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Irrelevant stimuli produce a path deviation in a driving-simulation task

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Abstract

Literature about the relationship between attention and movement has reported mixed results regarding the effect that attention has on movement and in establishing the time course of the effect. We found a veering away effect from a distractor in a driving context with different input devices: a mouse and a joystick. By using a continuous temporal task, it was possible to establish the time course of the effect.

Keywords: Movement; Attention; Distractor; Trajectory; Veer away

1. The effects of the presence of non-target stimuli in a tracking task

Popular conception of attention coincides with the majority of research studies in emphasising its cognitive aspects (Eimer, Forster, Van Velzen, & Prabhu, 2004). However, there are data which point to the possibility that attention directly affects motor systems, modifying movement in an involuntary manner. Specifically, certain findings relate “dorso frontoparietal” cortex activity with attentional and motor tasks as well as sensory tasks. This fact suggests that the processes of attention and sensory-motor control are not as independent of each other as was traditionally thought (Eimer et al., 2004).

According to premotor theory (see Rizzolatti, Riggio, Dascola, and Umiltà (1987), for an introduction), goal-directed movement control and attention are closely linked because of their neurological–structural relationship and their similar differentiation of the areas that make up their structure in spatial coordinates (Rizzolatti, Riggio, & Sheliga, 1994). Premotor theory suggests that movement attention is caused by the activation of common structures shared with motor programming areas. The evidence for this comes from the clear correlation in programming processes between saccadic movement and the visual displacement of attention. These results show that attention and saccadic movements are strongly correlated, with attention movements always coming first (Irwin & Gordon, 1998).

Comparatively few studies, however, have dealt with the influence of attention on other kinds of movement. One of the most important works is that of Welsh and Elliott (2004). These authors studied the influence of a distractor on the movement of a hand reaching towards a light. Their results suggest that (in a complex environment with more than one stimulus) the cognitive system has to inhibit any response elicited by non-target stimuli and to focus on the main goal of the task. The fact that these processes of selective attention and movement planning have traditionally been studied separately makes Welsh and Elliott (2004) the major exponents of the possibilities of this new relational topic between attention and movement, as detailed below.

Another line of research related to the topic of attention-movement derives from theories based on the concept

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of *affordance*, which postulates that the perception of any object depends on finding out which actions can be performed on it (see Tucker and Ellis (1998), for an introduction). A synthesis between the premotor theory and the affordance concept has been proposed by Tipper, Lortie, and Baylis (1992), who suggested that perception, both of target and distractor stimuli, elicits the automatic initiation of independent processes that programme favourable responses to both kinds of stimulus. This parallel programming makes it necessary to inhibit the response elicited by the distractors, which interferes with the subject's goals, resulting in not only a longer reaction time by the subject but also a longer time for the movement compared with the same goal in the absence of distractors. Coherent with the notion that distractor and object compete to emerge in behaviour, various studies have focused on the possible spatial repercussions in the execution of movement towards a goal (e.g. its trajectory). However, for some time these studies were inconsistent in their results, finding the trajectory of the subject's movement in one case veering towards the location of the distractor (Tipper, Howard, & Houghton, 1999) and in the other case away from it (Tipper, Howard, & Jackson, 1997).

This literature (based on discrete-trial tasks with simple limb movements, such as reaching) has suggested theoretical models that try to account for the pattern of results typically found and especially why the elicited movement is sometimes directed towards the distractors and sometimes it veers away from them.

A first model was the *vector response model* (Houghton & Tipper, 1999; Tipper et al.'s, 1999). It is based on Georgeopoulos's (1990) studies about neural motor programming in Rhesus monkeys, which showed that their arm movement was determined by the vector sum of the preferred movements by a large population of neurons. Tipper et al. assume that when both a target and a distractor are present at the same time, the movements towards both of them are activated and the resulting movement would be a sum of both, which would produce a deviation towards the distractor. However, the model also posits an inhibitory process that would attempt to keep such intruding movements from occurring. If this inhibitory process becomes large enough it would not only cancel the movement towards the distractor but it would even invert it. The model predicts that the main factor determining whether the inhibitory process is large enough is how salient the distractor is. More salient distractors would produce a strong activation of the inhibitory process, resulting in subjects deviating from the position of the distractor, whereas less salient stimuli would produce a smaller activation of the inhibitory process, allowing the movement towards the distractor to remain partially active and thus resulting in a deviation towards the distractor.

Welsh and Elliott (2004), however, found that the same distractor can produce both a veering away effect and a movement towards the distractor, which runs contrary to the predictions of the vector response model about the determining effect of the saliency of distractors. Instead, Welsh and Elliott showed that the effect depended on the time of appearance of the distractor relative to the target, measured as stimulus-onset asynchrony (SOA).

Five SOAs were used in the experiment: two negative values (−750 and −250 ms), meaning that the distractor stimuli appeared before those of the target; 0 ms (the distractor and target stimuli appeared on the screen simultaneously); and two positive values (250 and 550 ms), where the distractor stimuli were presented after those of the target. The data were analysed in several dimensions (temporal, kinematic and spatial), but of these only the spatial dimension will be examined, this being the most relevant for our study. In the −750 ms condition, when the distractor was presented in a position closer to the subject, the resulting movement towards the target was significantly greater than when the distractor appeared in a more distant position from the subject (that is, the final movement veered away from the distractor location). On the other hand, in the −250 ms condition, when the distractor appeared to the subject further away than the target, the movement was greater than when it appeared closer than the target. There were no significant results in the remaining conditions (0, 250, 550 ms).

Welsh and Elliott conclude that the determining factor is the temporal relationship between target and distractor. Their model (called *response activation model*) assumes (as the vector response model) that both target and distractor elicit movements towards their positions and that there is an inhibitory process responsible for the reduction of the unwanted deviation towards the distractor. This process, however, requires some time to complete. In the −750 ms condition, there is enough time to inhibit the response elicited by the distractor and even for it to become so large that it inverts the movement, resulting in a movement away from the distractor. If the distractor appears further from the subject than does the target, the movement ends up in a position closer to the subject than if the distractor appears further away. In the −250 ms condition, the response elicited by the distractor has insufficient time to be fully inhibited and, as a result, the final movement towards the target location is a mixture of the simple response to the target and the partial movement elicited by the distractor. In summary, Welsh and Elliott (2004) postulate that the inflection point of the effect is found between −750 and −250 ms, given that it is to within this interval that the effects revert.

Actually, a control condition is lacking in the Welsh and Elliott (2004) studies; the post hoc analysis in these works is carried out only between the two experimental conditions of the distractor position (taking the target location as reference point) in each of the SOAs used. This is a point we will properly deal with in our own experiments, introducing a control condition without distractors.

The Welsh and Elliott (2004) work has been one of the most important studies in showing the effects of the presence of non-target stimuli on movement and in establishing its temporal course. With respect to the kind of distractor that causes this effect, before Welsh and Elliott (2004) began to analyse the time course of inhibition, Lee (1999) had reported on the kinds of stimuli that could influence movement trajectory. Other studies have dealt with the types of distractor that can influence movement. The cues that can influence attention may be classified into two different kinds (Jonides, 1981). The exogenous cue, amongst other characteristics, triggers a priming effect with a time course of about 200 ms while, in contrast, the endogenous action control develops more slowly and in a voluntary way.

According to Lee (1999), the majority of studies dealing with this topic have had a limited vision of movement, given that they focus only on the influence attention has on reaction times, using solely non-continuous key-pressing tasks to test the possible effects. Welsh and Elliott's (2004) results were in agreement with Lee (1999), who affirmed that attention can also influence other aspects of movement, such as the initial direction of a movement or its trajectory. Only a few studies before that of Lee (1999) had examined this issue and in these, cued locations were never the targets of the movement, something that this author controlled in his experiments. Lee (1999) tested the effect of giving meaning to the cue, using both endogenous and exogenous cues and checking if there were statistical differences in the initial direction of the movement. Lee's (1999) main hypothesis was to verify that a priming effect could be attained depending on the meaning given to the cue; in other words, presenting a valid cue in a space which could later be occupied by the target.

Indeed, Lee (1999) found that with both types of cue, only those movements where distractors had been presented in a $\pm 90°$ position from the target and with movement initiation between 200 and 300 ms after the appearance of the target began with an initial veering located between target and cue positions, and these were gradually corrected later. This fact is consistent with the findings of Welsh and Elliott (2004) in the sense that when there is no time to inhibit the response elicited by a cue, the residual activation of it subsequently influences the target movement. Although Lee (1999) did not properly quantify the time course of this inhibition (using only ad hoc time intervals), the main contribution of this study is to demonstrate that both kinds of cue (exogenous and endogenous) can influence movement execution.

1.1. Research goals

Although many aspects remain to be researched, the results reviewed above show the direct link between attention and movement control. The present work intends to test to what extent and in which direction this effect could be relevant for real tasks, beginning with a simplified driving task (or tracking task) often used in ergonomic research (see Wickens and Hollands (2000) for a review).

It is important to highlight that theoretical and parametrical aspects are not the focus of our interest. The question is whether these effects can play a role in "real life". For this reason, we believe it is important to proceed step by step. Moving directly from a simple laboratory task to the study of a real driving task or even a complex simulator would prevent the control of a large number of unpredictable variables. The present paper is the first to explore the direct effect of attention on movement trajectory in a continuous task. Previous studies were based on discrete trials with a limited set of possible positions for target and cue. The tracking task, even when it is a simplified driving task, allows us to present an animation that seems continuous to the participant and to register frame by frame (in our case, 25 data per second for more than 10 min), which produces a large amount of information allowing a deeper analysis of the participant's behaviour as well as making the task more realistic. Moreover, the distractors are completely irrelevant to the task and can appear in almost any position on the screen. Under these conditions, small effects or those that are too fast or too slow, although interesting in theory, can completely disappear. Also, the existence of a large number of distractors (in totally random positions) could cancel the effects, which would eliminate the results found in previous experiments.

2. Experiment 1

Given that previous works had not found significant differences between endogenous and exogenous cues in influencing movement (Lee, 1999), we wanted in this first experiment to determine whether the simple presentation of an exogenous cue (*singleton*) could exert any influence on movement execution in this context (tracking task) specifically designed for the purpose. In order to measure this type of influence, the movement was recorded with a computer mouse, which the subject used to carry the out the task.

This study was focused on whether there could be an overall attentional effect on movement in this kind of context – independently of other variables such as practice or driving skill.

2.1. Material and methods

2.1.1. Participants

Ten subjects (with normal or corrected vision, undergraduates in Psychology from the University of Granada with ages ranging from 18 to 25) took part in this experiment. The subjects took part in exchange for experimental participation equivalent to 1 point, to be added to their practical marks in any topic in the field of Experimental Psychology included in their degree course.

2.1.2. Apparatus and materials

A simulated black road (with two continuous white lines that formed the boundary on each side and a width of 116 pixels) appeared on a computer screen with a green background. A continuous yellow line appeared in the middle of the road.

A *blue circle* always situated 300 pixels on Y axis (the screen had 800 pixels in total) and with dimensions 25×25 pixels, considerably less than the width of the road, was controlled by the subject and a *red circle* (the distractor, with dimensions 12×12 pixels) appeared randomly on almost any part of the screen except for an imaginary square (50×50) containing the *blue circle* (this being what was actually presented on the screen). Therefore, the distractor could never overlap in any way either the *blue circle* or the rest of the programming square in which it was contained. Apart from this restriction, the position of the distractors was decided in a random way. Once the distractor appeared, it remained on the screen for six frames (roughly 240 ms). After its disappearance, no other distractor was presented until at least six further frames had passed, with the aim of separating the effect of one distractor from the next. At no time were two distractors presented simultaneously. Apart from these other restrictions, the appearance of the distractor was randomly decided with equal probability.

The task consisted of tracking the road with the *blue circle* for approximately 10 min. The road was programmed (in programming language C) using Bezier serial curves, each with three random reference points, the only restriction being one of order (from the bottom to the top of the screen, the first Y coordinate could never be higher than the second or third, and the second coordinate could never be higher than the third). This premise ensured that the curve never turned over on itself. Apart from this characteristic, the coordinates of the points were random. Over this structure, the programme drew the road with a specific and constant width.

An Authentic AMD™ Processor computer (256.0 RAM Mb, 32 Bits Virtual Memory, and GeForce 2mx NVIDIA screen adaptator) was used to present the stimuli and record the subject's responses. Participants controlled the *blue circle* stimulus with a computer mouse. The movements of the mouse modified the position of the centre of the circle on the X axis but its position on the Y axis was fixed at a specific value, about a quarter of the screen height from its bottom.

2.1.3. Procedure

Once the subjects were seated comfortably in front of a computer and their details registered by means of a text window that appeared before the presentation of the task, the following instructions were given: "A simulated road will appear with two white lines forming its boundaries and a yellow line defining the centre of the road. Using the mouse, you can control the blue circle from right to left but not from top to bottom. Your task consists only in tracking the trajectory of the yellow central line with the blue circle for around 10 min. After this time, the programme will finish. If you have any queries, ask the experimenter. To continue, press OK when you are ready."

While the subject tracked the road along the X axis, a distractor appeared randomly on almost any part of the screen apart from a space previously specified. Once the presentation was over, the programme finished and the subject was rewarded.

2.1.4. Data analysis

Results were recorded at various levels, the programme codifying the following fields: Number of the subject; Trial (observing each of the frames presented); Time in milliseconds after the frame (each frame lasted 40 ms); Position on the X axis of the centre of the road at a specified point (coinciding with the point at which the centre of the circle's movement appears); Position on the Y axis of the centre of the road at this point (therefore always constant); Position of the left boundary of the road on the X axis; Position of the right boundary of the road on the X axis; Position of the centre of the *blue circle* on the Y Axis (constant since the *blue circle* did not allow movement on this axis); Position of the centre of the *blue circle* on the X axis; Position on the Y and X axis of the distractor if it appears.

Each field was recorded frame by frame, resulting in approximately 15,000 frames per subject. From the recorded results, the fields of each frame were taken on the X axis where the *blue circle* in a specific temporal position (the centre of the circle on the X axis in a particular frame) and coordinated where the *blue circle* should be (position on the X axis in the centre of the road in the same frame), this last being established by the instruction given to the subject to follow the centre of the road. The value of the subtraction of these two fields, frame by frame, gave the result as error with sign, both in the frames where the distractor was present and in those where it was absent. That is to say, when the ideal position was taken away and replaced by the real, if the ideal position (centre of the road) was higher (working from left to right of the screen) than the real position, this meant that the subject had veered to the left of the centre in this frame. If, on the other hand, the ideal position was lower than the real position, this meant that the subject had veered to the right of the centre of the road. Therefore, to put it another way, negative values indicated veering to the left and positive values indicated veering to the right. In the same way, a formula was programmed to filter the data, in the sense that if, on the X axis, the coordinate of the space where the distractor appeared was lower than the coordinate of the centre of the circle, this meant that the distractor had appeared on the left of the *blue circle*. Following the same logic, if the coordinate of the distractor on the afore-mentioned axis was higher than the coordinate of the centre of the circle, the programme codified this distractor as if it had been presented to the right of the *blue circle*. Lastly, if the coordinates were equal, the programme codified the distractor as the *centre* and these data were later filtered. Therefore, three conditions remained (two experimental and one control), these being: mean deviation when the distractor appears on the left of the circle; mean deviation when the distractor appears on the right of the circle; and mean deviation when no-distractor appears, all these frame by frame.

The frames of each presentation of the distractor were taken and the data were submitted to a repeated-measures variance analysis (ANOVA, taking .05 as the alpha level), with appearance of the distractor (no-appearance, left-appearance and right-appearance) as the only factor and using the error with sign as dependent variable. To analyse the frame by frame data, an SQL function was programmed, permitting fragmentation of the groups of six frames where the distractor was presented.

2.2. Results

For a global view of the data, a graph is attached, showing the differences between the experimental conditions and the statistical significance in the case (see Graph 1). Taking into account that the distractor was presented on average for all subjects 129.6 times for this Experiment 1, the pattern of results reveals that when the distractor appears on the right of the blue circle, deviation tends to increase to the left. Likewise, when the distractor is presented on the left, deviation tends to increase towards the right (i.e., it is quantitatively greater or taking more positive values, since the left-hand side of the screen is taken as a point of reference for the pixel count). There is a default deviation trajectory to the right, since the control condition has a positive value with respect to the centre of the road (see Fig. 1).

For the first frame, the results indicated that there were significant differences among the three experimental conditions, $F(2,18) = 7.62$, $MCE = 80.65$, $p < 0.005$. Equally, planned comparisons were carried out between the mean deviations towards the centre of the road when a distractor was present on the right and when no-distractor was present (Right–No-Distractor comparison); in this comparison, there were no significant differences between the two groups, $F(1,9) = 2.62$, $MCE = 12.57$, $p = 0.14$. Likewise, a planned comparison was carried out between the data pertaining to when the distractor appeared on the left and when it was absent (Left–No-Distractor comparison), where significant differences were shown between the two conditions, $F(1,9) = 18.33$, $MCE = 28.86$, $p < 0.003$. This pattern was maintained until the 12th frame (see Table 1).

However, in Frame 12, the differences between the conditions ceased to be significant, $F(2,18) = 2.38$, $MCE = 13.43$, $p = 0.12$. The analyses carried out on frames 13–30 showed that there were no significant differences between the conditions here either.

2.3. Discussion

We tested a veering away effect from the distractor (exogenous cue) on the *blue circle* trajectory in a tracking task. The mean of trajectory deviation when there is no-distractor increases gradually in the opposite direction to the side on which the distractor is presented when it appears. In other words, when distractors are presented on the left side of the *blue circle*, the mean of deviations is displaced to the right (taking more positive values), compared to the mean of deviations when the distractor is not present. Likewise, when distractors are presented on the right of the *blue circle* position, the mean of deviations rises, in this case towards the left (taking more negative values, see Fig. 1).

This veering away effect continues even when the distractor is not present, a fact that can be affirmed because the frames immediately following the disappearance of the distractor were analysed (what is in agreement with Welsh and Elliott (2004), studies in which an effect – independently of its nature – was observed after the disappearance of the distractor in both −750 and −250 ms conditions); the significant differences ceased in the 12th frame and continued in this pattern until at least the 30th frame.

3. Experiment 2

A second experiment was designed in order to check whether the effect encountered in Experiment 1 was specific

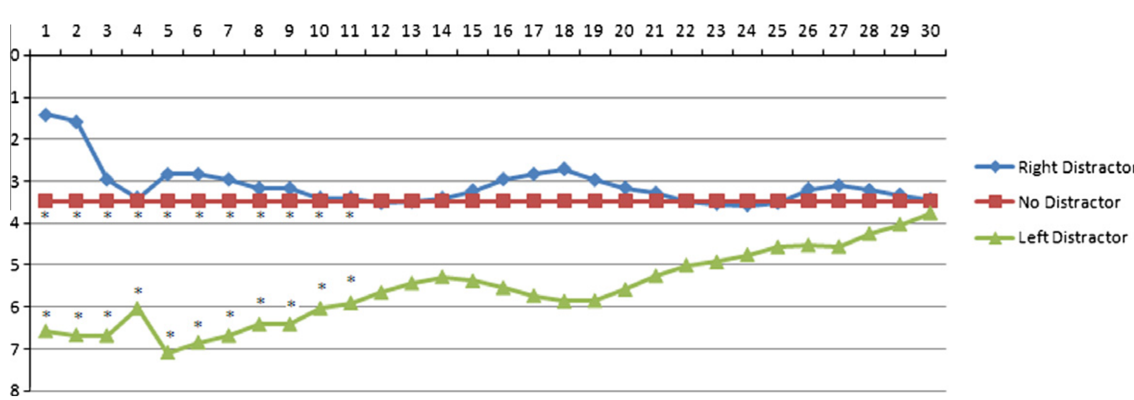

Fig. 1. Mean distance to the road centre for each of the experimental conditions for all experimental subjects and each frame in Experiment 1. Ordinate axis: Mean car position in pixels. Abscissa axis: Animation frames. Asterisks indicate that there was a significant difference for the corresponding frame. If the asterisk shows up below the "No-distractor" line, there was a significant simple main effect of the distractor across the three conditions (and thus the difference between the "Right distractor" and "Left distractor" conditions was significant). Asterisks near the "Left distractor" or "Right distractor" lines show that, additionally" the difference between that condition and the "No distractor" condition was also significant.

Table 1
Statistical analysis for Experiment 1. Both main effects and planned comparisons are shown for every frame we analysed. (Italicised data: Shots with statistical differences).

Experiment 1									
Main effect				Right Distractor–No Distractor comparison			Left Distractor–No Distractor comparison		
Shot	F	MCE	p	F	MCE	p	F	MCE	p
1	$F(2,18)=7.62$	80.65	*<0.005*	$F(1,9)=2.62$	12.57	$=0.14$	$F(1,9)=18.33$	28.86	*<0.003*
2	$F2,18)=6.93$	77.56	*<0.006*	$F(1,9)=1.94$	9.81	$=0.20$	$F(1,9)=14.67$	30.93	*<0.005*
3	$F(2,18)=6$	43	*<0.02*	$F(1,9)=0.0002$	0.0007	$=0.99$	$F(1,9)=10.2$	32.1	*<0.02*
4	$F(2,18)=4.94$	20.31	*<0.02*	$F(1,9)=0.56$	0.85	$=0.47$	$F(1,9)=10.34$	18.3	*<0.02*
5	$F(2,18)=8.05$	59.15	*<0.003*	$F(1,9)=0.56$	0.85	$=0.47$	$F(1,9)=10.34$	18.34	*<0.02*
6	$F(2,18)=6.7$	51.13	*<0.007*	$F(1,9)=0.03$	0.10	$=0.88$	$F(1,9)=12.45$	36.32	*<0.007*
7	$F(2,18)=6$	43	*<0.02*	$F(1,9)=0.0002$	0.0007	$=0.99$	$F(1,9)=10.2$	32.1	*<0.02*
8	$F(2,18)=4.66$	31.78	*<0.03*	$F(1,9)=0.06$	0.17	$=0.82$	$F(1,9)=9.93$	25.76	*<0.02*
9	$F(2,18)=5.1$	26.1	*<0.02*	$F(1,9)=0.13$	0.28	$=0.73$	$F(1,9)=11.77$	21.75	*<0.008*
10	$F(2,18)=4.94$	20.31	*<0.02*	$F(1,9)=0.56$	0.85	$=0.47$	$F(1,9)=10.34$	18.34	*<0.02*
11	$F(2,18)=3.73$	17.58	*<0.05*	$F(1,9)=0.56$	0.84	$=0.47$	$F(1,9)=6.94$	16.02	*<0.03*
12	$F(2,18)=2.38$	13.43	$=0.12$						

to certain conditions, (e.g., the apparatus or the muscles used by subjects to carry out the task) or general and therefore occurring in high-level phases of information processing. In this second experiment, a joystick was used instead of the computer mouse, given that, although both joystick and mouse movement were recorded on the X axis, the hand-controlled joystick movement is carried out on the X and Y dimensions (just like how it is conducted with real-driving steering wheel). The ultimate aim is to get closer to the real conditions of driving.

3.1. Material and methods

3.1.1. Participants

The participants in this second experiment were, as in Experiment 1, ten (different) students, likewise with normal or corrected vision, on degree courses in the Faculty of Psychology of Granada University and with ages ranging from 19 to 25 years. As in the first experiment, they took part in the study in exchange for experimental participation equivalent to 1 point, which could be included in their practical marks in any subject in the field of Experimental Psychology included in their degree courses.

3.1.2. Apparatus and task

On a computer screen with the same green background as in the first experiment, the same simulated black road appears with two continuous white lines which form the boundary on each side. The same continuous yellow line also appears in the middle of the road.

The subject controlled the *blue circle*, which had exactly the same dimensions as that used in the first experiment. A *red circle* (12×12 pixels dimension) was presented randomly in almost any space on the screen (in the same way and with exactly the same restrictions as in the previous experiment).

The task and the computer features remained the same as those used in Experiment 1. However, in contrast to the first experiment, the subject controlled the *blue circle* stimulus with a joystick.

3.2. Results

The same fields as in Experiment 1 were used to calculate error and the same left–right codification of distractors. To view the results of the data more clearly, a graph is attached (as in Experiment 1) with the differences between the distinct conditions, pointing out which are statistically significant (see Fig. 2).

Taking into account again that the distractor was presented on average 130.4 times for this Experiment 2, data were submitted to a repeated-measures analysis (ANOVA), all these frame by frame, in order to discover whether the distractor triggered a similar effect as in the previous conditions. This showed that in the first frame where the distractor was present, there were no significant differences between the three experimental conditions, $F(2,18)=0.82$, $MCE=11.85$, $p=0.46$.

Although these differences are not statistically significant, Graph 2 shows that when the distractor is presented on the right of the blue circle, the mean of deviations increases to the left, compared to when there is no-distractor. That difference is even greater when the distractor is presented on the left of the circle, when the mean of deviations takes a higher value to the right of the screen. These results follow the same pattern as in Experiment 1 but without the differences being statistically significant initially. The only exception is that, unlike in the previous experiment, the location of mean deviations when there is no-distractor is displaced to the left, since the mean of the control condition has a negative value (taking the road centre as reference point, see Fig. 2).

Given that the differences increase frame by frame in this experiment and it was possible to see that the effect remained (even when the distractor disappeared) until at least the 30th frame in Experiment 1, statistical analyses were also carried

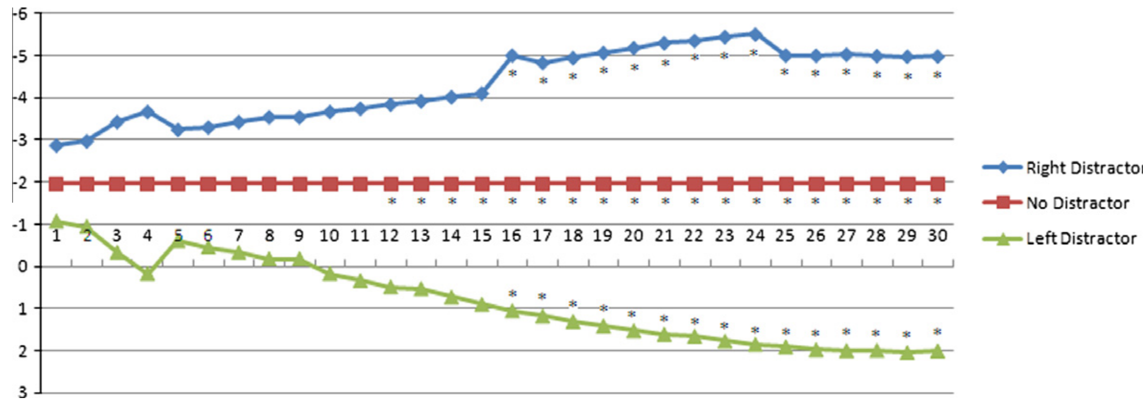

Fig. 2. Mean distance to the road centre for each of the experimental conditions for all experimental subjects and each frame in Experiment 2. Ordinate axis: Mean car position in pixels. Abscissa axis: Animation frames. Asterisks indicate that there was a significant difference for the corresponding frame. If the asterisk shows up below the "No-distractor" line, there was a significant simple main effect of the distractor across the three conditions (and thus the difference between the "Right distractor" and "Left distractor" conditions was significant). Asterisks near the "Left distractor" or "Right distractor" lines show that, additionally" the difference between that condition and the "No distractor" condition was also significant.

out until the 30th frame in this second experiment. There were no changes in the statistical pattern until the 12th frame (that in which the effect disappeared in the first experiment), when differences among the three experimental conditions began to be significant, $F(2,18) = 3.56$, $MCE = 82.11$, $p < 0.05$. The post hoc analysis between Right–No-Distractor, $F(1,9) = 3.30$, $MCE = 14.17$, $p = 0.10$, and Left–No-Distractor, $F(1,9) = 3.58$, $MCE = 27.62$, $p = 0.09$, were not significant.

The main effect remained constant frame by frame from the 13th until at least the 30th frame (see Table 2).

3.3. Discussion

In this second experiment, it is possible to find a similar pattern of results to that in Experiment 1, the only exception being a certain out of step effect at the beginning. As in the first experiment, a veering away effect from the position of the distractor is shown in both conditions (right and left), since compared with the mean when there is no-distractor, when the distractor appears on the left of the car, the subject veers more to the right and vice versa, in this case more clearly and symmetrically than in the previous experiment. This effect does not reach statistical significance until eleven frames after the first, where the distractor is presented, and is still significant at least eighteen frames later.

The differences between the results in both experiments (on their asymmetry and temporal course) could be caused by the different hand-device operation used during experiments. In the first one, the movement was carried out on just the X dimension and recorded in the same axis (mouse device), nevertheless, in the second one, the movement was executed on both X and Y dimensions and recorded on the X axis (joystick device).

Given that our target movement control apparatus is neither the computer mouse nor the joystick but a steering wheel (since we want to investigate real driving conditions), it does not make much sense to continue analysing the different frames to find out when the effect disappears using the joystick, once its existence has been verified.

Taking into account the results of both experiments, we can affirm that their pattern is not congruent with predictions of previous models. They might plead the existence of two different effects in every attentional cue presence – initially one attractive and subsequently other repulsive – and one temporal point in which there would be an inflection, reverting the initial effect to the opposite one .

4. Conclusions

Overall, it can be affirmed that the distractor had an influence on road tracking movement with the car (*blue circle*) in both the experiments carried out. This effect could, in principle, occur from a multitude of positions (given that the position in which the distractor appeared on the screen was designed to be random), although it is not known if the distance between the distractor and the *blue circle* could modulate the effect. This point will be explored in detail in future experiments.

Given that a similar pattern of results was found in the two experiments (taking into account that using the joystick involves a certain delay), it is possible to affirm that the effect does not depend on either the type of movement control apparatus used nor the particular muscles involved in controlling it.

According to the results obtained, it is possible to affirm that when a distractor is presented to the subject on the right-hand side of the screen, the mean of deviations from the centre of the road increases to the left (that is, taking more negative values). The same happens when the distractor is presented on the left-hand side of the screen, the mean, in that case, increasing to the right (taking more positive values).

In Welsh and Elliott's (2004) study, the whole inhibition time process was situated as beginning at any temporal

Table 2
Statistical analysis for Experiment 2. Both main effects and planned comparisons are shown for every frame we analysed. (Italicised data: Shots with statistical differences).

Experiment 2									
Main effect				Right Distractor–No Distractor Comparison			Left Distractor–No Distractor Comparison		
Shot	*F*	*MCE*	*p*	*F*	*MCE*	*p*	*F*	*MCE*	*p*
12	$F(2,18) = 3.56$	82.11	*<0.05*	$F(1,9) = 3.30$	14.17	= 0.10	$F(1,9) = 3.58$	27.62	=0.09
13	$F(2,18) = 3.85$	86.9	*<0.05*	$F(1,9) = 3.69$	15.52	= 0.09	$F(1,9) = 3.79$	28.58	=0.08
14	$F(2,18) = 4.37$	99.68	*<0.03*	$F(1,9) = 4.09$	17.25	= 0.07	$F(1,9) = 4.36$	33.47	=0.07
15	$F(2,18) = 4.9$	111.7	*<0.02*	$F(1,9) = 4.59$	18.9	= 0.06	$F(1,9) = 4.84$	38.05	=0.05
16	$F(2,18) = 6.12$	164.07	*<0.01*	$F(1,9) = 6.7$	39.52	*<0.03*	$F(1,9) = 5.34$	42.53	*<0.047*
17	$F(2,18) = 6.31$	161.79	*<0.009*	$F(1,9) = 6.57$	34.98	*<0.04*	$F(1,9) = 5.8$	46.17	*<0.04*
18	$F(2,18) = 6.86$	176.1	*<0.007*	$F(1,9) = 7.15$	38.01	*<0.03*	$F(1,9) = 6.33$	50.33	*<0.04*
19	$F(2,18) = 7.44$	189.74	*<0.005*	$F(1,9) = 7.77$	41.41	*<0.03*	$F(1,9) = 6.84$	53.73	*<0.03*
20	$F(2,18) = 8.1$	203.6	*<0.004*	$F(1,9) = 8.42$	44.69	*<0.02*	$F(1,9) = 7.49$	57.38	*<0.03*
21	$F(2,18) = 8.58$	216.5	*<0.003*	$F(1,9) = 9.14$	48.09	*<0.02*	$F(1,9) = 7.76$	60.39	*<0.03*
22	$F(2,18) = 8.95$	222.8	*<0.003*	$F(1,9) = 9.47$	49.86	*<0.02*	$F(1,9) = 8.05$	61.76	*<0.02*
23	$F(2,18) = 9.45$	237	*<0.002*	$F(1,9) = 9.96$	52.72	*<0.02*	$F(1,9) = 8.48$	66.03	*<0.02*
24	$F(2,18) = 9.68$	246.34	*<0.002*	$F(1,9) = 10.17$	54.65	*<0.02*	$F(1,9) = 8.64$	68.79	*<0.02*
25	$F(2,18) = 10.76$	221.11	*<0.0009*	$F(1,9) = 11.09$	41.06	*<0.009*	$F(1,9) = 8.75$	70.84	*<0.02*
26	$F(2,18) = 10.79$	225.96	*<0.0009*	$F(1,9) = 10.98$	40.96	*<0.01*	$F(1,9) = 8.8$	73.6	*<0.02*
27	$F(2,18) = 10.69$	229.43	*<0.0009*	$F(1,9) = 11.12$	41.69	*<0.009*	$F(1,9) = 8.54$	74.61	*<0.02*
28	$F(2,18) = 10.2$	227.11	*<0.002*	$F(1,9) = 10.75$	40.74	*<0.01*	$F(1,9) = 8.07$	74.5	*<0.02*
29	$F(2,18) = 10.32$	230.01	*<0.002*	$F(1,9) = 10.6$	40.33	*<0.01*	$F(1,9) = 8.16$	76.6	*<0.02*
30	$F(2,18) = 10.24$	227.3	*<0.002*	$F(1,9) = 10.45$	40.43	*<0.02*	$F(1,9) = 8.05$	74.98	*<0.02*

point between −750 ms and −250 ms before the target cue presentation (in which the inhibition process starts affecting movement, giving as result a veering-away-to-the target movement) and ending at any temporal point between −250 ms and 0 ms (in which there is no effect). Therefore, it is important to compare the time course of the effect in this study with Welsh and Elliott's (2004) results (although the effect is not the same and these authors were not accurate in measuring it). In our first experiment, it is already possible to observe statistical differences among the three experimental conditions from the first frame in which the distractor is presented, that pattern continuing until the 11th frame. As the animation speed was 25 frames per second, the duration of each frame was $25/1000 = 40$ ms. If the veering away effect from the distractor lasts until the 11th frame, the total duration of the effect would be eleven frames. If the number of frames in which the effect is significant is multiplied by the duration of each one, we get the figure of 275 ms. This approximate time (one could be more precise in measuring the time by taking more frames per second) gives us a rather more accurate idea of how much time the subject has to correct the movement elicited by the distractor than was provided by previous studies (Welsh & Elliott, 2004).

In our second experiment, the effect of the distractor began to be statistically significant from the 12th frame and continued to exercise a statistically reliable effect until the 30th frame. As we have already pointed out, it is possible to discover when the effect disappears but this is not our research goal and the experiment is not prepared for this purpose (because there is no way to control the overlap in presentation of the distractors). For this reason we limit ourselves to reporting that the effect is possible with other kinds of control apparatus.

The main contribution of the present study is to show that a distractor that was in no case related to the goals of the subject (paying attention to it does not imply any competitive advantage in carrying out the task, nor was this required in the instructions given to the subject) elicits a veering away effect in a continuous driving-simulation task. Our data also give a more precise estimation of the temporal course of this effect than was so far available in the literature.

The fact that the movement is always away from the distractor is at odds with Welsh and Elliott's (2004) response activation model, which was so far the only unfalsified model about the phenomenon in the literature, after they showed that the vector response model could not explain even the data in the discrete-trial task they used. There doesn't seem to be a second phase in which the movement is directed towards the distractor, as predicted by their model.

It remains an open question whether a veering effect towards the distractor can ever be found in a task of these characteristics. One of the goals of our future research will be to find out whether this is the case and what conditions can produce such an effect.

We conclude that the systematic study of this topic is relevant in a cognitive ergonomic sense, as it could help improve road design and thus make roads safer (activating more automatic cognitive mechanisms in our behaviour in the desired direction).

For example, if the pattern of results reported in this paper were confirmed in other contexts, it would be advisable to put illuminated signs on the left of the road on right-hand curves, and on the right of the road on left-hand curves, so that the effect on movement would be produced in the direction the driver should take, or at least not in the opposite direction. Obviously it is premature to propose such solutions at this stage of the research but we believe a sensible way of proceeding would be to carry out more detailed research in this direction, which could produce (not obvious) recommendations for improving the presentation of visual stimuli in the driving context.

We will continue to study this topic, designing more realistic traffic conditions, that is, using a steering wheel to control movement, designing a three-dimensional task, making possible the Y axis movement and introducing authentic driving signs, and check the partial effect of progressively introducing each of these new elements. A parametric analysis of the distance between distractor and car, the colour of the elements on the screen and the position of the distractor in relation to the car (left–right in front of and left–right behind) will be carried out in parallel in order to learn more about the conditions of the effect.

References

Eimer, M., Forster, B., Van Velzen, J., & Prabhu, G. (2004). Covert manual response preparation trigger attentional shifts: ERP evidence for the premotor theory of attention. *Neuropsychologica, 43*(6), 957–966.

Georgeopoulos, A. P. (1990). Neurophysiology of reaching. In M. Jeannerod (Ed.). *Attention and performance* (Vol. XIII, pp. 227–263). Hillsdale, NJ: Lawrence Erlbaum.

Houghton, G., & Tipper, S. P. (1999). Attention and the control of action: An investigation of the effects of selection on population coding of hand and eye movement. In D. Heinke, G. W. Humphreys, & A. Olsen (Eds.), *Connectionist models in cognitive neuroscience (Proceedings of the 5th neural computational and psychological workshop)*. New York: Springer-Verlag.

Irwin, D. E., & Gordon, R. D. (1998). Eye movements, attention, and transsaccadic memory. *Visual Cognition, 5*(1–2), 127–155.

Jonides, J. (1981). Voluntary versus reflexive control of the mind's eye's movement. In J. B. Long & A. D. Baddeley (Eds.). *Attention and performance* (Vol. IX, pp. 187–203). Hillsdale, NJ: Erbaum.

Lee, D. (1999). Effects of exogenous and endogenous attention on visually guided hand movements. *Cognitive Brain Research, 8*(2), 143–156.

Rizzolatti, G., Riggio, L., Dascola, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a promotor theory of attention. *Neuropsychologia, 25*, 31–40.

Rizzolatti, G., Riggio, L., & Sheliga, B. (1994). Space and selective attention. In C. Umiltà & M. Moscovitch (Eds.). *Attention and performance* (Vol. XV, pp. 231–265). Cambridge, MA: MIT Press.

Tipper, S. P., Howard, L. A., & Houghton, G. (1999). Behavioral consequences of selection form neural population codes. In S. Monsell & J. Driver (Eds.). *Attention and performance* (Vol. XVIII, pp. 223–245). Cambridge, MA: MIT Press.

Tipper, S. P., Howard, L. A., & Jackson, S. R. (1997). Selective reaching to grasp: Evidence for distractor interference effects. *Visual Cognition, 4*, 1–38.

Tipper, S. P., Lortie, C., & Baylis, G. C. (1992). Selective reaching: Evidence for action-centred attention. *Journal of Experimental Psychology: Human Perception and Performance, 18*(4), 891–905.

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance, 24*(3), 830–846.

Welsh, T. N., & Elliott, D. (2004). Movement trajectories in the presence of a distracting stimulus: Evidence for a response activation model of selective reaching. *The Quarterly Journal of Experimental Psychology, 57A*(6), 1031–1057.

Wickens, C. D., & Hollands, J. G. (2000). *Engineering psychology and human performance*. Upper Saddle River, NJ: Prentice Hall.