	5.21	6.97	11.57	12.59	19.10	15.23	42.25	29.44
	P3b-amplitude [μV]								
	Single BL	14.96	5.79	13.85	6.63	11.50	5.34	9.67	4.08
	BL + acous	13.75	4.61	13.00	6.63	9.72	5.33	8.31	5.07
	BL + vis	12.16	4.27	10.56	5.69	6.64	4.06	6.16	3.83



**Figure 3.** Mean braking RTs and standard errors of mean in trials with single brake light (BL), brake light + acoustic stimulus (BL + acous), and brake light + visual stimulus (BL + vis) of the four age groups, presented separately for perception-only, response, and inhibition task.

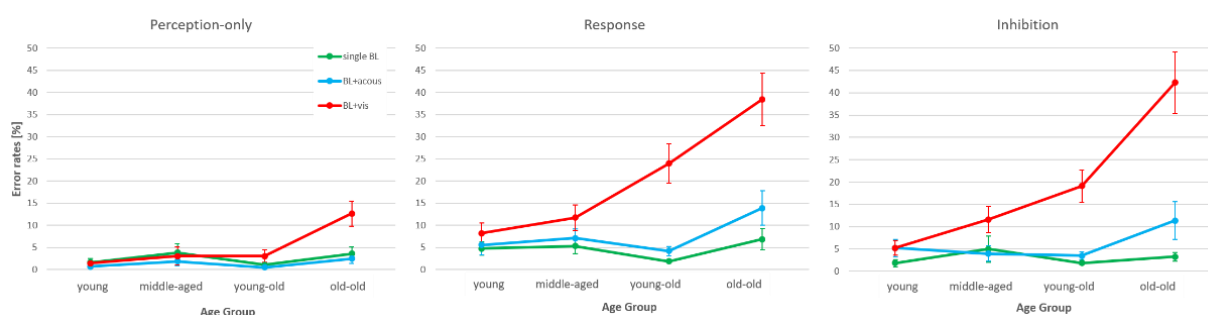
To sum up, the braking RTs decreased in the simple (perception-only) task in the two younger age groups in trials with acoustic and visual distraction stimuli, while it increased in the two older groups with visual distraction stimuli. In the more complex tasks, all groups showed an increase in braking RTs, relative to the single brake light. This could be observed in the response task, and in the two middle groups also in the inhibition task—regardless of the modality of the distraction stimuli. In the inhibition task, the younger group showed highest RTs in trials with additional acoustic distraction stimuli, while the oldest group showed highest RTs in trials with additional visual distraction stimuli.

### 3.2. Braking Error Rates

Similarly to the braking RTs, the analyses of braking error rates resulted in main effects of Age ( $F(3, 68) = 8.71, p < 0.001, \eta^2 = 0.28$ ), Task ( $F(2, 136) = 36.65, p < 0.001, \eta^2 = 0.35$ ) and Stimulus ( $F(2, 136) = 75.73, p < 0.001, \eta^2 = 0.53$ ). All two-way interactions also reached statistical significance (Task  $\times$  Age:  $F(6, 136) = 3.02, p = 0.009, \eta^2 = 0.12$ ; Stimulus  $\times$  Age:  $F(6, 136) = 17.05, \eta^2 = 0.43$ ; Task  $\times$  Stimulus:  $F(4, 272) = 27.36, p < 0.001, \eta^2 = 0.29$ ), as well as the three-way interaction of Task  $\times$  Stimulus  $\times$  Age ( $F(12, 272) = 5.08, p < 0.001, \eta^2 = 0.18$ ).

Post-hoc-tests showed that in the simple task (perception-only) there was no effect of additional distraction in the young, middle-aged, and young-old group (all  $p > 0.157$ ), whereas in the oldest group (old-old) the error rates changed in trials with additional distraction: Compared to single brake light, the lowest error rate was observed in trials with additional acoustic distraction ( $-1.2\%$ ,  $p = 0.046$ ), the highest with additional visual distraction ( $+9.0\%$ ,  $p = 0.001$ ).

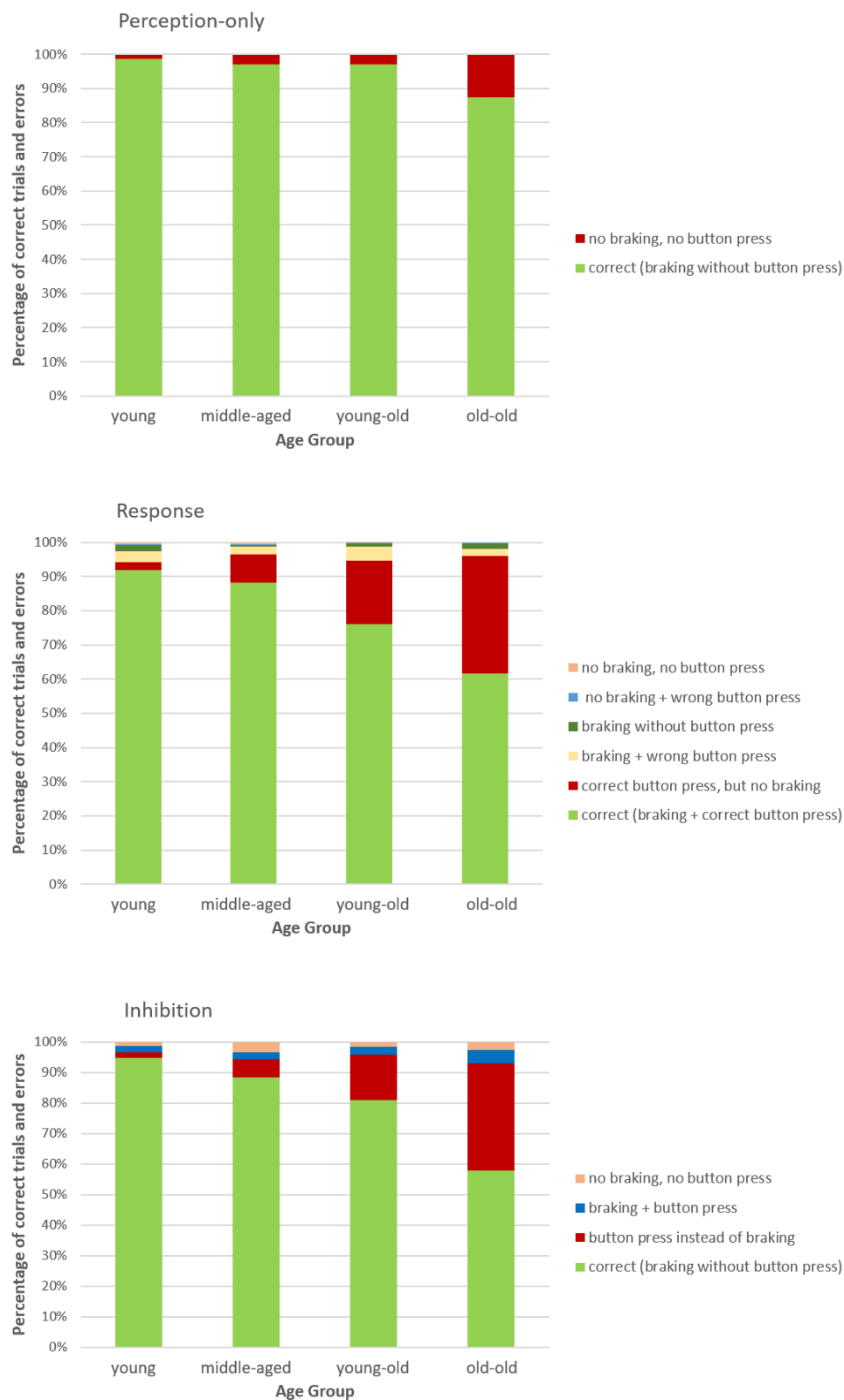
An increase in error rates was observed in the response and inhibition tasks (see Figure 4), but this clearly depended on age: In the two younger age groups, there was a slight to moderate increase with visual distraction stimuli (young:  $+3.5\%$ / $+3.4\%$  (response/inhibition task); both  $p > 0.055$ ; middle-aged:  $+6.4\%$ / $+6.6\%$ ; both  $p < 0.043$ ) and no or only a slight increase with acoustic distraction stimuli (young:  $+0.8\%$ / $+3.4\%$  (response/inhibition task); middle-aged:  $+1.7\%$ / $-1.0\%$ ; all  $p > 0.076$ ). In contrast, in the two older groups there was a considerable increase with visual distraction stimuli (young-old:  $+22.1\%$ / $+17.3\%$  (response/inhibition task); old-old:  $+31.6\%$ / $+39.0\%$ ; all  $p < 0.001$ ), while there was a slight increase in error rates with acoustic stimuli (young-old:  $+2.3\%$ / $+1.6\%$  (response/inhibition), both  $p > 0.053$ ; old-old:  $+7.1\%$ / $+8.1\%$ , both  $p < 0.045$ ).



**Figure 4.** Error rates and standard errors of mean in trials with single brake light (single BL), brake light + acoustic stimulus (BL + acous) and brake light + visual stimulus (BL + vis) of the four age groups, presented separately for perception-only, response and inhibition task.

As an additional analysis, the proportions of the different types of errors depending on the combinations of visual distraction stimuli and brake lights were investigated. The analysis revealed that with increasing age, essentially one type of error increased significantly: In the response task, the proportion of trials in which the subjects pressed the correct key, but omitted the braking reaction increased. In the inhibition task, the proportion of trials in which the test subjects pressed the button instead of the brake pedal increased (see Figure 5).

In summary, additional distraction in the simple (perception-only) task had no effects on the error rates of the first three age groups, only the oldest group (old-old) made significantly more errors under visual distraction. In the more complex conditions, however, the error rates under visual distraction increased significantly with increasing age, especially the number of trials, in which the subjects neglected the braking reaction in favor of the distracting task. In the oldest group, these effects were most pronounced in the inhibition task, in which they also showed an increase in the error rate under acoustic distraction.



**Figure 5.** Proportion of correct braking reactions and various types of errors in percent, presented separately for perception-only, response and inhibition task and the four age groups. Please note especially the age-related increase in the proportion of errors, in which the correct response to the distraction stimulus was given, but the brake response was omitted (red bars in response and inhibition).

### 3.3. P3b Amplitude

With single brake light stimuli, there was a main effect of Task ( $F(2, 136) = 3.83$ ,  $p = 0.029$ ,  $\eta^2 = 0.053$ ), which was further qualified by an interaction of Task  $\times$  Age ( $F(6, 136) = 3.44$ ,  $p = 0.005$ ,  $\eta^2 = 0.132$ ). The analyses of brake light + acoustic distractor and brake light + visual distractor reveal main effects of Age (acous:  $F(3, 68) = 3.33$ ,  $p = 0.025$ ,  $\eta^2 = 0.128$ ; vis:  $F(3, 68) = 5.70$ ,  $p = 0.002$ ,  $\eta^2 = 0.201$ ) and Task (acous:  $F(2, 136) = 13.55$ ,  $p < 0.001$ ,  $\eta^2 = 0.166$ ; vis:  $F(2, 136) = 50.40$ ,  $p < 0.001$ ,  $\eta^2 = 0.426$ ). In both stimulus conditions there was a significant interaction of Task  $\times$  Age (acous:  $F(6, 136) = 2.94$ ,  $p = 0.017$ ,  $\eta^2 = 0.115$ ; vis:  $F(6, 136) = 2.96$ ,  $p = 0.014$ ,  $\eta^2 = 0.116$ ; for an overview of the grand-average target-locked P3b components see Figure 6).



**Figure 6.** Grand-average target-locked P3b components of the four age groups in the perception-only task (Per), response task (Resp) and inhibition task (Inhi) shown at Pz, presented separately for single brake light, brake light + acoustic stimulus, and brake light + visual stimulus.

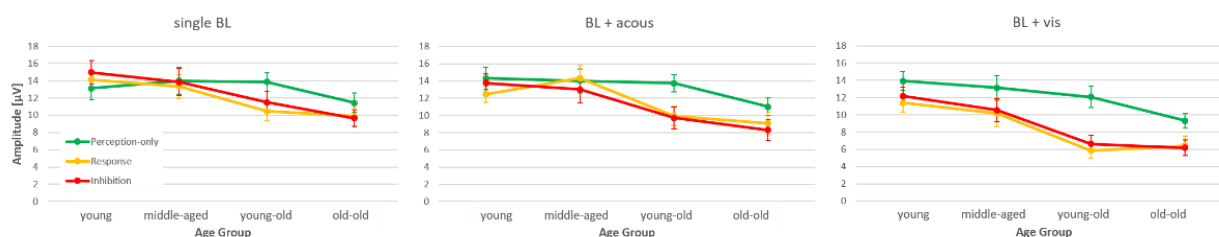
Post-hoc tests showed that almost all age groups (young, middle-aged, old-old) showed a comparable P3b in single BL in all three tasks (perception-only, response, inhibition; all  $p > 0.071$ ). Only in the young-old group was the P3b significantly smaller in the response and inhibition task than in perception-only (both  $p < 0.049$ , see Figure 7 Single BL).

A similar pattern of results was also found in trials with additional acoustic stimuli: The P3b of the young and middle-aged group was comparable in all three tasks (all  $p > 0.095$ ). But in this stimulus condition the P3b-amplitude of both, the young-old and old-old group, was significantly smaller in the response and inhibition task compared to perception-only task (all  $p < 0.050$ ).

A smaller P3b in the response and inhibition task compared to the perception-only task was observed in trials with additional visual stimulus in the old-old and young-old, but also in the middle-aged group (all  $p < 0.042$ ). However, in these trials, group 1 showed a significant smaller P3b in the response task compared to perception-only ( $p = 0.009$ ).

In summary, the reduction of P3b amplitude task in response and inhibition tasks (relative to perception-only task) was more pronounced with brake lights with acoustic or visual distracting stimuli than with single brake lights. Additionally, irrespective of

stimulus, this reduction of P3b amplitude in response and inhibition tasks (relative to perception-only task) was more pronounced in the two older age groups.



**Figure 7.** P3b-Amplitude in trials with single brake light (BL), brake light + acoustic stimulus (BL + acous) and brake light + visual stimulus (BL + vis) of the four age groups, presented separately for perception-only, response and inhibition task.

#### 4. Discussion

The present study examined the effect of acoustic and visual distraction stimuli on braking behavior of different age groups in a simple driving task in contexts of varying complexity. In particular, it was investigated whether people of different ages were able to suppress the reaction to distraction stimuli if necessary, and instead to focus on the primary traffic-related task in critical situations. Therefore, a driving situation was simulated in which a highly traffic-relevant event (i.e., the flashing up of the brake lights of a car ahead) occurred simultaneously with a less relevant event, and in which the drivers had to prioritize the relevant response. The secondary event was the verbal or visual presentation of city or country names, and was intended to simulate in-vehicle messages, as is common today in modern in-vehicle information systems (IVIS).

As expected, additional distraction stimuli in simple situations (perception-only task) had hardly any negative effect on braking behavior (Hypothesis 1)—at least in the two younger age groups. Here, the braking RTs in trials with additional distraction stimuli was even reduced, regardless of their modality. This could be due to an alerting function of suddenly appearing stimuli, which was already observed for acoustic stimuli in an earlier study [10]. In the present study, such an effect was also shown for additional visual distraction stimuli, albeit less pronounced. A similar phenomenon was described by Swallow and Jiang [37] in a dual-task paradigm, in which simultaneously presented information improved performance in a primary task. The authors attributed this improvement to an “attentional boost”, suggesting that the identification of a stimulus as a target stimulus triggers a selection mechanism that improves the short, but broad processing of information [38].

The additional distraction in the perception-only task had no influence on the error rates—except for the oldest group (old-old), who made more braking errors when distracted visually. Visual distraction also resulted in a longer braking response time in the two older groups. The greater distraction effect of visual stimuli in the driving context replicates the findings of previous studies (e.g., [10,11]) and is in line with the multiple resource model of Wickens [7,8]. This model predicts a resource conflict when processing similar stimuli, which has an adverse effect on stimulus processing and thus also on performance. Obviously, this resource conflict shows up earlier in the older groups (i.e., even in rather simple tasks, in which no overt response to the distraction stimuli was required), and seems to weaken their resistance to distractor interference reported by Rey-Mermet et al. [28]. No such effect was observed in the two younger groups.

With increasing task complexity, the need for resource allocation increases, which, at least in the two older groups, is reflected also at the neurophysiological level; as expected, the task complexity in the two younger age groups has no influence on the P3b amplitude, while the P3b in the two older groups was significantly reduced in the two more complex (response/inhibition) tasks, relative to the simple perception-only task (Hypothesis 4). However, this P3b reduction was observed with all stimulus types, i.e., irrespective of whether the brake light occurred alone or in combination with the distraction stimuli. As



a neurophysiological correlate of cognitive control or controlled stimulus processing, the P3b can vary depending on the task. A decrease in the P3b amplitude is associated with less controlled processing, which can be attributed, for example, to the complexity of the task [39]; the more complex the task, the more the available cognitive resources have to be divided up, which can lead to increased response times and error rates [21].

All groups showed an increase in brake RTs in more complex tasks (Hypothesis 2). This increase was observed in the response task in all age groups, regardless of the modality of the distraction stimuli. At first glance, the delays in the reaction time did not seem to be significant (max. 295 ms), but in the context of braking reaction time, even a slowdown of a few hundred milliseconds can increase the risk of an accident: After all, a vehicle driving with a speed of 50 km/h covers around 4 m in 300 ms, which is quite a lot when following another car with high traffic in real life. A modality effect was shown in the inhibition task; in the oldest group (old-old), the slowing down of the braking RTs to visual distraction stimuli was most pronounced, which in turn suggests a resource conflict, according to Wickens [7,8]. This is also supported by the fact that the error rates in the more complex tasks, especially with visual distraction, increased significantly with increasing age. The increase in the error rate in the inhibition task was greatest in the oldest group (see Hypothesis 3). This result is in line with the results of Rey-Mermet et al. [28], who found performance impairments of older people in tasks associated with the inhibition of prepotent responses. What was noticeable in our inhibition task (but also in the response task) was that the number of trials significantly increased, in which the subjects neglected the braking reaction in favor of the secondary task. In fact, nearly 40% of the braking responses were missed by the oldest (old-old) subjects when the brake lights appeared together with the visual distractor stimuli.

Here, it should be noted that it has hardly made any difference of whether the subjects had to respond to both stimuli in every trial (in the response task) or whether they only had to respond to the brake light (in the inhibition task). Both older groups thus tend to mix up the priorities of the individual requirements. Despite explicit instructions to prioritize the traffic-relevant event, they primarily carried out the reaction to the distraction stimulus, but omitted the more important braking reaction. Obviously, the keystroke response on the distracting stimuli was in some way “pre-defined” here, so that it was given priority. One can only speculate about the reasons for this. It may be because the reaction to the single distraction stimulus presented was expressly required in these two types of tasks. This could also be a reason why the two tasks implemented here (response/inhibition) do not differ very much. Another reason could be that the visual distraction stimuli were presented on a large surface and occupied a substantial space in the driver’s field of view, thus having a greater salience than the relatively small brake lights of the car ahead. This would suggest that bottom-up triggered distraction processes are more dominant in the elderly relative to top-down regulated attentional control. The same conclusion is drawn by Ridderinkhof and Wijnen [40], who showed in their study that salient distraction stimuli have an increasing distracting effect with increasing age. They suspect that this is due to the fact that salient stimuli trigger stronger eye movements on the one hand, and to a failing of top-down control processes on the other hand. In line with that acoustic distraction stimuli had a much smaller effect on brake responses. Also, the decline in P3b amplitude in the older groups was even more pronounced with visual (than acoustic) distraction stimuli, suggesting an unfavorable allocation of mental resources.

On the other hand, it must be taken into account that the situations simulated here are to a large extent artificial compared to real traffic situations and perhaps make differences between age groups more prominent than in everyday life. For example, it might be easier for drivers to suppress unnecessary or distracting behavior in favor of the braking reaction if they were free to react to the distraction stimulus during the entire driving task. This is indicated by studies that have shown that drivers in real traffic tend to forego additional activities in complex situations in order to possibly (unconsciously) avoid potential resource conflicts and the resulting impairment in performance (e.g., [31,41]). However, this was

not possible in the present study. Also, it was not possible to reduce the complexity of the task through compensatory behavior (e.g., by reducing the driving speed).

The constant speed at which the test subjects had to perform the driving simulation had another implication that must be taken into account when interpreting the results; the braking reaction performed here had no real braking effect, but were intended as a reaction task to the flashing-up of the brake lights. It is conceivable that the lack of braking action contributed to weakening the priority of this reaction. As with all driving simulation studies, this raises the question of the comparability of the simulated scenarios and reality. In view of the studies that ascribe a high level of validity to the driving simulator as an examination instrument (e.g., [42]), it can be assumed that the findings obtained here are also of importance for real traffic, while the extent of age-related differences may seem exaggerated. Regardless of this, the use of driving simulators to investigate distraction in critical traffic situations is essential for safety reasons alone.

As a concluding remark, it remains to be seen to what extent modern driver assistance systems will be able to support especially older drivers to deal with distraction stimuli in real traffic and to manage to react flexibly and appropriately when critical events occur. It is conceivable that as vehicle automation advances, some negative effects of distraction will be weakened, and older drivers, in particular, will benefit from increasing automation. However, there are some studies showing that older drivers in SAE Level 3 vehicles, in which the driver has to take control of the vehicle in certain situations, took longer to do this and the takeover was less successful—especially in adverse weather conditions [43] or when they previously had to deal with non-driving-related tasks [44]. It is also unclear whether, and to what extent training measures for older drivers, can possibly support the inhibition or management of distracting stimuli in a driving context. We know that training units in the driving simulator and in real traffic have a positive effect on the real driving performance of older drivers [45,46]. However, the driver's susceptibility to distraction and their ability to inhibit irrelevant stimuli was not explicitly recorded. Thus, there is still a need for research here.

## 5. Conclusions

Even in a simple task situation, older drivers show an increased braking reaction time and more braking errors under (visual) distraction. This effect increases as the task becomes more complex. This is especially true for visual distraction, which, with regard to the elderly, also means that previously allowed responses to distraction stimuli are not inhibited in critical situations. However, the results of the present study indicate that visual distraction stimuli in particular should be avoided as much as possible. This applies not only to the external, but also internal driving environment, where in-vehicle information systems should assist (and not distract or disrupt) the driver. This is particularly true for complex traffic situations in which the risk of critical situations is particularly high, for distraction stimuli that require a reaction, and for older drivers.

**Author Contributions:** Conceptualization, M.K., S.G. and E.W.; Methodology, M.K., S.G. and E.W.; Validation, M.K.; Formal Analysis, M.K.; Investigation, M.K.; Resources, M.K., S.G. and E.W.; Data Curation, M.K.; Writing—Original Draft Preparation, M.K.; Writing—Review & Editing, S.G. and E.W.; Visualization, M.K.; Supervision, M.K., S.G. and E.W.; Project Administration, M.K.; Funding Acquisition, M.K. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by a grant from the Deutsche Forschungsgemeinschaft (DFG, KA 4120/2-1). The publication of this article was funded by the Open Access Fund of the Leibniz Association.

**Institutional Review Board Statement:** The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the Leibniz Research Centre for Working Environment and Human Factors (“Autofahren unter Ablenkung: Einflüsse auf Hirnaktivität und Fahrleistung bei jungen, mittleren und älteren Fahrern” (Car driving under distraction: Effects on brain activity and driving performance in young, middle-aged and older drivers), 09.06.2015).

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** Data available from the corresponding author upon reasonable request.

**Acknowledgments:** We thank Ludger Blanke for technical assistance and Christiane Westedt, Lisa Moenig, Ann-Katrin Breidebach, Finja Joiko, and Iman El-Sayed for organizational assistance and their help in running the experiment.

**Conflicts of Interest:** The authors declare no conflict of interest. The sponsors had no role in the design, execution, interpretation, or writing of the study.

## References

1. National Highway Traffic Safety Administration (NHTSA) (2020). Distracted Driving 2018. Available online: <https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812926> (accessed on 2 February 2021).
2. Dingus, T.A.; Guo, F.; Lee, S.; Antin, J.F.; Perez, M.; Buchanan-King, M.; Hankey, J. Driver crash risk factors and prevalence evaluation using naturalistic driving data. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 2636–2641. [\[CrossRef\]](#)
3. Thompson, K.R.; Johnson, A.M.; Emerson, J.L.; Dawson, J.D.; Boer, E.R.; Rizzo, M. Distracted driving in elderly and middle-aged drivers. *Accid. Anal. Prev.* **2012**, *45*, 711–717. [\[CrossRef\]](#)
4. Cooper, P.J.; Zheng, Y. Turning gap acceptance decision-making: The impact of driver distraction. *J. Saf. Res.* **2002**, *33*, 321–335. [\[CrossRef\]](#)
5. Maples, W.C.; DeRosier, W.; Hoenes, R.; Bendure, R.; Moore, S. The effects of cell phone use on peripheral vision. *Optometry* **2008**, *79*, 36–42. [\[CrossRef\]](#)
6. Hibberd, D.L.; Jamson, S.L.; Carsten, O.M. Mitigating the effects of in-vehicle distractions through use of the Psychological Refractory Period paradigm. *Accid. Anal. Prev.* **2013**, *50*, 1096–1103. [\[CrossRef\]](#)
7. Wickens, C.D. Multiple resources and performance prediction. *Theor. Issues Ergon. Sci.* **2002**, *3*, 159–177. [\[CrossRef\]](#)
8. Wickens, C.D. Multiple resources and mental workload. *Hum. Factors* **2008**, *50*, 449–455. [\[CrossRef\]](#)
9. Sodnik, J.; Dicke, C.; Tomazic, S.; Billinghamurst, M. A user study of auditory versus visual interfaces for use while driving. *Int. J. Hum. Comput. Stud.* **2008**, *66*, 318–332. [\[CrossRef\]](#)
10. Karthaus, M.; Wascher, E.; Getzmann, S. Effects of Visual and Acoustic Distraction on Driving Behavior and EEG in Young and Older Car Drivers: A Driving Simulation Study. *Front. Aging Neurosci.* **2018**, *10*, 420. [\[CrossRef\]](#)
11. Karthaus, M.; Wascher, E.; Falkenstein, M.; Getzmann, S. The ability of young, middle-aged and older drivers to inhibit visual and auditory distraction in a driving simulator task. *Transp. Res. F* **2020**, *68*, 272–284. [\[CrossRef\]](#)
12. Caird, J.K.; Simmons, S.M.; Wiley, K.; Johnston, K.A.; Horrey, W.J. Does Talking on a Cell Phone, With a Passenger, or Dialing Affect Driving Performance? An Updated Systematic Review and Meta-Analysis of Experimental Studies. *Hum. Factors* **2018**, *60*, 101–133. [\[CrossRef\]](#) [\[PubMed\]](#)
13. Patten, C.J.D.; Kircher, A.; Östlund, J.; Nilsson, L. Using mobile telephones: Cognitive workload and attention resource allocation. *Accid. Anal. Prev.* **2004**, *36*, 341–350. [\[CrossRef\]](#)
14. Schweizer, T.A.; Kan, K.; Hung, Y.; Tam, F.; Naglie, G.; Graham, S.J. Brain activity during driving with distraction: An immersive fMRI study. *Front. Hum. Neurosci.* **2013**, *7*, 53. [\[CrossRef\]](#) [\[PubMed\]](#)
15. Strayer, D.L.; Cooper, J.M.; Turrill, J.; Coleman, J.R.; Hopman, R.J. Talking to your car can drive you to distraction. *Cogn. Res. Princ. Implic.* **2016**, *1*, 16. [\[CrossRef\]](#)
16. Zelazo, P.D.; Craik, F.I.M.; Booth, L. Executive function across the life span. *Acta Psychol.* **2004**, *115*, 167–183. [\[CrossRef\]](#)
17. Andrés, P.; Guerrini, C.; Phillips, L.H.; Perfect, T.J. Differential effects of aging on executive and automatic inhibition. *Dev. Neuropsychol.* **2008**, *33*, 101–123. [\[CrossRef\]](#)
18. Hasher, L.; Lustig, C.; Zacks, R. Inhibitory mechanisms and the control of attention. In *Variation in Working Memory*; Conway, A.R.A., Jarrold, C., Kane, M.J., Miyake, A., Towse, J.N., Eds.; Oxford University Press: Oxford, UK, 2007; pp. 227–249.
19. Stuss, D.T.; Toth, J.P.; Franchi, D.; Alexander, M.P.; Tipper, S.; Craik, F.I. Dissociation of attentional processes in patients with focal frontal and posterior lesions. *Neuropsychologia* **1999**, *37*, 1005–1027. [\[CrossRef\]](#)
20. Campbell, K.L.; Grady, C.L.; Ng, C.; Hasher, L. Age differences in the frontoparietal cognitive control network: Implications for distractibility. *Neuropsychologia* **2012**, *50*, 2212–2223. [\[CrossRef\]](#)
21. Polich, J. Updating P300: An integrative theory of P3a and P3b. *Clin. Neurophysiol.* **2007**, *118*, 2128–2148. [\[CrossRef\]](#)
22. Pires, L.; Leitao, J.; Guerrini, C.; Simoes, M.R. Event-related brain potentials in the study of inhibition: Cognitive control, source localization and age-related modulations. *Neuropsychol. Rev.* **2014**, *24*, 461–490. [\[CrossRef\]](#)
23. Hahn, M.; Wild-Wall, N.; Falkenstein, M. Age-related differences in performance and stimulus processing in dual task situation. *Brain Res.* **2011**, *1414*, 66–76. [\[CrossRef\]](#)
24. Fofanova, J.; Vollrath, M. Distraction while driving: The case of older drivers. *Transp. Res. F* **2011**, *14*, 638–648. [\[CrossRef\]](#)
25. Hancock, P.A.; Lesch, M.; Simmons, L. The distraction effects of phone use during a crucial driving maneuver. *Accid. Anal. Prev.* **2003**, *35*, 501–514. [\[CrossRef\]](#)
26. Hasher, L.; Zacks, R.T. *The Psychology of Learning and Motivation*; Bower, G., Ed.; Academic Press: San Diego, CA, USA, 1988; Volume 22, pp. 193–225.
27. Rey-Mermet, A.; Gade, M. Inhibition in aging: What is preserved? What declines? A meta-analysis. *Psychon. Bull. Rev.* **2017**, *25*, 1695–1716. [\[CrossRef\]](#)

28. Rey-Mermet, A.; Gade, M.; Oberauer, K. Should we stop thinking about inhibition? Searching for individual and age differences in inhibition ability. *J. Exp. Psychol.* **2017**, *44*, 501–526. [[CrossRef](#)] [[PubMed](#)]
29. Friedman, N.P.; Miyake, A. The relations among inhibition and interference control functions: A latent-variable analysis. *J. Exp. Psychol. Gen.* **2004**, *133*, 101–135. [[CrossRef](#)] [[PubMed](#)]
30. Pettigrew, C.; Martin, R.C. Cognitive declines in healthy aging: Evidence from multiple aspects of interference resolution. *Psychol. Aging* **2014**, *29*, 187–204. [[CrossRef](#)] [[PubMed](#)]
31. Charlton, J.L.; Catchlove, M.; Scully, M.I.; Koppel, S.N.; Newstead, S.V. Older driver distraction: A naturalistic study of behaviour at intersections. *Acc. Anal. Prev.* **2013**, *58*, 271–278. [[CrossRef](#)] [[PubMed](#)]
32. Hahn, M.; Wild-Wall, N.; Falkenstein, M. *Age-Differentiated Work Systems*; Schlick, C.M., Frieling, E., Wegge, J., Eds.; Springer: Heidelberg, Germany, 2013; pp. 299–317.
33. Saczynski, J.S.; Inouye, S.K.; Guess, J.; Jones, R.N.; Fong, T.G.; Nemeth, E.; Hodara, A.; Ngo, L.; Marcantonio, E.R. The Montreal Cognitive Assessment (MoCA): Creating a cross-walk with the Mini-Mental State Examination. *J. Am. Geriatr. Soc.* **2015**, *63*, 2370–2374. [[CrossRef](#)] [[PubMed](#)]
34. Nasreddine, Z.S.; Phillips, N.A.; Bédirian, V.; Charbonneau, S.; Whitehead, V.; Collin, I.; Cummings, J.L.; Chertkow, H. The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *J. Am. Geriatr. Soc.* **2005**, *53*, 695–699. [[CrossRef](#)]
35. Wascher, E.; Getzmann, S.; Karthaus, M. Driver state examination—Treading new paths. *Acc. Anal. Prev.* **2016**, *91*, 157–165. [[CrossRef](#)] [[PubMed](#)]
36. Gratton, G.; Coles, M.G.H.; Donchin, E. A new method for off-line removal of ocular artifact. *Electroencephalogr. Clin. Neurophysiol.* **1983**, *55*, 468–484. [[CrossRef](#)]
37. Swallow, K.M.; Jiang, Y.V. The attentional boost effect: Transient increases in attention to one task enhance performance in a second task. *Cognition* **2010**, *115*, 118–132. [[CrossRef](#)] [[PubMed](#)]
38. Swallow, K.M.; Jiang, Y.V. Attentional load and attentional boost: A review of data and theory. *Front. Psychol.* **2013**, *4*, 274. [[CrossRef](#)]
39. Fedota, J.R.; McDonald, C.G.; Roberts, D.M.; Parasuraman, R. Contextual task difficulty modulates stimulus discrimination: Electrophysiological evidence for interaction between sensory and executive processes. *Psychophysiology* **2012**, *49*, 1384–1393. [[CrossRef](#)]
40. Ridderinkhof, K.R.; Wijnen, J.G. More than meets the eye: Age differences in the capture and suppression of oculomotor action. *Front. Psychol.* **2011**, *2*, 267. [[CrossRef](#)]
41. Young, K.L.; Charlton, J.; Koppel, S.; Grzebieta, R.; Williamson, A.; Woolley, J.E.; Senserrick, T. Distraction and Older Drivers: An Emerging Problem? *J. Australas. Coll. Road Saf.* **2018**, *29*, 18–29.
42. Casutt, G.; Martin, M.; Keller, M.; Jäncke, L. The relation between performance in on-road driving, cognitive screening and driving simulator in older healthy drivers. *Transp. Res. F* **2014**, *22*, 232–244. [[CrossRef](#)]
43. Li, S.; Blythe, P.; Guo, W.; Namdeo, A. Investigation of older driver's take-over control performance in highly automated vehicles in adverse weather conditions. *IET Intell. Transp. Syst.* **2018**, *12*, 1157–1165. [[CrossRef](#)]
44. 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](#)]
45. Casutt, G.; Theill, N.; Martin, M.; Keller, M.; Jäncke, L. The drive-wise project: Driving simulator training increases real driving performance in healthy older drivers. *Front. Aging Neurosci.* **2014**, *6*, 85. [[CrossRef](#)] [[PubMed](#)]
46. Poschadel, S.; Bönke, D.; Blöbaum, A.; Rabczinski, S. *Trainierbarkeit der Fahrkompetenz Älterer Kraftfahrer im Realverkehr: Eine Kontrollgruppenbasierte Evaluationsstudie*; Schriftenreihe der Eugen-Otto-Butz-Stiftung: Mobilität und Alter; TÜV Media GmbH: Köln, Germany, 2012; Volume 6.