Attentional Capture in Driving Displays

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Abstract (198 words)

Drivers face frequent distraction on the roadways but little is known about situations placing them at risk of misallocating visual attention. To investigate this issue, we asked participants to search for a red target embedded within simulated driving scenes (photographs taken from inside a car) in three experiments. Distraction was induced by presenting, via a GPS unit, red or green distractors positioned in an irrelevant location at which the target never appeared. If the salient distractor captures attention, visual search should be slower on distractor-present trials than distractor-absent trials. In Experiment 1, salient distractors yielded no such capture effect. In Experiment 2, we decreased the frequency of the salient distractor from 50% of trials to only 10% or 20% of trials. Capture effects were almost five times larger for the 10% occurrence group than for the 20% occurrence group. In Experiment 3, the amount of available central resources was manipulated by asking participants to either simultaneously monitor or ignore a stream of spoken digits. Capture effects were much larger for the dual-task group than for the single-task group. In summary, these findings identify risk factors for attentional capture in real-world driving scenes: distractor rarity and diversion of attention.

Keywords: attentional capture, visual search, driving, GPS

Attentional Capture in Driving Displays

In complex driving environments, the allocation of visual attention toward task-relevant objects is crucial. Roadways and motor vehicles are rich in visual information, some of which is task-relevant (e.g., neon construction cones, flashing crosswalk signs, traffic lights, and police beacons) and some of which is not (e.g., a brightly-colored billboard advertisement or a jogger in the nearby park). Given that drivers are frequently traveling at rapid speeds that require fast reaction times, the slightest distraction could potentially have tragic consequences. Indeed, from 2005 through 2007 in the United States, 18% of all automobile crashes and 3,000 fatal crashes were due to distraction (Singh, 2010). Thus, the social and economic costs of misdirected visual attention while driving are enormous.

Although there has been considerable research on dual-tasking while driving (e.g., Levy & Pashler, 2008; Levy, Pashler, & Boer, 2006; Strayer & Johnston, 2001), little research has specifically studied the capture of visual attention while driving. Drivers frequently encounter salient visual stimuli, such as the appearance of new objects on a GPS, that are irrelevant to the immediate task of driving. Can these environmental changes automatically distract drivers from the road ahead? Or are individuals able to routinely ignore such visual distractions? The goal of the present study is to answer these questions under a variety of conditions that might represent risk factors, such as division of attention.

Visual Distraction and Attentional Capture

Visual distraction due to “involuntary attentional capture” has been studied using several visual search paradigms (for a review, see Simons, 2000). A key debate in capture research is whether salient-but-irrelevant stimuli can automatically draw visual attention. According to *stimulus-driven* theories, salient stimuli, such as brightly-colored or flashing objects, automatically capture attention (Franconeri & Simons, 2003; Theeuwes, 1992; Yantis & Jonides, 1984). For example, Theeuwes (1992) had participants search displays for a circle amongst diamonds and report the orientation of a line inside. On some trials, a diamond appeared in a unique color against a background of homogenously-colored items (e.g., a red diamond amongst many green diamonds). Even though this *color singleton* was completely task-irrelevant, participants were slower to detect the target when the color singleton was present than when it was absent; a slowing of reaction time called a *present-absent cost*. Theeuwes concluded that salient stimuli can automatically capture attention, independently of the observer's goals and intentions.

According to *goal-driven* theories, in contrast, only stimuli matching what people are currently looking for (called the *attentional set*) can capture attention (Ansorge & Becker, 2014; Ansorge, Horstmann & Scharlau, 2010; Folk, Remington, & Johnston, 1992; Gaspelin, Ruthruff, Jung, et al., 2012; Lien, Ruthruff, Goodin, & Remington, 2008; Lien, Ruthruff, & Johnston, 2010). For instance, Folk and colleagues (e.g., Folk & Remington, 1998, 1999, 2006; Folk et al., 1992) reported spatial capture of attention by an entirely irrelevant distractor precue if and only if it possessed the feature used to find the target—e.g., when the precue is red and the target is defined by being red. Strikingly, even a seemingly highly-salient precue failed to capture attention when unrelated to the target—e.g., when the precue was a white abrupt onset but the target was red. Based on these findings, Folk and colleagues proposed the "*contingent capture*" hypothesis: attentional capture, although involuntarily triggered (bottom-up) by the appearance of an appropriate stimulus, depends entirely on the (top-down) attentional goal of finding the target.

Driving scenarios would seem to inherently require quick responses to unexpected salient stimuli (e.g., a motorcycle crossing the driver's future path). Nevertheless, Most and Astur (2007) also reported capture strongly contingent on top-down goals in a realistic, first-person driving simulator. In their study, participants searched at every intersection for either a yellow or blue arrow indicating which way to turn. Most and Astur observed that the collision rate with a motorcycle suddenly veering into the car's path was 36% when its color did not match the participants' attentional settings (e.g., a blue motorcycle when looking for a yellow arrow) but only 7% when the colors matched (e.g., a yellow motorcycle when looking for a yellow arrow). In other words, this study suggests that drivers can miss salient events that fall outside of their immediate attentional set

Other studies of attentional capture in naturalistic scenes suggest that top-down control is imperfect. For example, Brockmole and Henderson (2005) had participants study naturalistic scenes for later recall. During study, participants were more likely to fixate on objects that abruptly appeared (i.e., abrupt onsets), even though they were task irrelevant. They concluded that certain transient bottom-up signals can automatically capture attention during visual search (see also Brockmole & Henderson, 2008).

Based on the above basic and applied studies of capture, it is clear that capture is strongest for the stimuli that match the current attentional goal (what the participant is looking for), especially under ideal circumstances (for evidence of top-down control even in the face of changing task-demands, see Lien, Ruthruff, & Johnston, 2010). Although salient-but-irrelevant stimuli do sometimes capture attention despite apparently not matching top-down goals, they nevertheless produce much smaller capture effects than salient stimuli with relevant features (e.g., see Gaspelin, Ruthruff, Lien, & Jung, 2012; Gaspelin, Margett-Jordan, & Ruthruff, 2014).

The Current Study

Virtually all previous capture studies have employed unrealistically sparse and meaningless displays, such as a few letters in fixed positions on a homogenous background (but for a notable exception, see Most & Astur, 2007). This simplified basic science approach is efficient, but makes it difficult to generalize the findings to real-world scenarios of practical importance. Therefore, our goal is to explore the phenomenon of attention capture in more realistic scenarios.

We explored several dimensions of increased realism. First, basic capture studies usually use simplistic letter arrays, whereas real-world displays are usually rich in visual information. Second, basic capture studies tend to place distractors only in possible target locations, whereas real-world scenes are often segregated into relevant regions and irrelevant regions (e.g., the road ahead vs. billboards on the side of the road). Third, most capture studies present distractors on every trial, whereas real-world distractors can be quite unpredictable. Fourth, capture studies tend to involve only a single task (visual search), whereas real-world scenarios often involve multiple tasks (e.g., lane following, maintaining speed, listening to the radio). It is unclear how the first dimension (scene complexity) might influence capture, but the second dimension (placing distractors in irrelevant locations) should decrease capture, and the third (rarity) and fourth (diversion of attention) would likely increase capture.

To begin, we examined the ability to identify a target presented in red (a color chosen because it is common for warning signals) on a driving photograph in the face of distraction consisting of color changes (red or green) on a GPS unit positioned in an entirely irrelevant location where no target ever occurred (Experiment 1). We then investigated some conditions that may potentially hinder the ability to identify the target: reduction in the frequency of distracting color changes (Experiment 2) and reduction of the available central resources by adding another task (Experiment 3). Note that although we have increased realism along several dimensions (naturalistic scenes, irrelevant locations, reduced distractor frequency, diversion of central attention), the task is still visual search. This hybrid approach allows us to examine the impact of greater realism, while still maintaining contact with basic science studies and benefitting from their efficiencies (holding extraneous variables constant, collecting a large amount of data in a short period of time).

Experiment 1

Experiment 1 assessed attentional capture by distractors in driving displays. The participants searched for a red target (either the letter T or L) embedded in a photograph of a driving scene. Because they closely resemble each other, Ts and Ls are not identified preattentively but rather require spatial attention. Thus, any misallocation of attention by a distractor should slow target detection. Each trial began with a fixation point (presented centrally) on a white display, followed by a dashboard containing a steering wheel and a blank (i.e., uniformly gray) GPS at the bottom of the display (see Figure 1). Then, this display was followed by a visual search display containing a driving photograph. On half of the trials, the GPS remained unchanged (i.e., gray) after the visual search display appeared and, on the other half of trials, the GPS was activated, showing a route. When the GPS became activated, the displayed route could have the same color as the target (for half of the trials) or a different color (for the other half of the trials).

In traditional capture studies, salient stimuli often have detrimental effects on search performance, but only when they match the target-defining properties, such as its color. This contingent capture account predicts that, in a search for a red target letter embedded within a still photograph taken from inside a car while driving, only GPS screens containing a red distractor will produce present-absent costs but GPS screens containing a green distractor or remaining gray will not. What is unclear is whether the contingent capture results obtained with sparse displays will generalize to rich displays of driving scenes. According to Boot, Kramer, and Becic (2006), for instance, generalization of capture effects from sparse to richer displays may be weak: "[…] it has become increasingly clear that laboratory findings regarding attentional capture may not always scale-up to more complex, real-world situations."

According to stimulus-driven accounts, present-absent costs should instead be observed from both red and green GPS screens. Finally, salient distractors (both relevant and irrelevant) might fail to capture attention if participants are able to ignore locations known to be entirely irrelevant because a target never appears there. This case is important to study because it often occurs in real-world situations (though rarely in traditional capture experiments).

Method

Participants

Twenty-five students from a French University volunteered to participate in this experiment. All self-reported normal or corrected-to-normal visual acuity and normal color vision. The mean age of the participants was 22.7 years and 15 were female.

Materials

One hundred and twenty photographs, taken from the inside of a car, were used. Each photograph was displayed at a 1024 x 758 resolution and subtended 36.68° horizontally and 23.38° vertically at a typical viewing distance of 46 cm. Embedded in the foreground of each photograph was a steering wheel, a dashboard, and a GPS in the lower right corner (see Figure 1). The GPS screen subtended 7.46° horizontally and 3.74° vertically. Two versions of each photograph were created: one with a gray GPS screen (“GPS distractor absent”), the other one with a color GPS screen (“GPS distractor present”). The colored GPS screen represented a road path unrelated to the driving-scene photograph. The path color was red for one half of the “GPS distractor present” photographs (i.e. 60 photographs) and green for the other half (i.e. for 60 photographs), so they either possessed a color that was relevant (i.e., red) or irrelevant (i.e., green) relative to the target color (which was always red).

[Insert Figure 1 about here]

On each of the photographs, we embedded the red target, which was a single T or L in Times New Roman font. The target subtended 1.49° horizontally by 1.49° vertically. Across trials, the target was distributed randomly and uniformly across the total area of the driving-scene photographs.

Apparatus

Stimulus presentation, timing, and collection of responses were performed by a Dell Latitude D630 laptop computer controlled by software E-Prime 2.

Procedure

Before starting the experiment, participants were told that, in driving situations, it is crucial to quickly detect and appropriately react to red stimuli such as red breaking lights or red traffic lights. Participants were informed that, to study these kind of behaviors, the experimental task was to detect and identify as quickly and accurately as possible to a red target letter embedded within a still photograph taken from the inside of a vehicle. They responded to the letter T by pressing the ‘s’ key and to the letter L by pressing the ‘l’ key on an AZERTY keyboard.

Participants completed 5 practice trials followed by 240 experimental trials, which were randomly ordered from the 120 “GPS distractor present” photographs and 120 “GPS distractor absent” photographs. As shown in Figure 1, each trial began with a black fixation cross presented for 1 s in the center of a white screen, followed by the presentation of a display for 1 s containing the steering wheel, the dashboard, the GPS with a screen filled in grey, and the black cross. Then, the still photograph was presented and remained on the screen for 3 s, during which time participants could respond. To start the next trial, participants pressed the space bar. The experimental session was broken into two blocks of 120 trials, separated by a 5-minute break.

Results

Trials with RTs between 100 ms and 2,500 ms were analyzed. These RT cutoffs led to the removal of 1.04% of the trials. Trials with errors were excluded from the RT analyses. The resulting mean RTs and error rates are displayed in Table 1. Figure 2 shows mean RTs as a function of distractor presence.

[Insert Table 1 about here]

[Insert Figure 2 about here]

Reaction Times

We performed two paired-samples *t*-tests. The first one compared RT when a distractor (whether red or green) is present versus absent. The second one compared RTs when the distractor color is relevant (i.e., red, like the target) versus irrelevant (green).[1]

Mean RT was almost identical whether the distractor was present (M = 944 ms) or absent (M = 942 ms), $t(24) < 1$, leading to a negligible present-absent cost (2 ms). The 95% confidence interval for the overall present-absent effect was -8 ms to 13 ms, so the data are precise enough to rule out even a substantial capture effect.

There was no significant effect of whether the distractor color was relevant (M = 946 ms) or irrelevant (M = 943 ms), $t(24) < 1$. The relevance cost was negligible (3 ms) with a 95% confidence interval of -10 ms to 16 ms.

Error rates

The overall percentage of incorrect responses was 4.2%. Error rates were influenced by neither distractor presence, $t(24) < 1$, nor distractor relevance, $t(24) = 1.63$, $p = .116$.

Discussion

[1] Note that present-absent and relevant-irrelevant are not orthogonal, so they cannot be combined in a two-way ANOVA.

In this experiment, participants searched for a color target positioned on a driving photograph, while colored distractors appeared in an irrelevant location (i.e., the GPS zone). No capture effects were discernible, suggesting that the salient disctractors could be largely ignored, even in the relevant target-finding color (red). Given that a large number of traditional studies have reported large amounts of capture by relevant-colored distractors, the most obvious interpretation is that it is easier to ignore distractors when they appear in task-irrelevant locations (never containing a target).

Experiment 2

We found no evidence of capture when distractors appeared on 50% of trials. Here, we manipulated the frequency of the color change on the GPS screen (either 10% or 20%) to determine whether distractor rarity increases capture. One might predict that infrequent distractors would produce greater attention capture effects than frequent distractors, due to a weakening of the attentional goal to ignore distractors occurring in an irrelevant location. Consistent with this prediction, previous research by Forster and Lavie (2007) showed greater attention capture effects for distractors occurring infrequently, on 10% of the trials, compared to distractors occurring more frequently, on 50% of the trials (see also Folk & Remington, 2015; Horstmann, 2002; Johnston, Ruthruff, & Lien, 2015). But note that none of these studies used naturalistic scenes and other basic studies have failed to find an effect of rarity (e.g., Noosen, Lien, & Ruthruff, 2014). The issue is important because salient distracting stimuli might be relatively rare in real-world conditions, rather than occurring every few seconds (as in most traditional experiments).

Method

Participants

Fifty students from a French University volunteered to participate in this experiment. They were 18-23 years old and all had normal or corrected-to-normal visual acuity and normal color vision.

Procedure

The procedure was identical to the one used in Experiment 1, except that half of the participants were randomly assigned to the 20% distractor occurrence condition and the other half to the 10% distractor occurrence condition.

Results

Trials with RTs between 100 ms and 2,500 ms were analyzed. These RT cutoffs led to the removal of 0.59% of the trials. Trials with errors on the search task were excluded from the RT analyses (1.79%).

Reaction Times

An ANOVA was conducted on RT with distractor presence (present vs. absent) as a within-subjects factor and distractor frequency (10% vs. 20% occurrence) as a between-subjects factor. Overall visual search speed was comparable between the 20% occurrence group (M = 929 ms) and those in the 10% occurrence group (M = 922 ms), $F(1, 48) < 1$. Unlike in Experiment 1, participants responded more slowly when the distractor was present (M = 944 ms) than when it was absent (M = 907 ms), $F(1, 48) = 20.09$, $p < .001$ (partial $\eta^2 = .30$). This main effect of distractor presence was qualified by an interaction with distractor frequency, $F(1, 48) = 8.72$, $p < .01$ (partial $\eta^2 = .15$). The present-absent cost was much larger in the 10% occurrence condition (cost of 61 ms) than in the 20% occurrence condition (cost of 13 ms), $t(48) = 2.95$, $p < .01$ (see Figure 2). Follow-up t-tests showed that the present-absent cost was significant in the 10% occurrence condition, $t(24) = 4.46$, $p < .001$, but not in the 20% occurrence condition, $t(24) = 1.38$, $p = .18$.

We also carried out an ANOVA on RT with distractor relevance (relevant red color vs. irrelevant green color) as a within-subjects factor and distractor frequency (10% vs. 20% occurrence) as a between-subjects factor. No significant RT difference was found between relevant (M = 953 ms) and irrelevant distractors (M = 934 ms), $F(1, 48) = 2.72$, $p = .106$ (partial $\eta^2 = .05$). Although this trend of a 19-ms relevance effect did not reach significance, it would be premature to conclude that there is no effect of relevance; more likely, it is simply difficult to detect because rare distractors leave few trials to analyze and because even the green distractors often captured attention. Indeed, a similar trend will be reported in Experiment 3. Neither the main effect of distractor frequency, $F(1, 48) < 1$, nor the interaction between distractor relevance and distractor frequency, $F(1, 48) < 1$, was significant.

Error rates

The percentage of incorrect responses did not significantly differ between the 10% occurrence condition (M = 1.59%) and the 20% occurrence condition (M = 2.39%), $F(1, 48) = 2.00$, $p = .163$ (partial $\eta^2 = .04$). It also did not significantly differ between distractor-present (M = 1.88%) and distractor-absent trials (M = 2.10%), $F(1, 48) < 1$. Furthermore, there was no significant interaction between distractor presence and distractor frequency, $F(1, 48) < 1$.

Error rates were smaller when the distractor was presented in the relevant red color (M = 1.17%) rather than the irrelevant green color (M = 2.58%), $F(1, 48) = 5.47$, $p < .05$ (partial $\eta^2 = .10$).

Discussion

Distractor frequency (occurrence on 10% vs. 20% of the trials) influenced attentional capture in driving photographs: present-absent costs were nearly five time larger in the 10% occurrence group (61 ms) than in the 20% occurrence group (13 ms). Note that the present-absent cost observed for the 20% occurrence group (13 ms) is numerically smaller than the present-absent cost found in Experiment 1 (2 ms) when GPS distractors occurred on 50% of the trials, but the small difference did not reach statistical significance, $t(48) < 1$.

One possible explanation for the influence of distractor frequency on attentional capture is that participants can habituate to distractors when they occur on at least 20% of the trials but not when they occur less often. Another possibility is that the attentional goal of suppressing salient distractors occurring in a particular irrelevant location was weakened when the distractors occurred very infrequently (i.e., on 10% of the trials), leading to less effective suppression of capture (see, e.g., Gaspelin, Leonard, & Luck, 2015; Sawaki & Luck, 2010). Regardless of the precise explanation, we speculate that those distractors occurring less often in real-world driving situations are the most distracting. For example, windshield wipers might be much less distracting than an unusual billboard.

Experiment 3

In real-world scenarios, drivers frequently perform two tasks simultaneously, such as talking on a cell phone while driving. In Experiment 3, we ascertained whether diverting central attentional resources toward a secondary source of information would influence attention capture effects by distractors (for evidence of capture effects modulated by dual-task situations with abstract displays, see Boot, Brockmole, & Simon, 2005). To this end, the visual search task from Experiment 1 was performed simultaneously with a stream of spoken digits, inspired by the auditory stream from Boot et al.'s (2005) study. The stream was monitored by one half of the participants (who counted the number of sequential digit repetitions) and ignored by the other half. Distractor frequency was 50%, as in Experiment 1.

Method

Participants

A new sample of 48 students was recruited from a French University to participate in this experiment. They were 18-24 years old, and all had normal or corrected-to-normal visual acuity and normal color vision.

Materials

The visual material was identical to that used in Experiment 1, but we added an auditory stream of digits. The auditory material consisted of 60 recordings of a male voice reading a string of 10 digits (ranging from 1 to 9) at a rate of two digits per second for 5 s. Half of the recordings contained two sequential repetitions (e.g., 3, 4, 4, 5, 2, 8, 6, 6, 1, 9), and half contained three repetitions (e.g., 7, 5, 5, 4, 8, 8, 6, 6, 1, 9).

Apparatus

The apparatus was identical to that of Experiment 1, except for the addition of headphones.

Procedure

The procedure was identical to that of Experiment 1 with the following differences. All participants heard auditory strings of digits while performing the visual search task. The start of each 5-s auditory stream coincided with the start of each 5-s visual stream (i.e., the onset of the fixation cross). Participants were randomly assigned to either the single-task group or the dual-task group. Participants from the single-task group were informed that the auditory stream was irrelevant and, as such, they should ignore it. But participants from the dual-task group were instructed to count the number of sequential repetitions within the auditory stream. Even though three repetitions in a stream was the maximum, the instructions implied that up to four repetitions could occur, thus encouraging continuous attention even after three repetitions had been counted. After the search task, participants indicated how many repetitions of digits they heard by pressing the key labelled 1, 2, 3, or 4 on the AZERTY keyboard.

Results

Trials with RTs between 100 ms and 2,500 ms were analyzed. These RT cutoffs led to the removal of 1.55% of the trials. Trials with errors on the search task were excluded from the RT analyses (2.49% for the single-task group, 2.06% for the dual-task group). For the dual-task group, trials with errors on the auditory task were also excluded from RT analyses (25.71%)[2]. Figure 3 shows mean RTs as a function of distractor presence (present vs. absent) and divided-attention group (single-task group vs. dual-task group) in Experiment 3.

[Insert Figure 3 about here]

Reaction Times

An ANOVA was conducted on RT with distractor presence (present vs. absent) as a within-subjects factor and divided-attention group (single-task vs. dual-task) as a between-subjects factor. Results showed that mean RTs were longer by 163 ms for the dual-task group (M = 1,074 ms) than for the single-task group (M = 915 ms), $F(1,46) = 19.64$, $p < .001$ (partial $\eta^2 = .30$). Participants responded more slowly overall when the distractor was present (M = 1,007 ms) than when it was absent (M = 982 ms), $F(1, 46) = 24.65$, $p < .001$ (partial $\eta^2 = .35$). Also, the main effect of divided-attention group was qualified by an interaction with distractor presence, $F(1, 46) = 4.09$, $p < .05$ (partial $\eta^2 = .08$). The present-absent cost was larger for the dual-task group (cost of 36 ms) than for the single-task group (cost of 15 ms), $t(46) = 2.02$, $p < .05$. Note that the present-absent cost was significant both for the dual-task group, $t(23) = 4.35$, $p < .001$, and for the single-task group, $t(23) = 2.47$, $p < .02$.

We also conducted an ANOVA with distractor relevance as a within-subjects factor (relevant red color versus irrelevant green color) and divided-attention group (single-task vs. dual-task) as a between-subjects factor. Results showed that mean RTs were longer by 170 ms for the dual-task group (M = 1,092 ms) than for the single-task group (M = 922 ms),

[2] Note that while 25.71% represents a substantial percentage of trials, the analyses reported in the main text nevertheless exclude the errors for reasons of data quality control.

$F(1,46) = 22.25$, $p < .001$ (partial $\eta^2 = .33$). Mean RTs did not significantly depend on whether the distractor had the relevant red color (M = 1,015 ms) rather than the irrelevant green color (M = 1,000 ms), $F(1, 46) = 2.33$, $p = .134$ (partial $\eta^2 = .05$). This trend of a 15-ms relevance effect was uninfluenced by divided-attention group, $F(1, 46) < 1$. Given that a similar trend was observed in Experiment 2, there might be a genuine relevance effect that would be detected in a larger sample.

In any case, it is clear that the distractors are capturing attention given the overall present-absent cost (though perhaps nearly as strongly for irrelevant stimuli as for relevant stimuli).

Error rates

The percentage of incorrect responses did not significantly differ between the dual-task group (M = 3.65%) and the single-task group (M = 2.78%), $F(1, 46) = 2.66$, $p = .110$ (partial $\eta^2 = .05$). Participants tended to commit slightly more errors when the distractor was present (M = 3.52%) than when it was absent (M = 2.90%), as evidenced by a marginally significant main effect of distractor presence, $F(1, 46) = 3.67$, $p = .06$ (partial $\eta^2 = .07$). The interaction between distractor presence and divided-attention group was not significant, $F(1, 46) = 1.13$, $p = .293$ (partial $\eta^2 = .02$).

Error rates were smaller when the distractor was presented in the relevant red color (M = 2.88%) rather than the irrelevant green color (M = 4.17%), $F(1, 46) = 9.18$, $p < .01$ (partial $\eta^2 = .17$).

Discussion

The results from Experiment 3 demonstrate that visual search is generally slowed (by more than 160 ms) by a secondary task that requires central attentional resources. This reduction in available central resources also increased capture effects: the present-absent cost was only 15 ms for the single-task group but was 36 ms for the dual-task group. As in

Experiment 2, there was also a tendency, albeit not significant, for more RT slowing when the target and the GPS distractor shared the same color, relative to when they did not (relevance effect of 15 ms). As shown next in the General Discussion, a pooled analysis of Experiments 2 and 3 revealed a significant relevance effect, thus confirming a role of top-down goals in attentional capture.

Overall, the findings from Experiment 3 confirm that capture is possible with rich displays, even for distractors in irrelevant locations that never contained a target. Furthermore, the findings support the view that salient stimuli capture attention more easily when less central attentional resources are available. Perhaps such situations weaken the ability to maintain the attentional goal to suppress visual distractors in working memory (see Engle, 2002).

General Discussion

Even though misallocation of visual attention due to distraction can have detrimental effects in driving situations (i.e., tragic accidents), the capture of visual attention has typically been studied only using very simple and artificial stimuli displays (e.g., circular array of letters or basic shapes on a homogenous background). Previous studies have also focused almost exclusively on single-task situations in which a distractor appears on nearly every trial. Therefore, it is important to examine attentional capture in more realistic situations.

The present study determined whether searching for a red target in a driving scene is compromised by salient visual distractors. In three experiments, we introduced visual distractors by filling a GPS screen with colored elements. In Experiment 1, GPS distractors (whether of a relevant or an irrelevant color relative to the red target color) occurred randomly on 50% of the trials. Both the present-absent cost (2 ms) and the relevance cost (3 ms) were negligible, thus showing a preserved ability to avoid capture by salient distractors under favorable conditions (i.e., high distractor frequency of 50%, constant distractor location in an irrelevant display region, and no other concurrent tasks).

In Experiment 2, we manipulated GPS distractor frequency: the distractors occurred either on 10% or 20% of the trials. Attention capture was almost five times larger when the distractor occurred on only 10% of the trials (present-absent cost of 61 ms) relative to when it occurred less infrequently on 20% of the trials (present-absent cost of 13 ms). In Experiment 3, participants were asked to either monitor or ignore an auditory stream while performing the search task. A larger present-absent cost was found when less central resources were available due to monitoring of the auditory stream (present-absent cost of 36 ms) relative to when more attention was available (present-absent cost of 15 ms).

Taken together, the results from Experiment 1-3 suggest that participants are reliably able to resist to distraction occurring in an irrelevant location, provided that distractors occur quite frequently (on at least 20% of the trials) and central resources are fully available. However, real-world scenarios are likely to often involve low frequency events and reduced central resources, either of which by itself opens the door to capture. Thus, the present results (Experiments 2 and 3) also suggest that attentional capture can occur in real-world driving situations.

Effect of Rarity

The rarity effect is consistent with findings from previous studies (e.g., Forster & Lavie, 2008; Müller, Geyer, Zehetleitner, & Krummenacher, 2009; Neo & Chua, 2006; Folk & Remington, 2015; but see also Noosen, Lien, & Ruthruff, 2014). According to Müller et al. (2009), participants can ignore a distractor only with frequent distractor occurrence, aided by habituation. The authors explain the differences shown in the literature as follow: "*the extent of distractor interference is dependent on two factors: (a) acquisition of a top-down suppression strategy during (initial) practice and (b) incentive to use such a suppression* *strategy*" (Müller & al., 2009, p. 3). We hypothesize that the occurrence of distractors on 10% of the trials greatly reduced the activation of the "suppression strategy" in working memory, thus facilitating attentional capture by the GPS distractor (see Gaspelin et al., 2015; Sawaki & Luck, 2010).

Although reduction in event frequency increases capture for irrelevant events, it appears to have the exact opposite effect for target events (e.g., Wolfe, Horowitz, & Kenner, 2005). Johnston et al. (2015), for example, reported a reduction in capture by searched-for peripheral events in air traffic control displays when those events were rare and participants performed a demanding central task.

Effect of Reducing Available Central Resources

Monitoring an auditory stream reduced the amount of available cognitive resources which, in turn, facilitated attentional capture by GPS distractors (as evidenced by a present-absent cost of 36 ms for the dual-task group in Experiment 3). To account for this effect, we propose a weakening of the maintenance of the attentional goal in working memory. Instead of setting themselves to ignore the irrelevant GPS, participants set themselves to monitor the auditory stimuli (which were quite salient). While driving, reduction in central resources could be caused by many different activities, such as talking on a cell phone or intently listening to the radio. Thus, objects from the entire visual field might become capable of capturing attention, not just those in the regions most releveant to the task of driving.

Effect of Relevance

We had expected that, if capture occurred, it would occur more strongly for GPS distractors in the same color as the target because they match the attentional set used to find the target (Folk et al., 1992). So it was surprising the effect was, overall, quite weak. We observed a trend in this direction with infrequent distractors (cost of 19 ms in Experiment 2) and when central resources were less available (cost of 15 ms in Experiment 3), though neither effect reached significance. To evaluate whether these trends are genuine, we combined the data from Experiment 2 (n = 50) and Experiment 3 (n = 48), thus increasing our sample size up to 98 participants. We then compared RTs using a paired-samples *t*-test. This analysis revealed a significant relevance effect of 17 ms: RTs were longer when the GPS distractor had the relevant color (M = 983 ms) relative to when it had the irrelevant color (M = 966 ms), $t(97) = 2.27$, $p < .03$. Therefore, we tentatively conclude that attention capture effects observed in the present real-world visual scenes were contingent on the observer's goals, as found in basic capture experiments (e.g., Folk & Remington, 1998, 1999; Folk et al., 1992).

Note, however, that we did observe residual capture effects even for GPS color (i.e., green) that did not match the target color (red). Specifically the present-absent costs for green GPS distractors were significant in Experiment 2 (cost of 27m), $F(1, 48) = 6.78$, $p < .02$ (partial $\eta^2 = .12$), as well as in Experiment 3 (cost of 18 ms), $F(1, 46) = 7.85$, $p < .001$ (partial $\eta^2 = .15$). Thus, capture effects in the present context might be driven as much salience as by relevance. Moreover, while Experiments 2 and 3 (when analyzed separately) show trends for a stronger capture effect when the distractors are similar with the target (i.e. red) than when they are dissimilar (i.e. green), error rates analyses in both experiments show significantly higher response accuracy when distractors are similar rather than dissimilar. This raises the question about the cause(s) of the attention capture effect when distractors are similar with the targets (i.e., red). Is the capture effect due only to visual similarity between the distractor and the target, or are the RTs affected (i.e. slowed) by the need to be more concentrated on the task in order to make less mistakes (i.e. higher response accuracy) when the distractor and the target are similar? Future research is needed to determine the exact cause of this effect.

Concluding Remarks

In this study, we investigated visual attentional capture in real-world driving scenes. Participants searched for a red target letter embedded in driving scenes, while trying to ignore a salient GPS distractor that could match or mismatch the target-finding property (i.e., red). When the distractor appeared frequently and without a secondary task, participants could successfully ignore it (even when drawn in the task-relevant color). But participants had difficulty ignoring it when the GPS-distractor appeared rarely or along with a secondary task. The latter conditions are likely to prevail in many real-world situations, suggesting that capture frequently occurs. The present findings bear on the largely neglected role of attentional capture in real-world driving scenes, which has implications for roadway safety and motor vehicle design.

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[Table 1]

Table 1. Mean Reaction Time (ms) and Error Rate (%) By Distractor Presence (Present vs. Absent), Distractor Color Relevance (Relevant Red vs. Irrelevant Green) for Experiments 1, 2, and 3.

	GPS Distractor Present				GPS Distractor Absent	
	Relevant Red Color		Irrelevant Green Color		Gray Color	
	RT	ER	RT	ER	RT	ER
Experiment 1						
50% Distractor Presence	943	3.82	946	5.14	942	3.97
Experiment 2						
20% Distractor Presence	946	1.33	924	3.17	922	2.52
10% Distractor Presence	961	1.00	945	2.00	892	1.69
Experiment 3						
Single-Task Group	932	1.94	912	3.89	907	2.92
Dual-Task Group	1097	3.82	1087	4.44	1056	3.16

Note. RT = Reaction Time; ER = Error Rate.

[Figure 1]

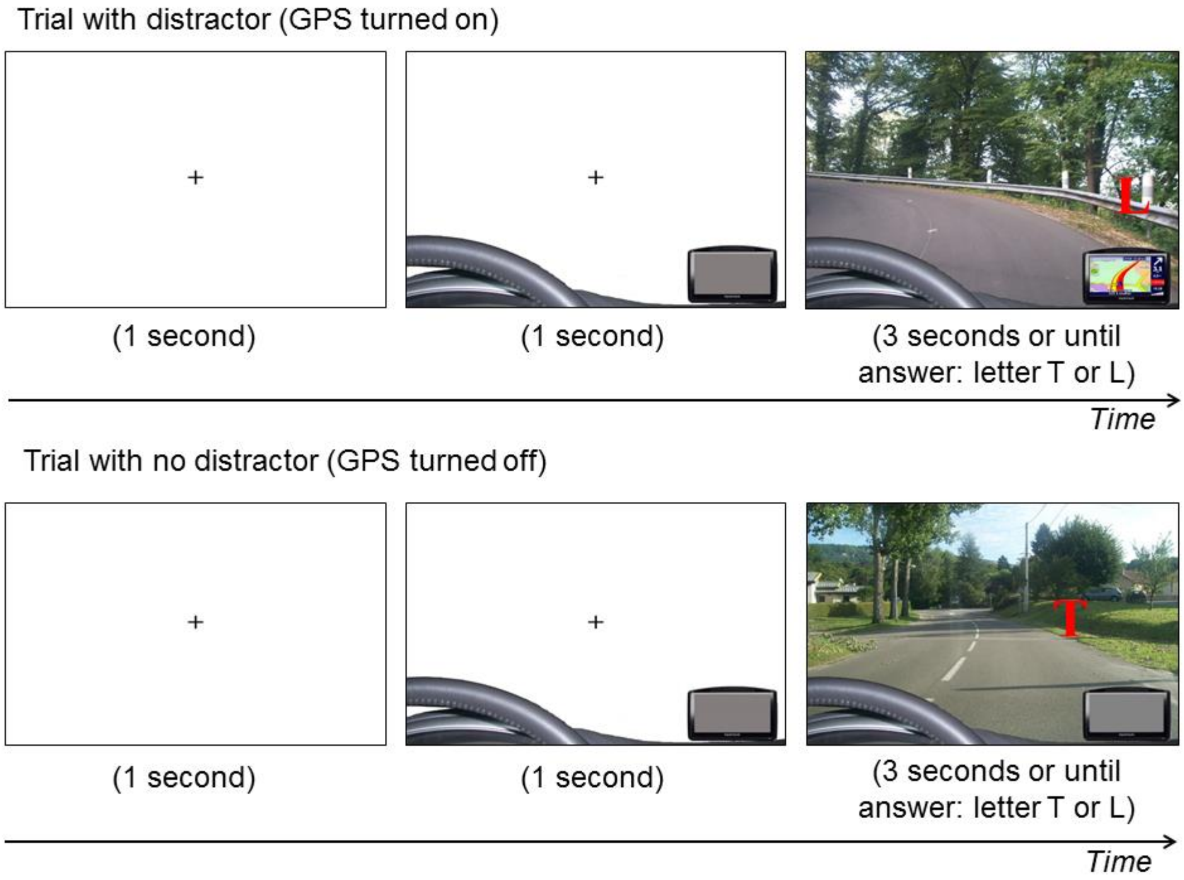

Figure 1. Timeline for a trial with GPS distractor present (top sequence) and for a trial with no GPS distractor (bottom sequence). Relative to the red target that participants searched for, the color of the GPS distractor was either relevant (i.e., red, as shown on the Figure) or irrelevant (i.e., green, not shown on the Figure). For better visibility, the size of the red target letter has been quadrupled.

[Figure 2]

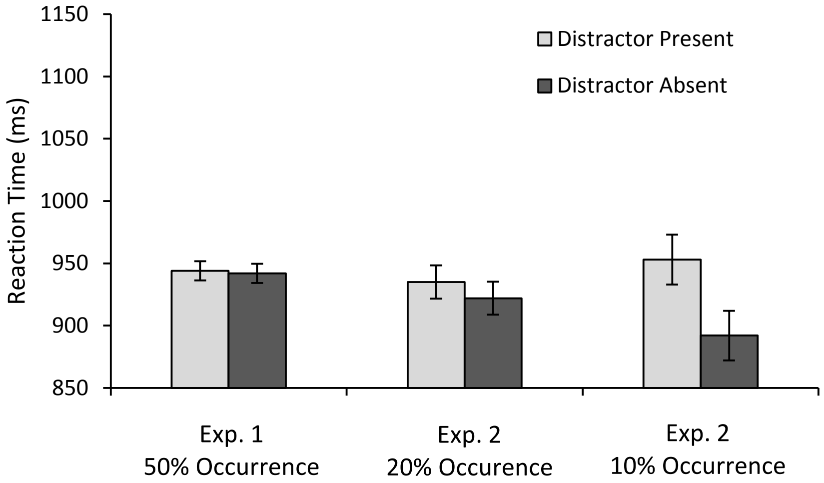

Figure 2. Reaction times as a function of GPS distractor presence (present vs. absent). In Experiment 1, GPS distractor occurred on 50% of the trials. In Experiment 2, it occurred on 20% of the trials for one half of the participants and on 10% for the other half. Error bars represent the within-subjects confidence intervals, calculated using the Cousineau-Morey method (Cousineau, 2005; Morey, 2008).

[Figure 3]

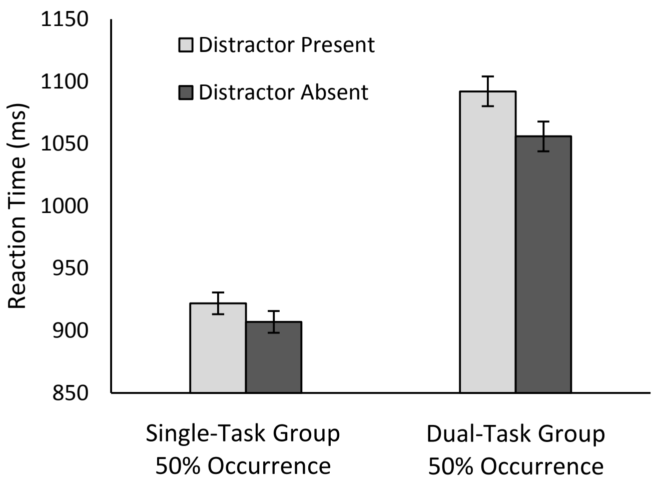

Figure 3. Reaction times in Experiment 3 as a function of GPS distractor presence (present vs. absent) for participants who ignored the auditory stream of information (single-task group) and those who simultaneously monitored it (dual-task group). Error bars represent the within-subjects confidence intervals, calculated using the Cousineau-Morey method (Cousineau, 2005; Morey, 2008).