When motion and color compete for selective attention, motion induces a stronger distraction.

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Abstract: According to some authors, a task-irrelevant but highly salient stimulus will always capture attention at first, regardless of the Attentional Control Setting (ACS) defined by observer’s goals. In this way, motion stimuli are known to be particularly salient and therefore may be easily selected when necessary but act as powerful distractors when irrelevant. Nevertheless, previous studies investigating the capacity of irrelevant motion stimuli to override an ACS for color produced conflicting results. The aim of our study was to compare to what extent focusing on motion can prevent a distraction effect by color and *vice versa*, when both dimensions compete for attentional selection. In Task 1, participants performed a visual search task for a target defined as a color-singleton while having to ignore an irrelevant motion-singleton. In Task 2, the instructions were reversed. Our results revealed a distraction effect in both tasks, suggesting that an ACS for a particular dimension is not sufficient to prevent attentional distraction by an irrelevant one. Moreover, our results showed a larger distraction effect for motion-distractors than for color-distractors. Our results are discussed in regard to current models of attentional control.

1. Introduction

Driving in such a complex environment as an urban context is an intricate activity. Indeed, a large amount of information reaches our senses and all could potentially influence our driving behavior: the change of a traffic light’s color, a walking pedestrian or the car’s stoplights ahead are relevant information for a safe driving. However, owing to our limited capacity for perceptual processing, only a few can be selected for further processing. Such a selection is achieved through the mechanisms of *selective attention* [1] . In this way, it is not surprising that *attentional failures* (i.e., distraction or inattention; see [2] , for the

European Commission) are implicated in a large range of car accidents [3]. Thus, it is crucial to understand how our attentional system selects and prioritizes some information over others in order to improve the selection of relevant information for a safe drive and avoid useless distraction. This need is increasingly pressing if we consider that new sources of distraction are proliferating outside but also inside the car (from digital billboards displaying dynamic and colorful advertising to multiple connected car devices).

Saliency [4–7] has received a large amount of interest in visual attention studies as one of the major determinants of selective attention. For the *salience-based selection hypothesis* [8], attention will always be captured at first by the most salient stimulus in the environment, even if it is completely irrelevant for the task at hand [9,10]. The idea is that stimulus selection would be mediated by an attention-guiding "salience map" which computes feature contrasts against surrounding locations: the more a localized stimulus differs from those in its surrounding, the stronger its salience signal is [11]. According to [8], this bottom-up saliency signal *determines* the selection order because a winner-take-all mechanism selects the location on the salience map which exhibits the highest level of activation. Consequently, a highly salient digital advertising billboard or a moving cyclist wearing a fluorescent jacket should invariably capture the driver's attention. However, from an opposite view, called *the contingent capture hypothesis* [12], the ability of visually salient stimuli to capture attention would be modulated by the goals we pursue. An Attentional Control Setting (ACS), defined by those goals (i.e., depending on the ongoing task) would play a major role in the control of selective attention: the observer's attention will be captured by an irrelevant salient stimulus only if it shares some of the features defining the target stimulus he is looking for. Thence, an irrelevant but salient billboard displaying dynamic advertising should not capture a driver's attention if attention is set to detect a static speed limit road sign as for instance in the static versus dynamic control architecture proposed by [12].

Attentional studies with laboratory settings have shown that motion is a particularly salient and behaviorally relevant feature, and may therefore capture attention in a strong automatic way, even when irrelevant to the task at hand [13–16]. Consistent with this proposal, digital billboards displaying video advertising seem to have a stronger influence on visual attention and driving behavior than static advertising [17]. Nevertheless, it remains unclear whether motion, when completely irrelevant, can override an ACS for another dimension (e.g., an ACS for color). To our knowledge, two studies have produced conflicting results on this issue [18,19]. Besides, they both used a *spatial cueing paradigm* in which the motion (cue) and color (target) stimuli were not displayed at the same time but occurred in rapid temporal succession. A situation in which a cue briefly appears and disappears just before the appearance of a relevant target is not a usual situation in everyday life in general, and in driving contexts in particular. Besides, these spatial cueing paradigms are not suitable to investigate the capacity of an irrelevant dimension to override an ACS for another when they are in competition for attentional selection (i.e., when they are simultaneously present in the visual field). From a theoretical perspective, investigating attentional distraction when salient stimuli are in competition is crucial because the relative salience of the target and distractor seems a critical factor to determine attentional selection. Indeed, when a target is more salient than a salient but irrelevant distractor, attentional capture by the distractor could be eliminated [9,10].

Therefore, the aim of the current study was to address the following questions. Can an irrelevant motion stimulus capture an observer’s attention when it is set to detect a color stimulus? On the contrary, when looking for a motion stimulus, can attention be captured by an irrelevant but highly salient color distractor? Or in other words, could motion / color override an ACS respectively set for color / motion when motion and color directly compete for attentional selection?

To answer these questions, we adapted the *additional singleton task* developed by [9,10]. A first group of observers (Task 1) had to respond to a highly salient target singleton defined by its color (a red, blue or green circle among black circles) and to ignore a highly salient additional motion singleton – the distractor (a moving black circle). For a second group of participants (Task 2), the instructions were reversed (respond to the moving circle, ignore the color one). According to the contingency hypothesis [12], we should observe no distraction effect (i.e., no slowing of reaction times) in any group because the distractor never shares any feature with the target. According to the salience-based selection hypothesis [8] , we should observe a distraction effect only in one experimental group. Indeed, when the target is more salient than the distractor, and following [9,10] results, no distraction effect should be observed. Therefore, if motion (resp. color) is more salient than color (resp. motion), it will exhibit the higher level of bottom-up activation and will be selected first, leaving no room for distraction by color (resp. motion) distractor. Note however that one could object that a mere increase in RTs may not be related to the orientation of spatial attention but rather reflects the effortful and time-consuming non spatial filtering operations required when several salient stimuli are simultaneously presented on the same display [20]. In order to ensure that the to-be-ignored distractor does indeed capture attention, one can investigate the *compatibility effect* [21]. The reasoning is that if the salient distractor truly captures attention, the processing of a response-compatible distractor (same line orientation than target) will lead to shorter RTs relative to a response-incompatible distractor (different line orientation). If it is assumed that distractor cost is not sufficient to claim about attentional capture, compatibility effect is thought to provide a strong argument in favor of it [22,23].

2. Method

2.1. Participants

Forty-three students from Université Clermont Auvergne participated for partial fulfillment of course credits. Each participant performed only one of the two tasks. All observers were right handed and reported normal or corrected to normal vision. They also performed the Ishihara Color Blindness Test to ensure correct color perception. Twenty-one participants took part to Task 1 (all females, aged 19.9 ± 2.0

years). Data from one participant in Task 2 were discarded because of a deficit in color perception. Data of the remaining 21 observers in Task 2 were analyzed (14 females; age: $M = 19.9 \pm 1.4$ years). They all gave their inform consent and this study was approved by the local ethic committee.

2.2. Apparatus

Participants were tested individually in a quiet room with constant ambient illumination, in front of a 14-in VGA monitor (1024 × 1280 resolution, 60 Hz) at a distance of approximately 50 cm. The presentation of the stimuli, timing operations and data collection were controlled by E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA, United States).

2.3. Stimuli

A trial was composed of a fixation cross display, followed by a search display, a feedback display and finally a blank screen (Figure 1). All stimuli were displayed on a white background (RGB: 255; 255; 255). In the fixation cross display, a black fixation cross (0.57° of visual angle) appeared at the center of the screen for 500 ms. In the search display, six black circles (RGB: 0; 0; 0; ~17.7 cd/m²; 2.75° each) were arranged around an imaginary circle (11.46° in diameter) with the fixation cross at the center of the screen. The space between two adjacent circles was 2.86°. Each circle contained a horizontal or vertical line (1.1 * 0.1°) at its center. The line orientation was chosen randomly. Before the onset of the color- and/or motion-singleton, all the circles with their line inside were displayed in black for 300 ms [24]. The target could appear equally often at each of the six locations. After 300 ms the target in Task 1 equally often turned to blue (RGB: 89; 131; 255; ~37.62 cd/m²), green (RGB: 0; 159; 80; ~37.68 cd/m²) or red (RGB: 255; 0; 0; ~37.93 cd/m²) until response or for 1,500 ms. The motion target (RGB: 0; 0; 0; ~17.7 cd/m²) in Task 2 executed a linear outward radial translation (distance = 0.57°, speed = 0.1 m/s) created by two successive frames: after 300 ms it appeared at 0.28° of its initial location for 50 ms, and then appeared at 0.57° of its initial location until response or for 1,500 ms. The distractor could appear equally often at each of the four lateral locations. It executed a linear outward radial translation in Task 1. It equally often turned to blue, green or red in Task 2. A feedback was given to the participant at the end of each trial with written words: “correct” (i.e., correct answer); “erreur” (i.e., wrong answer); “manqué” (i.e., no answer); “bien” (i.e., no answer given on a trial without target). Feedbacks were displayed in black at the center of the screen during 500ms. A blank screen separated two consecutive trials during 250 ms.

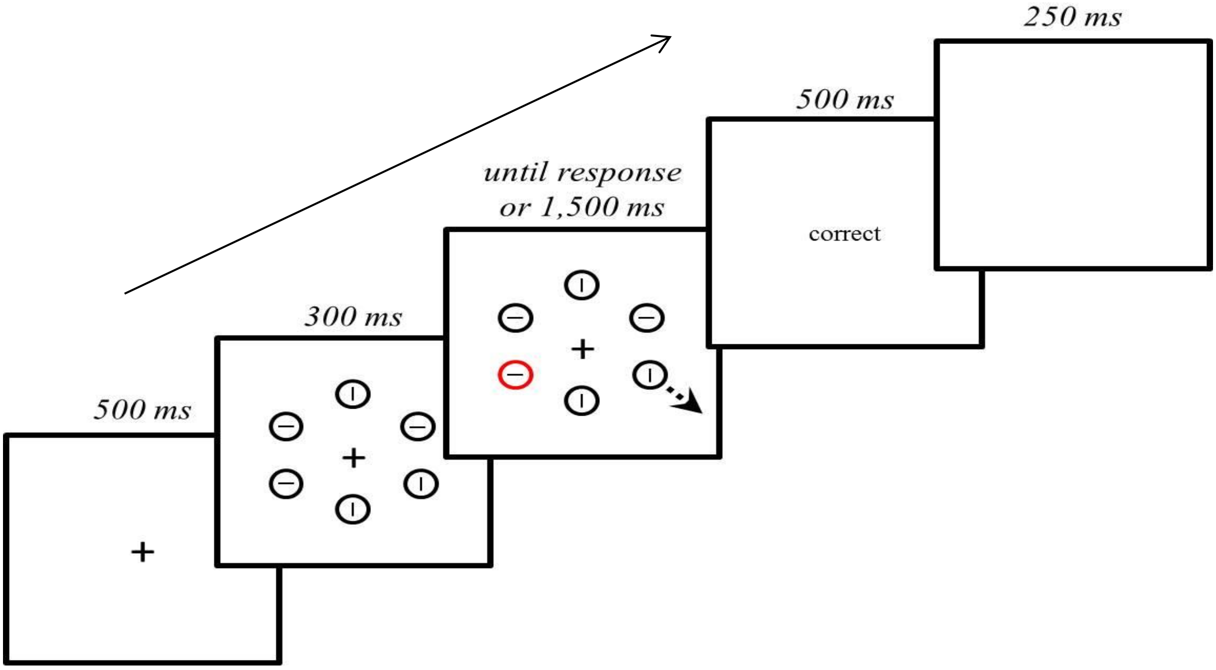

Figure 1: Time course of a trial with motion- and color-singleton. The dashed arrow represents the path followed by the motion-singleton.

2.4. Procedure

Each task lasted about 45 minutes and contained 864 trials (18 blocks of 48 trials). The target appeared in 75% of all trials, with an additional-singleton in two thirds of these trials. For the remaining 25% of all trials, the additional-singleton was present on the search array without target (i.e., no go trials). No response was required on target-absent trial. In a block, the color of the singleton (i.e., blue, red or green) was chosen randomly but each color appeared equally often across the session. Trials were also run randomly. A short break was given to the participants between blocks. The participants had to report as quickly as possible, minimizing errors, the line orientation contained inside the color circle (Task 1) or inside the motion circle (Task 2) by pressing two vertically aligned buttons with their left or right indexes. The right hand was always assigned to the upper button. Orientation-to-response-key mapping was counterbalanced across participants. Each participant performed a training block at the beginning of the session.

3. Results

The data from one participant in Task 1 and one participant in Task 2 were excluded from the analysis because their mean RTs were more than 2.5 SDs above their respective group's mean. Trials with errors were excluded from the analysis. For each participant, RTs plus/minus 2.5 absolute deviation around the median [25] were discarded. Errors and outliers RTs represented less than 10% of all available data.

3.1. Distractor Effect

A two-factors repeated measures ANOVA was performed, with Distractor (absent / present) as a within-subjects factor and Task (1 / 2) as a between-subjects factor. We observed a significant main effect of Distractor [$F(1, 38) = 94.5$, $p < .001$, $\eta^2_p = .71$, Greenhouse-Geisser corrected] where RTs in the Distractor present condition were longer (M = 569 ms) than RTs in the Distractor absent condition (M = 552 ms). There was no main effect of Task [$F(1, 38) = 2.5$, n.s.]. Interestingly, the two-way interaction between Distractor and Task was significant [$F(1, 38) = 15.7$, $p < .001$, $\eta^2_p = .29$]. *Post-hoc* analysis with Bonferroni corrections showed that while there was no difference between Tasks in the distractor-absent condition ($M_{\text{Task 1}} = 560$ ms, $M_{\text{Task 2}} = 545$ ms, n.s.) RTs were significantly longer with a motion distractor in Task 1 than with a color distractor in Task 2 ($M_{\text{Task 1}} = 584$ ms, $M_{\text{Task 2}} = 555$ ms, $p < .05$). Analyses also revealed that the distractor effect (i.e., RTs distractor present versus RTs distractor absent) was strongly significant in the two groups (*p*s < .001). A two samples t-test on distractor effect indicated that the distractor effect was larger in Task 1 (24 ms) than in Task 2 (10 ms) [$t(38) = 3.96$, $p < .001$].

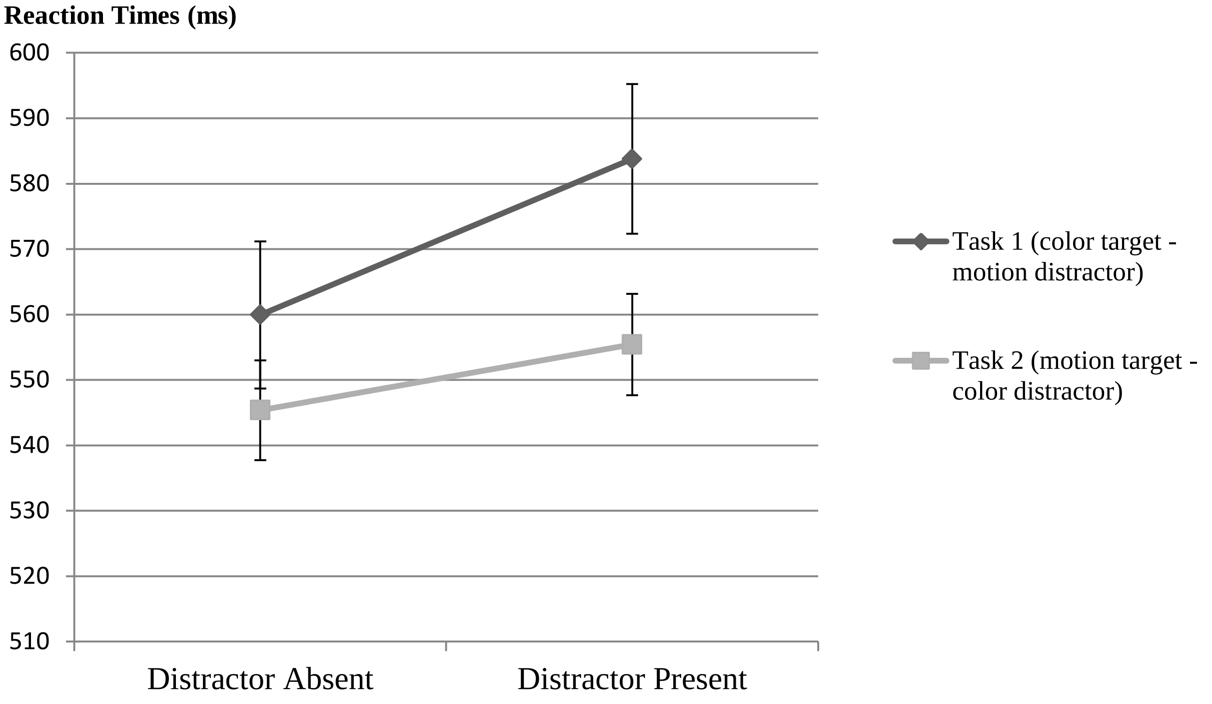

Figure 2: Mean reaction times when distractor was Absent or Present for Task 1 (dark grey) and Task 2 (light grey). Error bars represent Standard Error of the Mean (SEM).

3.2. Compatibility Effect

A two-factors repeated measures ANOVA was performed, with Compatibility (incompatible / compatible) as a within-subjects factor and Task (1 / 2) as a between-subjects factor. We observed a significant main effect of Compatibility [$F(1, 38) = 69.2$, $p < .001$, $\eta^2_p = .64$, Greenhouse-Geisser corrected]: RTs were longer in the incompatible condition (575 ms) than in the compatible condition (563 ms). The interaction between Compatibility and Task was also significant [$F(1, 38) = 15.7$, $p < .05$, $\eta^2_p = .13$]. *Post-hoc* analysis with Bonferroni corrections showed that while the difference was non-significant between Tasks when the distractors were compatible ($M_{\text{Task 1}}$ = 575 ms, $M_{\text{Task 2}}$ = 551 ms, n.s.), the participants were significantly slower with incompatible motion distractors in Task 1 than with incompatible color distractors in Task 2 ($M_{\text{Task 1}}$ = 590 ms, $M_{\text{Task 2}}$ = 560 ms, $p < .05$). Moreover, the compatibility effect (i.e., RTs incompatible distractor versus RTs compatible distractor) was highly significant in both groups (*p*s < .001). A two samples t-test on compatibility effect [t(38) = 2.34, p < .05] revealed that the compatibility effect was larger in Task 1 (15 ms) than in Task 2 (8 ms).

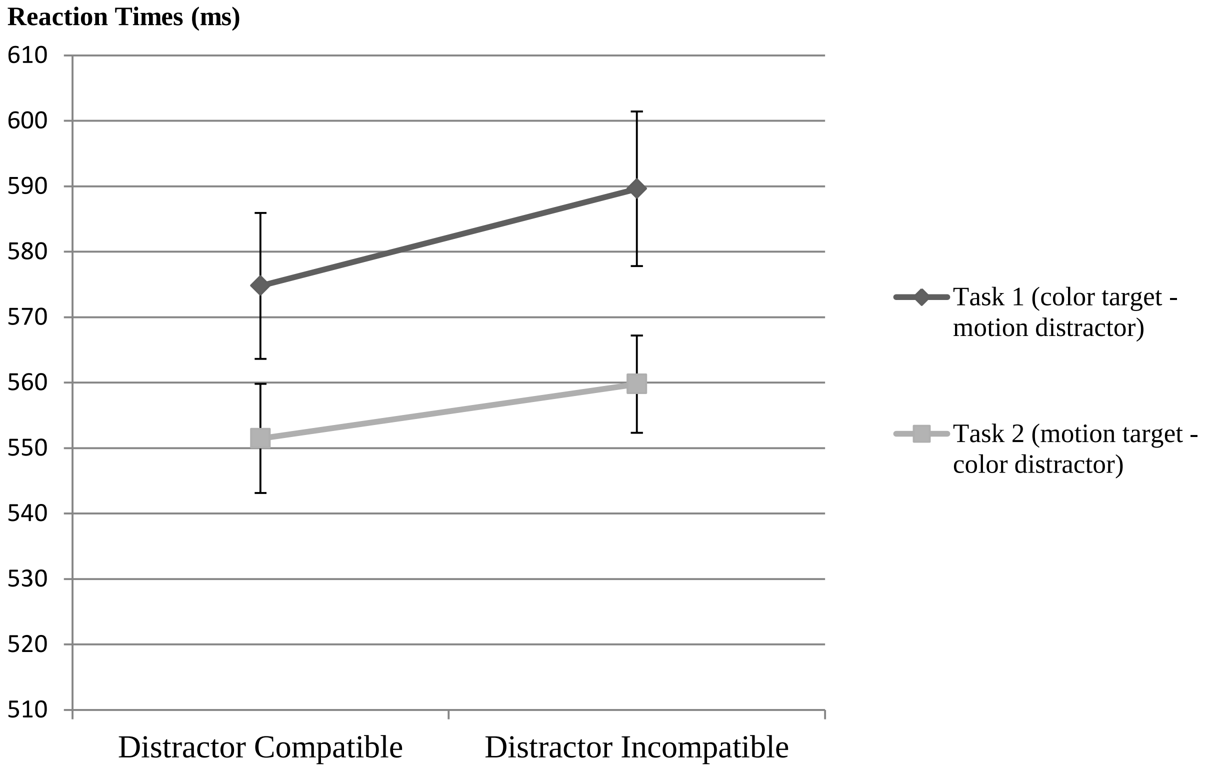

Figure 3: Mean reaction times when distractor was Compatible or Incompatible for Task 1(dark grey) and Task 2 (light grey). Error bars represent Standard Error of the Mean (SEM).

4. Discussion

By using a paradigm which created a competition for attentional selection between two supposedly highly salient singletons, our first objective was to draw conclusion about the capacity of an irrelevant but salient distractor to override an ACS for another dimension. Our second objective was to compare directly the distraction induced by an irrelevant motion stimulus to the distraction induced by an irrelevant color stimulus. In Task 1, irrelevant motion distractors produced a distraction effect while the participants were looking for color targets, indicating that motion distractors can override an ACS for color. Interestingly, we also found a significant distractor effect with irrelevant color distractors when participants had an ACS for motion in Task 2. The comparison between the two tasks revealed that the distraction effect was larger for motion distractors than for color distractors, thereby suggesting that motion is a more potent dimension to override an ACS for color than the reverse. Importantly, the analysis of the compatibility effects indicated that the slowing of RTs observed in the presence of distractors did not result from non-spatial filtering costs but truly reflected an attentional capture by these distractors [22]. Moreover, consistent with the finding that the distraction effect was larger for motion distractors than for color distractors, the compatibility effect was also larger for motion than for color distractors. Therefore, the present study provides evidence that motion singletons induce stronger attentional capture than color singletons but that an ACS for motion is not sufficient to prevent an attentional capture by an irrelevant but salient color singleton when both are in competition for attentional selection.

Thus, the distraction effects observed in our two tasks do not support the contingent capture hypothesis [12,26]. Indeed, despite the fact that the participants were looking for a color (resp. motion) singleton, a motion (resp. color) distractor that did not share any feature with the target captured attention. Moreover, the finding that motion distractors can override an ACS for color is consistent with the results reported by [18] but stands in sharp contrast with those reported by [19]. The discrepant results between these two earlier studies could stem from methodological differences. For the former, the stimulus-onset asynchrony (SOA) between the rotating cue and the color target was 100 ms whereas it was 240 ms for the later. A cue-target SOA exceeding 100 ms is enough to permit an attentional *disengagement* from the rotating cue after an initial capture [27]. This could explain why [19] failed to demonstrate an attentional capture by a rotating cue: attention may have been captured by the rotating cue, but by the time the target appeared on the screen, attention may have been disengaged from the cue location. Whatever, in these two studies, the irrelevant (cue) motion stimulus and the relevant (target) color stimulus appeared on successive displays and were therefore not strictly in competition for attentional selection. We propose that attentional distraction and the impact of ACS on attentional selection are better understood with competition paradigms. Also, together with [28], we think it is an important step for studies with laboratory settings to create conditions that better approximate situations that people encounter in the real world. This does not simply mean that future research should use more ecological stimuli but that paradigms themselves ought to capture important aspect of natural settings, in order to facilitate the transfer to applied studies, particularly in the driving field. The use of a competition paradigm was also motivated by theoretical considerations. Indeed, in previous studies using similar visual search paradigms where the shape distractor was made less salient than the color target no distraction effects were observed [9,10]. Hence, the *relative* salience of a singleton is a critical factor to investigate attentional distraction by an irrelevant highly salient stimulus.

What do the current results tell us about the relative salience of motion and color? In accordance with the saliency based selection hypothesis [8] the distraction effect produced by motion distractor in Task 1 reflects a higher activation level on the saliency map for motion singletons than for color singletons. If the bottom-up salience signal indeed fully determines the selection order for focal attention [8], we should not have observed distraction effects with color singletons in Task 2. Importantly, attentional capture by the most salient stimulus has been frequently demonstrated but attentional capture by distractors less salient than the target has only been reported twice [29,30]. Yet, other visual search models assume that although attention is guided to the location with the highest activation, noise may influence various stages of salience computation [11,31]. This implies that salience computation turns into a stochastic process where the more salient the target, the higher the *probability* that it is the first stimulus to be selected. In this way, attentional selection would rather be *proportional* to the *relative* salience of the target and the distractor. Thus, even if the distractor is less salient than the target, it would capture attention on some proportion of trials. The larger the RT interference, the higher the proportion of attentional capture events by distractors. In this way, the absence of distraction effect caused by a shape singleton when participants searched for a color target [9,10] could stem from the fact the perturbation induced by the saliency of a shape singleton is too small to affect attentional selection thus did not permit to observe a significant distraction effect on RTs. Such interpretation, with the need for a strong enough perturbation to have a significant effect on the deployment of attention, is compatible with dynamic neural field models of attention where target selection if driven by a combination of saliency and non-linear dynamics [32]. The larger distraction effect and the larger compatibility effect we observed for motion distractor could reflect a higher relative salience for motion than for color. However, because of the variability involved in neural computations, a color distractor could become sufficiently salient to influence the dynamics of target selection (or even sometimes be the first stimulus selected) on enough trials to exhibit a significant distraction effect in Task 2. The larger interference in RTs observed for motion distractor could be understood in terms attentional capture in higher proportion of trials than for color distractor.

To sum up, the present study provides new evidence of the strong distraction caused by moving objects, while showing that highly salient and relevant moving objects cannot prevent attentional capture by irrelevant highly salient but static objects. Moreover, our study shows an asymmetric distraction effect in favour of motion over color when both compete to summon attention.

It is obviously difficult to generalize our findings as they are to real-world scenario of driving. However, we believe that the basic science approach employed here can be fruitful since it is indisputably efficient regarding the number of trials performed by participants and regarding the control of a large range of variables that prevent noise intrusion in collected data. Capitalizing on its limits, the present study is a first step for a further integration of others factors influence on attentional capture in driving situations. For example, we have used very simple and meaningless visual displays whereas real-world scenes are usually very rich in visual information. In line with the Load Theory [33], one could therefore object that the current tasks both involved a low perceptual load, where available resources could spill over to the irrelevant distractors. Tasks involving high perceptual load that engage full capacity may simply leave no capacity for irrelevant motion or color distractor processing. Such considerations about the influence of perceptual load, which could be, for example, understood in terms of traffic density, could be relevant for driving studies of distraction [34,35]. Thus, future studies should investigate whether it takes a higher perceptual load to prevent attentional capture by motion distractors than other salient but static ones. In the same way, distractors were placed in possible target locations in our study, whereas driving-irrelevant information are often segregated from driving-relevant ones in natural driving scenes. In addition, distractor-present trials may have been over-represented in our study whereas real-world distractors are unpredictable and might occur with more rarity. Finally, our participants were engaged in a simple visual search task with no time pressure whereas drivers are often involved in multiple tasks where time is of the essence. Thus, to better understand distraction by salient stimuli in driving situations, it could be particularly relevant to investigate how factors such as the use of top-down knowledge, distractor rarity, multitasking and time pressure can modulate the current findings (but see [36,37]). Our study with the paradigm we used is the first step for a further integration of those factors into a more dynamic situation.

Nevertheless, the present study is relevant for the driving field. As traffic signs are the main communication media towards the driver, the estimation of saliency is of importance for engineers who aim at making traffic signs salient enough to attract driver’s attention. In this way, some authors have attempted to build a system for automatic estimation of road sign saliency [38,39]. The present investigation therefore gives a new insight regarding the role of saliency in computational models. Our findings could serve the improvement of existing models for automatic saliency diagnosis. Also, such findings may also help improving Advanced Driver Assistance Systems to better take into account human attentional capabilities. For instance, several car models now embed Traffic Sign Recognition systems to alleviate the driver’s attentional load in complex situations [40], with machine learning now outmatching human performance [41]. These systems nevertheless do not usually take into account the relative motion of objects of interest, or the factors that could facilitate distraction, thus not adapting to the driver’s needs.

Altogether, these results would contribute to the analysis of the impact of new sources of distraction from outside the vehicle (e.g., moving advertising billboards [17,42]), or from inside it [43] (e.g., In-Vehicle Information Systems – IVIS). Also, as emotional or rewarded stimuli are known to have a strong impact on attentional capture [44] it appears necessary to take into account those dimensions provided by advertising contents, as well as social reward [45] provided by new wearables devices or infotainment systems that support an ever-growing list of features (e.g., Facebook, Instagram, etc.).

5. References

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