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Cognitive demands of hands-free-phone conversation while driving

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Abstract

In four field experiments the participants drove an instrumented car provided with a hands-free phone and performed several cognitive tasks while driving including phone conversations. The study focussed the cognitive component of the conversations, excluding dialling. The cognitive demands of the conversations were varied and in two of the experiments the same tasks had two versions: by phone and in live conversation with the experimenter in the car. Several dependent measures like visual search behaviour, driving speed, visual detection and response selection capacities and others were analysed. Like in previous experiments of the same authors the more demanding cognitive tasks produced higher interference effects, but when the same tasks performed by phone were compared with its live versions no differences were observed. Once the manual phone operation has been technically suppressed the risk of phone conversations relies on the demands of the message content and its equivalent to talking to a passenger. Implications for safety are discussed.

Keywords: Attention; Eye movements; Mental workload; Traffic; Phone

1. Introduction

The interest of applied science on the impact of mobile phones on road safety has resulted in a diversity of questions and behavioural studies. While it seems unacceptable to be a victim of a distracted businessman involved in a sales discussion, an urgent message can reach a doctor while driving and help to save a human life. Recently in Spain, two terrorists were captured by the

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police just after making explode a bomb in Madrid because a driver followed them while keeping in phone contact with the police office during 15 min among heavy urban traffic. This driver was seen as a hero and obviously, nobody criticised his behaviour of driving while keeping on the phone.

Independently of the positive value of the increased communication potential of modern technology, phone talking can lead to distraction and road accidents. The safety problem is then an attentional problem: the studies tend to identify different sources of interference and evaluate its impact on the driving task when phone talking and driving are performed simultaneously. Consequently, the dual task paradigm seems an acceptable approach. However using a phone and driving, more than two experimental tasks, are both complex tasks involving very different subtasks and psychological processes. Making or receiving a call, searching for a number, dialling, processing the message content, etc. Besides this, different phone models, cars, traffic demands, subjective priorities and motivations among drivers add more complexity to the problem.

In consequence there is not a simple answer to a complex question. Due to the high social impact of this problem it's not difficult to find studies that overemphasise and overgeneralise the applied value of some weak experimental data obtained in conditions remotely comparable either with phone use, or with actual driving, or both. Haigney and Westerman (2001) insist on the need to specify the conditions in which the experiments are performed and to restrict their conclusions to those conditions. Specifications about the type of phone used, operations performed, the demands of the phone task, the driving conditions, the type of car (automatic vs. manual gear box) and the driving parameters evaluated as performance criteria are essential.

According to Bailey (1994) the possible interferences of mobile phone use can be manifested on four sub-systems: visual processing, auditive processing, cognitive functions and kinaesthetic processes. It is generally accepted that conventional manual phone operation can disturb driving performance. Reed and Green (1999), based on simulator and on real driving conditions, provided experimental evidence of negative effects on lane keeping, steering performance and accelerator control. Besides the hands, manual dialling or navigating through the phone menu implies also the need to take the eyes off the road for long periods of time. Technological solutions like hands-free phones and voice operated dialling options seem to eliminate the major constraints. Accepting the multiple resource taxonomy of Wickens (1984, 1992), we should expect no processing conflict between visual and auditive input. Given that kinaesthetic processes are mostly automatic, the hands-free phone should make the phone conversation comparable to a talk with a passenger and its potential interference should be reduced to the cognitive component of the conversation itself.

Briem and Hedman (1995) studied the effects of a hands-free phone in an experiment in which 20 participants were asked to perform several secondary tasks like radio operation, phone calls and memory tasks. According to its content, there were two levels of difficulty in the phone calls. The authors concluded that "easy" phone calls did not disturb driving, while the "difficult" conversations could interfere with the driving task, particularly when the traffic demands were high.

In four experiments carried out in real traffic conditions we included the study of the effects of phone conversation using a hands-free phone. These experiments were included in a broader framework of experimental research focussing explicitly the effects of endogenous distraction on visual search and driving performance, (Recarte & Nunes, 2000; Recarte, Nunes, & Conchillo, 1999). In a first stage two exploratory studies included low demanding phone conversations in a set of different cognitive tasks: while the first, (experiment 1) focussed the generalisation of previously observed visual search changes to a wide variety of tasks, the second (experiment 2) focussed the study of possible effects on detection and decision-making capacities. In the second stage we studied experimentally the effects of the cognitive component combined with the phone use in experiments 3 and 4: several cognitive tasks were performed under two versions: either included in a phone conversation or in live conversation in the vehicle. Thus, the cognitive load was controlled and the effects on visual and driving performance were analysed.

We hypothesised that the possible interference of the tasks should be attributed to its cognitive component and expected no additional effect of the phone condition. In other words, the phone risk does not rely on the existence of a particular attentional setting imposed by the device itself but on the complexity of the message and the psychological processes invoked. In this sense it is comparable to the risk of a standard conversation with a passenger, and even with the risk of covert mental activity like our everyday internal monologues. In this paper we analyse the four above cited experiments, all of them carried out under real traffic conditions. Regarding the phone study the experiments 1 and 2 were pilot studies and their results will be very briefly summarised. More detailed information is offered about the experiments 3 and 4.

The stated hypothesis implies two predictions: the effect of secondary cognitive activity and the lack of effect of the hands-free-phone use when comparing similar cognitive tasks in live version or by phone. The main purpose of this study is to provide empirical evidence to support the second prediction. But if the mere presentation of null results is a poor argument, the combination of positive task effects with the absence of differences between phone and live task versions becomes a convincing argument if this is reproduced in several experiments with different tasks, participants and dependent measures. However, an exhaustive presentation of a high amount of experimental work would enlarge excessively the size and the scope of this paper. In consequence, in benefit of the purpose of this study we restricted to the essential the presentation of positive results about the effects of mental tasks and provided substantial information about the experimental conditions and dependent measures analysed to help to understand the relative validity of what was not found, despite of all.

2. The experiments

2.1. Basic experimental setting, instruments and procedure

Independently of the particular objectives and conditions of each experiment a description of some basic generalities about its procedure, instruments and dependent measures used will help to avoid further unnecessary redundant explanations.

The experiments were run in a Spanish highway with real traffic and normal daylight conditions. The Argos instrumented car, a Citroën BX-GTI (Nunes & Recarte, 1997) was used. It includes a video-based eye-tracking-system, (Dornier/ASL), Gottlieb, Scherbarth, and Guse (1996) that allows unobstrusive measurement of ocular behaviour and free head motion with a temporal sampling rate of 50 Hz and a spatial resolution below one degree of visual angle. A standard Nokia 5110 was integrated in the audio system of the car. To answer a call the driver had just to press a single button, and the same was required to make a call, (no manual dialling was needed) as the phone number was preset. Except for the particular instructions given about the experimental tasks, the participants were encouraged to drive as normally as they could. An experimenter travelling in the car (the car experimenter) instructed the participant about the phone functioning and advised the driver not to feel forced to answer a phone call if he or she considered it dangerous in that moment. A second experimenter (the remote experimenter) made the appropriate phone calls to the driver according to the design. The participants were volunteers and paid for their participation.

The experiments 2 and 4 were designed to test how visual detection, discrimination and response selection capacities were affected by the performance of cognitive tasks during driving. For this purpose, the experimental car was provided with a set of visual targets consisting in flashing light spots that could be randomly presented on the drivers' visual field and two response buttons. A computer controlled the activation of the flashing light stimuli that should be detected during the experiment. These consisted in 10 light beams, four of them presented by reflection on the windshield and six high luminance diodes in several locations: one on the lower left corner of the internal mirror, two on the left windshield pillar and three on the dashboard. This pool of targets covered a range of 60° horizontally and 25° vertically of the visual field. The size of each target was around 30 min/arc. Two response buttons, one for each hand, were ergonomically installed close to the steering wheel. (See Fig. 1). According to given instructions the driver should press one of them depending on a stimulus characteristic like its spatial location or its flashing rate. Although this task implies stimulus detection, discrimination, response selection and response performing, we will call it in short "detection task". The performance in the detection task could be evaluated in hits, errors and response times, combined with the target's eccentricity with respect to the eye fixation point, and all this as a function of performing or not an additional cognitive task.

Although these experimental stimuli were not really meaningful for the driving task, flashing lights are common relevant traffic events (e.g. flashing warning lights, turning signals), what contributes to the ecological validity of this approach. Similar experimental settings have been used in equivalent experiments: Miura (1990), Lee and Triggs (1976) and Pottier (1999) used similar techniques.

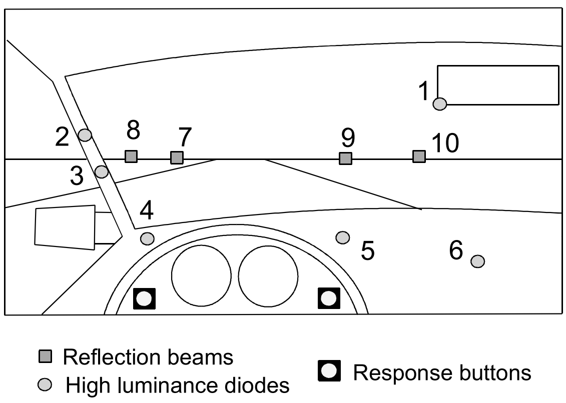

Fig. 1. Targets and response buttons location.

2.2. Dependent measures

The basic ocular parameters were the fixations coordinates, fixation duration, and pupil size. The spatial gaze variability was studied by assigning a variability score for each participant and each individual task, consisting in the standard deviation of X and Y gaze coordinates for that individual and task. Blinking rate and duration were analysed in all but the first experiment. Regarding its particular significance for driving, there is a systematic analysis of the speedometer and mirrors inspection frequency and also of driving speed. In addition to objective measures, the participants rated the subjective effort of each cognitive task performed in the experiments. The above cited measures of the detection task were considered in experiments 2 and 4. In the following sections we include a description of each experiment and its conclusions.

3. Experiment 1

In this experiment, 21 different cognitive tasks were tested with six participants of both sexes. As a detailed description of all tasks exceeds the purpose of this paper, in short, there were listening and learning audio messages, several verbal production tasks with either abstract or spatial imagery contents, memory, arithmetical calculation, etc. Two of these tasks were phone calls. In one of them the remote experimenter called the driver and made a trivial interview about his or her driving habits, experience, type of car and mileage driven, etc. In the other, the car experimenter asked the participant to call to the Traffic Information Service of the D.G.T. and ask for information about the status of the traffic flow in a given location. As the phone number was preset no dialling was needed: the call was initiated by pressing a button. After each call, the driver should rate the subjective effort of the task in a 10-point scale. Among the other tasks, one of them consisted in a live interview with the car experimenter about some trivial subject like hobbies, studies and so on. As this task was intended to look an apparently spontaneous conversation, no subjective rating was asked in this case. The duration of each task was around 2 min. Similar periods of time of ordinary driving (with no task) were included between tasks.

3.1. Results and conclusions

The data suggest no differences between live conversation and the phone tasks. Trivial conversations seem innocuous, and accordingly, the subjective effort of phone tasks was rated as low. Although no quantitative data are displayed, the other tasks were rated as more demanding, and apparently, reproduced the expected changes in the visual search behaviour, according to previous research (Recarte & Nunes, 2000; Recarte et al., 1999): pupillary dilatation, spatial gaze concentration and higher impact of spatial imagery contents including longer ocular fixations.

On one hand, the lack of phone effects seemed to contradict the common expectation about an hypothetical increased difficulty attributable to phone talking. On other hand, it is true that the cognitive component of the phone tests was very low demanding. However, the changes in the visual parameters produced by some mental tasks need an interpretation and the lack of effects of some tasks could hide other effects, non-evident in terms of ocular behaviour, but that could imply some kind of impairment of the information processing. That is why we decided to retest the same apparently low demanding phone test in the second experiment.

4. Experiment 2

The objective of this experiment was to get experimental evidence to interpret the practical implications of spatial gaze concentration due to cognitive activity in terms of visual perception and decision-making capacities. Six drivers performed 10 cognitive tasks combined with the above described "detection task", (see again Fig. 1) which included detection, discrimination and response selection. One of the 10 tasks was like the phone reception task of experiment 1, and there was also a similar live conversation task.

During the experiment a flashing spotlight could be activated at any time in any of 10 possible locations. The response selection rule was dependent either of the stimulus-flashing rate (high vs. low) or of its spatial location (right hemifield vs. left hemifield), according to given instructions.

4.1. Results and conclusions

With respect to visual search changes the results of the first experiment were reproduced: The phone task was rated as the easiest task and produced the smallest or null changes in fixation duration, spatial gaze variability, or mirrors and speedometer inspection. With respect to the detection task the percentage of hits was not affected: phone task 57%, live conversation 60%, ordinary driving 56%. No differences were found in response times and very few errors occurred.

However it is remarkable that, except the phone task, all the other mental tasks performed in this experiment, like mental currency calculation and others did produce the expected ocular changes and affected negatively the detection task. Comparing no mental task with mental task (all tasks together) the detection rate was reduced from 56% to 44%. This represents a 21% reduction in detection rate when mental tasks are present. Regarding each mental task individually all but the phone showed a reduced detection capacity.

In conclusion, the demands of a trivial conversation are low and the phone use did not cause an increment in the cognitive load of the task. On other hand the detection task was demonstrated to be sensitive to increased cognitive load, which encouraged us to focus our attention in the risk of the cognitive load imposed by message content. To allow an experimental control of the message content we included in the following two experiments two demanding mental tasks that had to be performed under two versions: in live conversation with the experimenter in the car and by phone.

5. Experiment 3

The general purpose of this experiment was to increase the variety of cognitive tasks tested and focus its effects on the speed control when an explicit speed instruction is given, (see Recarte & Nunes in this volume). Twelve participants, six men and six women, performed 27 mental tasks. The main interest for the phone study was to look for differences attributable to task version between tasks that do produce effects. Two demanding tasks were chosen: mental currency

Table 1
Subjective effort, general ocular measures, mirrors and speedometer inspection frequency in the control condition of ordinary driving (no task) and in phone and live versions of euros and memory tasks in experiment 3

Measure	Condition				
	No task	Euros task		Memory task	
		Phone	Live	Phone	Live
Subjective effort (10-point scale)	–	7.38	6.85	4.54	4.82
Pupil size (Diameter in pixels)	640	679*	667*	658*	667*
Blinking rate (Blinks/s)	0.58	0.88*	0.93*	1.03*	0.85*
Fixation duration (ms)	242	257	230	244	242
Vertical gaze direction (degrees)	−0.90	0.02*	−0.15*	0.02*	−0.035*
Horizontal gaze variability (degrees)	8.00	5.61*	6.33**	5.74*	5.95*
Vertical gaze variability (degrees)	3.83	1.72*	1.90*	1.78*	1.71*
External mirror inspection (% fixations)	1.04	0.14*	0.25*	0.54*	0.57*
Internal mirror inspection (% fixations)	0.71	0.28**	0.54	0.44	0.80
Speedometer inspection (% fixations)	2.06	0.38*	0.46*	0.29*	0.38*

*$p < 0.01$.
**$p < 0.05$.

conversion, *euros task*, and autobiographic recall, *memory task*, (where they were and what were doing five days ago at 3 o'clock). This means, for the high demanding condition, an orthogonal design of two tasks by two versions, with a control condition of no task, (ordinary driving). As an additional secondary control, two low demanding phone conversations replicated those of experiment 1.

5.1. Results and conclusions

Table 1 displays the results of subjective effort, six general ocular parameters and three specific visual search measures: mirrors and speedometer inspection for the high demanding conversations. When comparing the conditions task/no task, we found, according to previous expectations, significant effects of both versions of euros and memory tasks: incremented pupil size and blinking rate, slight mean gaze shift upwards, and spatial gaze concentration. The reduction of mirrors and speedometer inspection was also observed. No effects were found in fixation duration. A *t*-test with repeated measures between phone and live versions of each task was performed for each variable, and none of the comparisons revealed a significant difference. Like in experiments 1 and 2 the low demanding conversations produced null or small effects.

Concluding, the presence of effects attributable to the cognitive load and the absence of differences attributable to the phone use stresses the importance of the message complexity and reinforces the hypothesis of no additional effects of hands-free-phone use.

6. Experiment 4

Following the aim of experiment 2, this one was designed to get more solid data about the effects of different cognitive tasks on the detection and decision-making capacities, and help to find the psychological significance of the spatial gaze concentration. Another 12 participants, (six men and six women) performed 13 different cognitive tasks in two conditions: either combined with above mentioned *detection task* (see Fig. 1 and experiment 2), or with no detection task.

The *detection task* included also discrimination and response selection based on the stimulus-flashing rate: high vs. low rate, balanced with right vs. left response button. The same live and phone versions of *euros* and *memory* tasks of experiment 3 were performed. Ordinary driving periods with no task were used as control condition.

6.1. Results and conclusions

The results of subjective effort, general ocular variables, speedometer and mirrors inspection are displayed in Table 2. Like in experiment 3, the euros task was rated as subjectively more demanding, and the same general effects can be observed, with the exception of blinking rate in euros task, but with equivalent results with respect to task version.

Regarding the analysis of the performance in the detection task, the comparison between the detection and no detection conditions is not essential but it is useful to understand a general effect produced by the use of the detection task as a criteria to evaluate the visual and decision-making capacities: when the detection task is active, the spatial eye gaze variability increases significantly. The explanation seems obvious: in most occasions the participants looked to the spotlights before selecting the appropriate response button. These glances to the targets demonstrated to be useful to increase the reliability of the targets flashing rate identification. Thus, the detection task as evaluation method produced a systematic bias in the spatial gaze variability (Fig. 2). However, this bias did not affect selectively any of the tested tasks, and because of this, the comparison between tasks is also valid under the detection condition.

The results of the detection task confirm those found in experiment 2: mental tasks produced a decrement in the proportion of hits (correct responses among detected targets): 72.17% for or-

Table 2
Subjective effort, general ocular measures, mirrors and speedometer inspection frequency in the control condition of ordinary driving (no task) and in phone and live versions of euros and memory tasks, in experiment 4

Measure	Condition				
	No task	Euros task		Memory task	
		Phone	Live	Phone	Live
Subjective effort (10-point scale)	–	8.21	7.98	5.60	4.90
Pupil size (Diameter in pixels)	716	749**	752*	739**	756*
Blinking rate (Blinks/s)	0.44	0.59	0.54	0.61**	0.66**
Fixation duration (ms)	224	208**	213	199*	189*
Vertical gaze direction (degrees)	−1.81	−0.50*	−0.82*	−0.52*	−0.83*
Horizontal gaze variability (degrees)	8.89	6.48*	7.17**	7.64	7.87
Vertical gaze variability (degrees)	4.59	2.17*	2.28*	2.46*	2.52*
External mirror inspection (% fixations)	0.54	0.04*	0.09*	0.08*	0.10**
Internal mirror inspection (% fixations)	0.74	0.13*	0.36*	0.36*	0.16**
Speedometer inspection (% fixations)	3.35	0.45*	0.49*	0.52*	0.94**

* $p < 0.01$.
** $p < 0.05$.

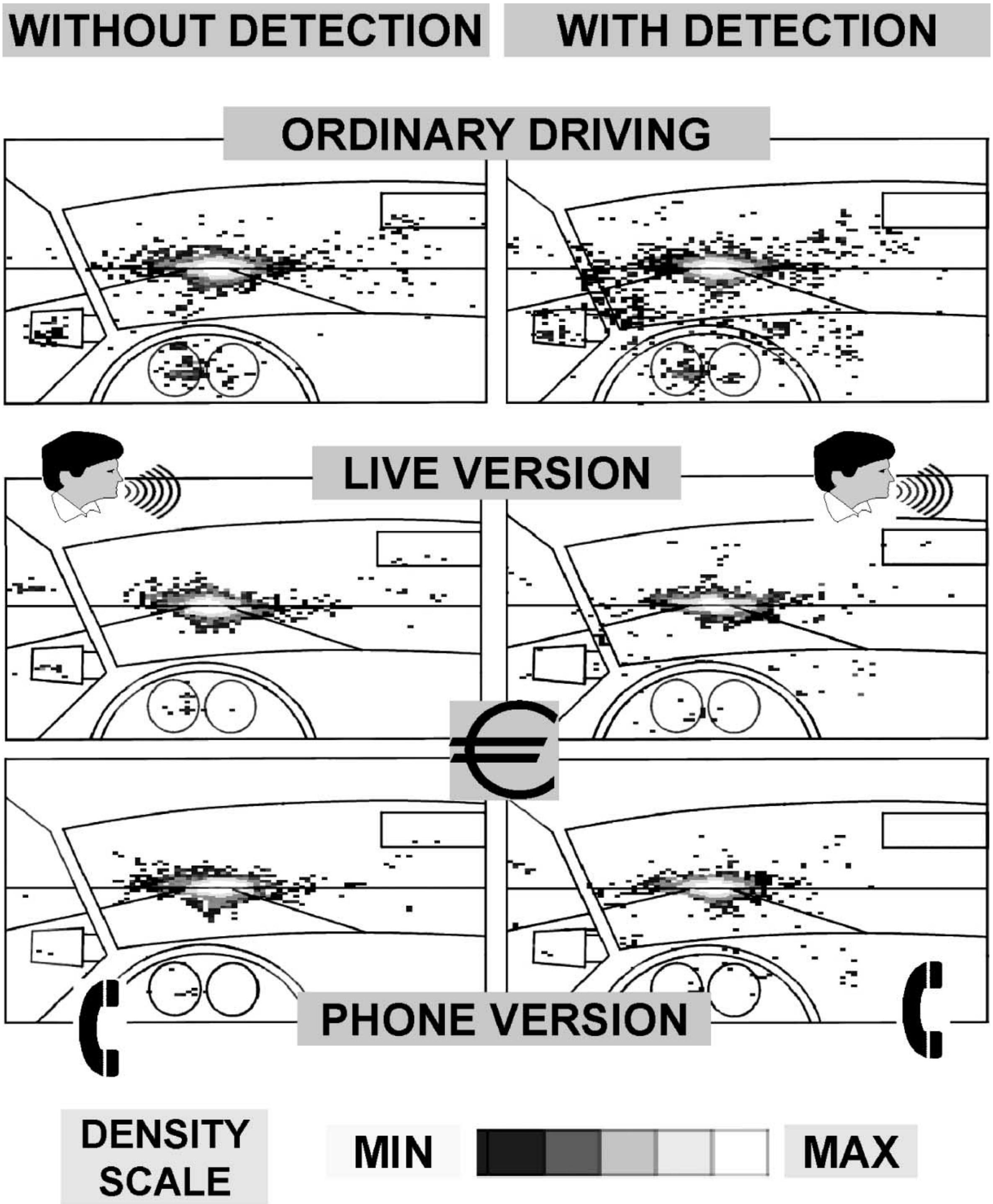

Fig. 2. Spatial gaze distribution in both detection conditions and comparing ordinary driving with live and phone versions of euros task.

Table 3
Percentage of detected targets, hits and statistic values (F, p) for live and phone versions of euros and memory tasks and for ordinary driving

Task	Detected targets (%)	F	p	Hits (%)	F	p
Euros (LIVE)	55.00	5.739	0.036	75.76	3.751	0.094
Memory (LIVE)	63.33	1.462	0.252	84.21	2.746	0.141
Euros (PHONE)	66.67	0.762	0.401	80.00	4.528	0.130
Memory (PHONE)	55.00	12.413	0.005	75.76	1.724	0.071
Ordinary driving	72.04			88.81		

dinary driving against 64.24% for task performance. A t-test with repeated measures shows this difference was significant, $t = 2.59$ (11 df); $p = 0.025$. Table 3 shows the data referred to both versions of euros and memory, and the control condition of ordinary driving.

Like in experiment 3, a t-test with repeated measures between phone and live versions of each task revealed that no differences were found in any dependent measure, except a small difference in the subjective effort rating: phone versions were rated as more effortful, which agrees with the findings of Fairclough, Ashby, Ross, and Parkes (1991) and Parkes (1991).

Observing Fig. 2 it can be seen the higher spatial gaze dispersion in all the detection graphs, the marked spatial gaze concentration of task performing compared with ordinary driving, and the great similarity in the spatial gaze distribution when comparing the live and phone versions of the task.

The conclusions from this fourth experiment are: (a) The classical changes on visual patterns were again reproduced and with no differences attributable to the task version in all the objective measures with the only exception in the subjective higher effort of the phone versions reported in this case. (b) The detection and decision-making capacities were affected by different mental tasks but there were no differences between live and phone versions of the same tasks.

7. Summary and discussion

In the above described four experiments a high variety of cognitive tasks were performed, and some of them were phone conversations with a hands-free phone. The secondary cognitive tasks demonstrated to affect the information processing capacities including visual search behaviour, speed control, detection and decision-making capacities. The magnitude of the observed effects was sensitive to task demands and this results agree with previous findings of Recarte et al. (1999), Recarte and Nunes (2000). Low demanding phone conversations produced null or low effects and high demanding phone conversations affected significantly the visual processing capacities, which agrees with the results of Briem and Hedman (1995). When the same cognitive tasks were tested both in live and phone versions, the produced effects were of the same magnitude and consequently, no differences were found between task versions. Considering that this phenomenon was reproduced in different experiments we conclude that there is strong evidence to support the stated hypothesis: Talking on a hands-free phone is like talking with a passenger but the conversation content and its complexity are really potential distractors.

The equivalence between live and phone conversation has been discussed in the literature based on differences in subjective effort rating. Fairclough et al. (1991) suggest that the higher subjective effort of phone could be due to its higher ‘‘psychological distance’’. Parkes (1991) suggests that phone talking can be more threatening because passengers can be aware of the traffic demands and adapt the rhythm of the conversation accordingly. The lack of information about the traffic demands creates an expectancy of a continuous conversation with no interruptions (McKnight & McKnight, 1993). These arguments, however, are speculative and paradoxal as seem to presume that passengers think like drivers while the drivers do not. Moreover, if some passengers are careful and collaborative co-drivers others are careless and display a highly interfering behaviour. According to the results the subjective effort is highly dependent of the conversation content and this was not controlled in the cited literature. When the content has been strictly controlled, the difference in subjective effort between phone and live task versions was null or small (experiments 3 and 4 respectively) compared with the existing differences attributable to the task content. Moreover, the small differences found in subjective effort were not reflected in any of the objective dependent measures.

The advantages of increased communication and information availability, and the inconvenience derived from the risk of distraction have to be balanced. The interference of operations like manual dialling or navigating through the phone menu was omitted from this study. Although we presume that these operations are risky regarding road safety there are available technological solutions to practically eliminate the manipulative component and make possible safe phone communication. However few drivers have hands-free phones installed in their cars, few of them include voice operated functions and we should keep in mind that the conversation itself can produce distraction.

Meanwhile, cellular phones are widely used under non-optimal conditions. Legal restrictions and enforcement measures have little opportunity to be effective to avoid the use of conventional phones. Moreover, if it is possible to control the use of a device it is impossible to control the driver’s attention and their subjective priorities. If a hands-free phone is not a mind free device, a phone free driver’s mind is equally vulnerable to any other source of distraction like passengers, in car devices, or internal monologues and thoughts.

Road users should be encouraged to avoid unnecessary phone calls while driving. Hands-free-phone installations could be sold cheaper and be included as a standard by car manufacturers. Mobile phone industry could also include a safety measure: when anyone calls a driver, an automatic warning message could say ‘‘sorry, I am driving now, if it’s not urgent call me later, if you insist press key * and be patient’’. If the caller insists, a warning message could alert the driver: ‘‘you have a phone call, please be aware of traffic’’. This way, phone users would have more opportunity not to disturb those who are driving and the drivers could be alerted to be careful when talking on the phone.

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