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Leftward attentional bias in a simulated driving task

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ABSTRACT

With the aim of studying attentional leftward bias in a driving context, we combined recording of gaze behaviour with a simulated driving task (Lane Change Test – LCT) in spatial symmetry conditions. The LCT requires driving along a straight traffic-free three-lane road, changing lanes according to the information provided by two identical road signs displayed concurrently on both left and right sides of the road. Participants directed most of their attention to the left-hand signs. The prevalent visuospatial nature of the driving task – which is supposed to mostly activate the right cerebral hemisphere – could have caused a contralateral attention shift. The introduction of a secondary task – performed with the right hand, concurrently with the LCT – attenuated the leftward bias.

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1. Introduction

Healthy individuals typically show a mild asymmetry in spatial attention orienting, in which the left side of space tends to be favoured to the right one. This leftward error, also known as pseudoneglect (Bowers & Heilman, 1980), has been investigated with several research protocols, such as line bisection tasks (for a review, see Jewell & McCourt, 2000), chimeric-faces stimuli (Failla, Sheppard, & Bradshaw, 2003), judgments of brightness, numerosity and size (Nicholls & Roberts, 2002). Navigation tasks, namely collision while walking, were also investigated (Hatin, Tottenham, & Oriet, 2012), however the driving task has not been studied yet, although it includes strong visuospatial and navigation components. According to the large body of literature, pseudoneglect could be influenced by left-to-right scanning biases (Jewell & McCourt, 2000), unilateral motor activity (Nicholls & Roberts, 2002), and asymmetries in hemispheric activation, namely a right hemisphere (RH) dominance during visuospatial tasks (de Schotten et al., 2011), which should bring more attention to the contralateral left hemisphere. This latter explanation, also known as the activation-orientation hypothesis (Kinsbourne, 1970; Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990), could well survive to years of experimental investigation (Failla et al., 2003), and a large body of literature supports it (Bultitude & Aimola Davies, 2006).

Recently, researchers have tried to explain real-life attentional asymmetries with respect to pseudoneglect, investigating, for example, its relationship with sports performance (Roberts & Turnbull, 2010) and mental imagery (McGeorge, Beschin, Colnaghi, Rusconi, & Della Sala, 2007). In this context, we extended the study of attentional leftward bias to the driving domain, coping with the complexity of visual behaviour in everyday life activities. To the authors' knowledge, no previous

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study on attentional bias has been done in a driving context, and very few imply such a particular sensorimotor activity. Therefore, we combined recording of gaze behaviour with a normative simulated driving task, the Lane Change Test (LCT; ISO, 2010). The LCT requires people to drive along a straight traffic-free three-lane road, changing lanes according to the information provided by two identical road signs displayed concurrently, and placed at regular intervals on both left and right sides of the road. The whole experiment was conducted on a single-seat driving simulator, with full control over the spatial symmetry of visual stimuli (see Section 2.4.2). Such a symmetrical setting allowed us to investigate how visual attention was distributed between the left and right hemispaces, namely whether participants would look at either the right or left road sign to acquire task-relevant information for performing lane changes. Participants carried out six driving trials of which the first and the last were single tasks, and the remaining four were dual tasks (ISO, 2010). While the single tasks consisted of performing the LCT alone, in dual tasks the LCT was performed along with a visual-manual secondary task (Surrogate Reference Task – SuRT; Mattes, 2003), displayed on a touchscreen installed to the right of the steering wheel.

The paper is organised as follows: Section 1.1 presents the hypotheses of the study. The method (participants, experimental design, stimuli, apparatus) is described in Section 2, and Section 2.5 is dedicated to the validation of the spatial symmetry requirements of the experimental setup. The results are described in Section 3, and discussed in Section 4.

1.1. Hypotheses

According to the SEEV model (Wickens, Helleberg, Goh, Xu, & Horrey, 2001), four main factors could influence visual attention allocation: *Salience* (salient objects are likely to capture visual attention), *Effort* (people tend to minimise both eye and head movements), *Expectancy* (monitoring sources of high task-relevant event rate), and *Value* (monitoring sources of high task-relevant importance). In the single task condition of our experiment, the right and left road signs share equal levels of *Salience* (the two signs look exactly the same), *Effort* (from the participant's point of view, the two signs are equally distant, see Section 2.5), *Value* and *Expectancy* (the same lane change information is presented at the same time on both signs). Thus, the SEEV model would be of poor aid in predicting whether people would attend to either the right or left road sign. In turn, the activation-orientation hypothesis would predict a leftward orienting of attention (i.e. people would attend to the left sign): during simulated driving, previous studies showed the RH to be more activated than the left hemisphere (LH), possibly because driving is mainly a visuospatial task (Lust et al., 2011; Vingerhoets & Stroobant, 1999). Therefore, since hemispheric activation – however generated – can elicit contralateral attention and gaze shifts (Reuter-Lorenz et al., 1990), people would direct more attention towards the left. This would confirm the existence of pseudoneglect in driving. In the dual task condition, the physical distance between the touchscreen and the right sign is shorter than the distance between the touchscreen and the left sign (see Section 2.5). While the right and left road signs still share equal levels of *Salience*, *Value* and *Expectancy*, the levels of *Effort* differ. Thus, the SEEV model would predict participants to mostly look at the right sign to gather the lane change information, since less *Effort* is required (i.e. head and eye movements would be minimised). Moreover, according to the activation-orientation hypothesis, a LH activation should draw more attention towards the contralateral (right) hemisphere (McCourt, Freeman, Tahmahkera-Stevens, & Chaussee, 2001; Nicholls, Loftus, Mayer, & Mattingley, 2007). Such LH activation should be caused by two factors, i.e. (a) the secondary task is located to the right and (b) the secondary task is performed with the right hand.

2. Method

Different data from this experiment have been used to test different hypotheses. Previous studies have shown the reliability of this protocol for studying workload, using both eye-movement (Benedetto, Pedrotti, & Bridgeman, 2011; Benedetto, Pedrotti, Minin, et al., 2011) and vehicle trajectory (Minin, Benedetto, Pedrotti, Re, & Tesauri, 2012) measures. The present article discusses leftward orienting of attention with respect to previous literature on leftward bias.

2.1. Participants

Fifteen right-handed participants (12 males, mean age = 31 years, SD = 4), selected from a right-hand traffic population (Italian), were recruited and informed about the general purpose of the experiment (driving simulation). All of them had valid Italian driving licenses, a driving experience ranging from 6 to 18 years (mean = 13, SD = 4), a minimum of 3000 km driven per year (max = 40,000, mean = 23,000, SD = 10,000), and were used to interact with in-vehicle information systems (IVIS) while driving. All of them had normal or corrected-to-normal vision (contact lenses, but not glasses were accepted), and were naïve as to the aims and expected outcomes of the experiment.

2.2. Experimental design

A full within-subjects design was employed, with two levels of mental workload (*single task* = LCT; *dual task* = LCT + Secondary task). After training, participants carried out a baseline run (A) with the LCT only, followed by four dual-task runs (B–E) in which the LCT was performed along with an additional secondary task (SuRT). This task requires participants to locate a target among distractors, and then to select, with the right hand, the portion of screen where the target is located. Finally,

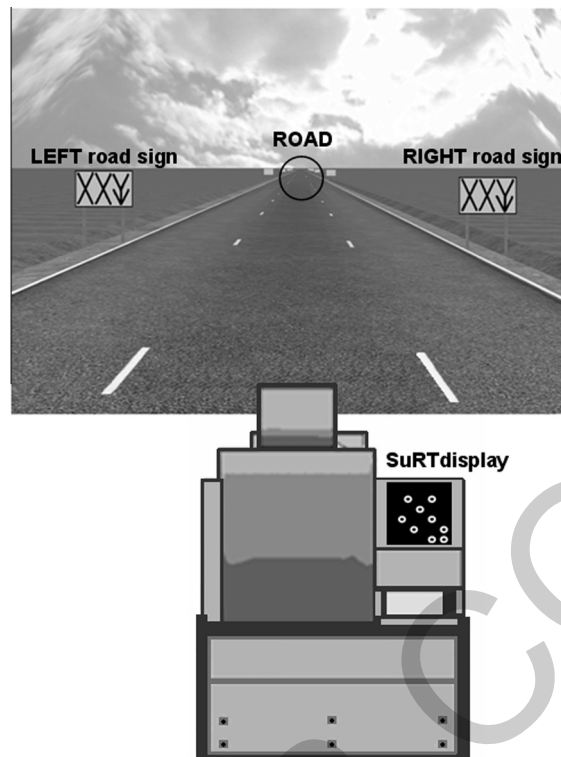


Fig. 1. Schematic representation of the experimental setup: driving simulator with secondary task (SuRT) display, and LCT scenario. Superimposed text refers to the four AOI.

another single-task run (F) was performed to disclose possible time-on-task effects (Benwell, Harvey, Gardner, & Thut, 2012; Dufour, Touzalin, & Candas, 2007; Manly, Dobler, Dodds, & George, 2005).

2.3. Stimuli

The LCT requires people to drive on a three-lane straight track and change lanes according to the information provided by two identical road signs placed on both sides of the road (ISO, 2010). The lane change signs were counterbalanced between lane changes to be performed towards the left, the centre and the right, and were presented every 150 m. The signs were always visible but blank until participants were 40 m far from them. At that moment, the lane change information was visible for 2.4 s (40 m covered at a constant controlled speed of 60 km/h). Participants had to perform 18 lane changes within each 3-min block (of which 6 toward the left lane, 6 toward the right lane, and 6 toward the central lane). According to ISO 26022 (ISO, 2010), participants were instructed to perform good lane keeping and to start the lane change as soon as they could see the signs, but not before. No instructions were provided about how to prioritize attention between the left and the right road signs, nor between the primary and the secondary task. The dual task condition consisted of performing the LCT concurrently with a visual–manual secondary task (SuRT, Mattes, 2003), which simulates the interaction demands of a generic IVIS. The SuRT (Fig. 1, bottom right) requires participants to double-click as fast as possible the portion of the screen where a target (larger circle) is located, among several distractors (smaller circles). This secondary task had to be performed continuously: every manual response was followed by the appearance of a new stimulus on the screen.

2.4. Apparatus

2.4.1. Eye-tracking

A SMI HED monocular head-mounted eye-tracker was used for the experiment. A five-point calibration was made for each participant. In order to ensure the highest quality of eye-tracking data, calibration was further checked with a laser-pointing device before and at the end of each trial. Gaze data were sampled at 200 Hz and analysed using Begaze 3.0 analysis software (SMI, 2011). This software allows studying eye movements towards moving objects by defining dynamic areas of interest (AOI). AOI are *dynamic* in that they can be adjusted – during offline analysis – on a frame by frame basis, according to stimuli displacements caused by both participants' head movements and changes in the visual scene as filmed by the head-mounted integrated camera.

2.4.2. Driving simulator

An Oktal I-Drive driving simulator was used for the experiment. Settings were made according to the specifications of ISO 26022 (ISO, 2010). The simulator was a light single-seat mock-up with actual car components, with no windshield, nor windshield frame: in this setting, the driver's seat is laterally centred with respect to the centre of the projection screen. The simulated scenario was projected on a 244 × 180 cm screen. The average distance between participant and screen was 274 cm. A touchscreen for the secondary task was installed to the right of the steering wheel, which is a usual location for IVIS; the distance between participant and touchscreen was approximately 75 cm.

2.5. Data verification and validation

In order to validate the reliability of the LCT for studying attentional leftward bias, we needed our stimuli to trigger a stable gaze behaviour pattern, wherein most fixations occur in the centre of the scene – because of people's need to maintain the vehicle's lateral control and anticipate their trajectory (Donges, 1978) – and some fixations are clustered into two small areas, on the left and the right sides of the road (road signs). With respect to pseudoneglect, we believe that, *mutatis mutandis*, the LCT has some similarities with central fixation tasks used for studying leftward bias in visuospatial attention (e.g. Corbetta, Miezin, Shulman, & Petersen, 1993; Okon-Singer et al., 2011; Siman-Tov et al., 2007). The LCT offers a good opportunity to embrace research protocols where the central fixation is not a forced requirement imposed by the test, rather an implicit need of the task itself. The LCT, as the central fixation task, consists of a sequence of central fixations made on the road and around the vanishing point (Land & Horwood, 1995), followed by simultaneous peripheral presentation of two objects (the road signs). Thus, since vision is the primary source of information for driving, we assumed that eye fixations are behavioural correlates of attention orienting. Hence, attention was supposed to be momentarily directed towards the hemispace (either left or right) where the current fixation was located (overt attention, Posner, 1980). In this framework, fixations made on the road must be equally distant – in terms of angular distance – from the left and right road sign areas (i.e., the *Effort* associated to the left sign should equal the *Effort* associated to the right sign). This would exclude a preference for either one or the other sign. With the aim of testing this requirement, fixation position (FP) was calculated. The position of a fixation was defined as the couple (x, y), corresponding to its horizontal and vertical coordinates respectively. FPs were plotted for each participant and trial on a dispersion graph for preliminary visual inspection. Plots revealed fixations to be clustered according to the expected pattern, with three putative AOI for the single-task condition (road, left sign, right sign) and an additional area for the dual task (SuRT display). Consequently, three AOI were created – using the SMI BeGaze software – for the two single task conditions (15 participants × 2 conditions = 30 trials), and four for the dual task (15 participants × 4 conditions = 60 trials). AOI were discrete polygons that did not overlap.

Average FPs (with standard deviations *SD*) were calculated for each participant and each experimental condition (15 participants × 6 conditions = 90 trials) within each AOI. Subsequently, all horizontal (x) values were averaged together per AOI, and the same was done for all the vertical (y) values. The result is a couple (\bar{x}, \bar{y}) for each AOI, with average standard deviations (*SD*) indicating the average spatial dispersion. In order to ensure that fixations made on the road were equally distant from the left and right road signs, the average angular distances between FPs were calculated as the size of the angle originating from the participants and pointing towards the two FPs (Table 1). This symmetry requirement was validated by the non-significant paired *t*-test on angular distance, using left and right as between factors ($p > .05$).

2.6. Dependent variable

AOI transition rate (AOI TR) was defined as the number of transitions between AOI and was calculated for each participant and condition. A transition between an AOI(a) and an AOI(b) was defined as the occurrence of a fixation in (a) followed by a consecutive fixation in (b). By definition, a saccade separates the fixation in (a) from the fixation in (b). Concerning our research question, only transitions from the road (central fixation point) to the left and right signs were considered for analysis. Moreover, since driving on both left and right lanes brings participants to look for the closer road sign (left lane = left road sign; right lane = right road sign, because of lower *Effort*), only the gaze transitions made when the car was on the central lane were considered.

3. Results

AOI TRs were extracted for each participant and each experimental condition (15 participants × 6 conditions = 90 trials). AOI TR descriptive statistics (means with standard deviations) are reported in Table 2. Three AOI (road, left sign, right sign)

Table 1
Average angular distances between AOI. Means and SD (*italic*) for 15 participants.

Average angular distance (°) from	Average angular distance (°) to		
	LEFT road sign	RIGHT road sign	ROAD
RIGHT road sign	36 (<i>3</i>)		
ROAD	21(<i>2</i>)	20 (<i>3</i>)	
SuRT display	53 (<i>3</i>)	30 (<i>3</i>)	31(<i>3</i>)

Table 2
AOI TR descriptive statistics. Means and SD (*italic*) for 15 participants.

AOI TR		A Single Task	B Dual Task	C Dual Task	D Dual Task	E Dual Task	F Single Task
From ROAD to LEFT road sign	Mean	15.50	7.07	7	6.07	5.53	13.27
	SD	2.32	5.40	6.20	5.53	4.81	5.30
From ROAD to RIGHT road sign	Mean	2.20	2.87	2.87	2.47	2.67	5.67
	SD	2.36	3.44	4.14	3.85	3.44	9.59

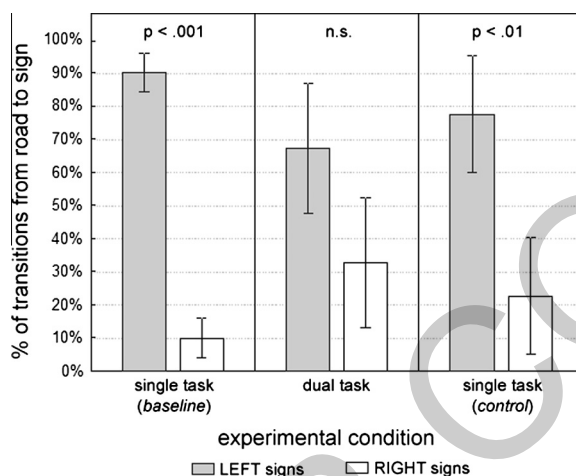


Fig. 2. Percentages of transitions from the road to the left and right road signs: p values are relative to the paired t -tests on transition percentages using left and right as between factors. Vertical bars denote 95% confidence intervals.

were extracted for the single-task conditions, and four (road, left sign, right sign, SuRT display) for the dual-task ones. AOI TRs relative to the transitions from the road to the left and right road signs were analysed with paired t -tests for each experimental condition, using left and right as between factors. Such analysis allowed us to test the hypothesis of an attentional preference for the left hemispace (where the left sign was located) with respect to the right one. In the baseline condition (A), 90% of fixations from the road were directed towards the left road sign ($t(14) = 14.53$ $p < .001$), indicating an attentional leftward bias. Since the repeated measures ANOVA on AOI TR revealed no significant differences between the four dual-tasks conditions, B, C, D and E were pooled into one category labelled dual task. In this dual task condition, 67% of fixations from the road were directed towards the left road sign. The paired t -test between Left and Right did not reach significance ($t(14) = 1.88$, $p = .08$), which suggests an attenuation of the attentional leftward bias triggered by the secondary task. If the bias were still present, one should expect a significant difference between the amount of fixations directed to the left with respect to the right, in favour of the former. In the control condition (F), 77% of fixations from the road were directed to the left road sign ($t(14) = 3.34$ $p < .01$), indicating an attentional asymmetry in favour of the left hemispace. Fig. 2 summarises the described effects.

4. Discussion

The results of the present study provide evidence of gaze behaviour asymmetries in a simulated driving context. The participants massively directed their attention to the left in both single-task conditions, while the attentional bias was attenuated in dual-task conditions. These results could be well explained by the activation-orientation hypothesis (Kinsbourne, 1970): driving is mainly a visuospatial task, and the RH has been shown to be more activated than the LH during such a task (Lust et al., 2011; Vingerhoets & Stroobant, 1999). As a consequence, attention is more likely to be shifted towards the contralateral left hemispace, although one should expect people to prefer the right-hand signs as a consequence of prior experience and habituation, since most road signs are normally placed on the right side of the road (this is true for right-hand traffic countries, see UNECE, 1968, chapter II, article 6). In the dual task, the percentage of leftward attention orienting dropped from 90% (baseline) to 67% (dual task). If the SEEV hypothesis was true, participants would have mostly directed their visual attention to the right signs, since less *Effort* was required. Although the paired t -test between left and right did not reach significance ($p = 0.8$), such a still large percentage of leftward attention orienting in the dual task, slightly discredits the SEEV hypothesis. Other factors could influence attentional leftward biases, namely unilateral motor activity, left-to-right scanning biases, time-on-task, and task-related asymmetries (Benwell et al., 2012; Bradshaw, Bradshaw, Nathan,

Nettleton, & Wilson, 1986; Dufour et al., 2007; Manly et al., 2005; Nicholls & Roberts, 2002; Sampaio & Chokron, 1992; Schiff & Truchon, 1993). Concerning the unilateral motor activity hypothesis, we introduced an IVIS while the driving task was performed: if the interaction with the device is performed with the right hand, then an additional LH activation should occur, which should cause attention to be pulled towards the right hemispace. Results from the dual-task condition suggested an attentional leftward bias attenuation, triggered by the secondary task. One limitation of our protocol concerns the impact of both hands use on leftward attentional bias: only the right hand was used to perform the secondary tasks, since this appears to be the most common situation in real-life settings (at least for right-hand traffic populations). While we still would expect to observe a leftward bias in single-task conditions, the use of the left hand for a secondary task should probably foster the bias, rather than moderating it. This could be the case in left-hand traffic populations, and future studies may investigate this issue. With respect to left-to-right scanning influences on attentional bias, we could not speculate on their relevance since we did not manipulate the direction of scanning (being our task under free-viewing), nor reading habits (all participants were natural left-to-right readers). Concerning time-on-task, Benwell et al. (2012) recently reported a reliable left-to-right shift effect as a function of fatigue in a landmark task. The same reversing effect was found by Manly et al. (2005), though others (Dufour et al., 2007) could not replicate this finding. Our results from the control condition (F) still indicate a significant leftward bias, even if the percentage of leftward attention orienting dropped from 90% (baseline) to 77% (control). Some studies proposed the RH (frontal and parietal cortex) dominance for the maintenance of vigilance (e.g. Lewin et al., 1996; Pardo, Fox, & Raichle, 1991): it could be speculated that the alertness reduction at the end of our study (control trials labelled F) had some effect on proximal networks engaged in spatial attention orienting. As Dufour et al. (2007) pointed out, it might be possible that the decrease of orienting bias could have resulted in a reversed bias if more blocks were added, which would result in longer time-on-task and – as a consequence – higher fatigue for participants. In our study, the time spent driving totals 18 min (6 blocks of 3 min each), but if we consider the training sessions and the workload questionnaires between driving trials it is reasonable to state that participants were cognitively engaged for 45 min minimum: we can speculate that this duration was sufficient for tiring participants since significantly longer eye-blink durations were found (Benedetto, Pedrotti, Minin, et al., 2011). As to task-related asymmetries, we controlled the experimental setup so that any asymmetry could be reasonably excluded.

In conclusion, this study demonstrated a leftward orienting of attention in a simulated driving task, the LCT. Although the participants of our experiments attend to road sign placed on their right during real life motorway driving, they used the signs on their left to gather task-relevant information. We proposed that the activation-orienting hypothesis could well explain the mechanism underlying this attentional bias, in terms of RH dominance for visuospatial tasks. These results can have implications for future studies on visual attention involving driving simulation with similar settings. Finally, we would like to underline that the utility of these findings might be transferred to the real driving context only if further experimental evidence from more naturalistic environments and conditions will be found.

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