Natural scene perception requires attention

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Abstract

Is visual attention required for visual consciousness? In the past decade, many have claimed that awareness can arise in the absence of attention. This claim is largely based on the notion that natural scene (or “gist”) perception occurs without attention. Against this, we first show that when observers perform a variety of demanding, sustained attention tasks, inattentional blindness occurs for natural scenes. In addition, scene perception is impaired under dual-task conditions, but only when using sufficiently demanding tasks. This suggests that previous studies claiming to have demonstrated scene perception without attention failed to fully engage attention and that natural scene perception does indeed require attention. Thus, natural scene perception is not a “preattentive” process and cannot be used to support the idea of awareness without attention.
A central debate in consciousness studies is whether visual attention is required for visual awareness (Block, 2005; Koch, & Tsuchiya, 2007; Lamme, 2003; O’Regan, & Noë, 2001; Posner, 1994). Classic models of vision claim that conscious perception of feature conjunctions and whole objects require attention to reach awareness (Treisman, & Gelade, 1980). A variety of psychophysical paradigms involving inattentional blindness, change blindness, and the attentional blink support this view by showing that significant events and changes will not reach awareness without attention (Joseph, Chun, & Nakayama, 1997; Mack, & Rock, 1998; Rensink, O’Regan, and Clark, 1997).

Amidst all of this research, however, one stimulus category stands out: natural scenes appear to be perceived “without attention.” This view was initially based on everyday visual phenomenology: the rest of a scene does not disappear when attention is focused on one item (Block, 1995; Wolfe, 1999). A variety of empirical studies have since supported this claim by demonstrating the robustness of scene perception. In one powerful demonstration, Mack and Rock showed that natural scenes are immune to inattentional blindness: the inability to perceive an otherwise salient stimulus because attention is directed elsewhere (Mack & Rock, 1998). Similarly, when performing demanding primary tasks, the ability to detect and classify items in a scene was not impaired under dual-task conditions (Li, VanRullen, Koch, & Perona, 2002; Rousselet, Fabre-Thorpe, & Thorpe, 2002). Furthermore, in change blindness studies, while certain objects embedded in a scene could appear and disappear for over a minute without being noticed, participants instantly noticed if the meaning or “gist” of the scene was altered (Rensink, O’Regan, and Clark, 1997; Simons & Levin, 1997). Finally, for several decades it has been known that certain types of semantic information can be extracted from a scene in under 150 ms, which is thought to be too fast for focused attention to play any substantive role (Biederman, 1972;, 1975; Thorpe, Fize, & Marlot, 1996). The apparent ability to consciously perceive scenes without
attention has been repeatedly cited as support for the notion of awareness in the absence of attention (Koch & Tsuchiya, 2007; Lamme, 2004; Rensink, 2007; Tononi & Koch, 2008; Tsuchiya & Koch 2008).

Is it the case that conscious perception of natural scenes does not require attention, or is it that natural scene perception is so efficient that it requires very little attention, making it relatively impervious to dual-task interference and thus classified incorrectly as a “preattentively processed” visual stimulus? This second possibility is hinted at in previous studies using the attentional blink (Marois, Yi, & Chun, 2004; Potter, Wyble, Pandav, & Olejarczyk, 2010), dual-task situations (Walker, Stafford, & Davis, 2008), rapid presentation (Evans & Treisman, 2005), and perception of two superimposed scenes (Neisser & Becklen, 1975), which showed that natural scene perception can be compromised under specific experimental conditions.

Here we used multiple object tracking (MOT) (Pylyshyn & Storm, 1988) and rapid serial visual presentation (RSVP) as our primary tasks and found that natural scene perception was not immune to inattentional blindness and was impaired under dual-task conditions. Importantly, we found that dual-task interference only occurs when the primary task is sufficiently demanding. Taken together, these results demonstrate that attention is required to consciously perceive natural scenes, and suggest that the tasks used in previous studies were not demanding enough, allowing for excess attention to be allocated to the natural scene. Furthermore, the present findings pose a major challenge for models of consciousness that claim awareness can arise without attention. Indeed, without the notion of preattentive scene perception, there is no longer any empirical evidence of consciousness in the absence of attention.
General Methods

Participants.

87 total participants were tested (ages 18 - 37). All reported normal or corrected-to-normal visual acuity. All participants gave informed consent to participate, which was approved by the Harvard University Human Subjects Institutional Review Board, and were paid $10/hour.

Apparatus.

Stimuli were presented on a 24-inch color iMac running OS X 10.5.6 and were programmed in MATLAB 7.5 (The MathWorks) using the Psychophysics Toolbox routines (Brainard, 1997; Pelli, 1997). Monitor spatial resolution was set at 1920 x 1200 pixels with a refresh rate of 60 Hz. Observers were seated approximately 57 cm from the monitor so 1 cm on the screen subtended one degree of visual angle.

Stimuli.

For MOT conditions, identical discs moved while images rapidly changed in the background. For the RSVP task, letters and digits were presented with background images changing in the background. Background masks were colored checkerboard that were either 4 x 4, 8 x 8 equal sized boxes, or a combination of both sized boxes generated by randomly assigning RGB values to the individual squares (see Supplementary Material for examples). All masks were grouped together and presented in a randomized order. For all experiments, scenes were always the second to last image presented and were followed by one mask. In every experiment, the size of the background images was constant and took up 21° of visual angle with the MOT discs and RSVP stream being drawn in a 20.5° x 20.5° imaginary window.
**Experiment 1: Inattentional Blindness for Natural Scenes**

It has previously been claimed that inattentional blindness does not occur for natural scenes (Mack & Rock, 1998). It remains possible that previous research did not fully engage attention with the central tasks, so in the current study, we employed paradigms that require continuous, sustained attention, and therefore are likely to be more attentionally demanding than tasks employed in previous work. For Exp. 1A, participants tracked four of eight identical black discs moving at 10.5 deg/s (see Fig. 1A). The MOT task has two advantages over previous tasks: (1) tracking requires continuous, sustained attention, because even a momentary lapse in attention can cause observers to lose track of targets without any possibility of recovery, and (2) the load of the tracking task can be systematically varied by adjusting, say, the speed of the targets. For Exp. 1B, we used an RSVP task (see Fig. 1C), which also requires sustained attention, to ensure that the effects we obtained were because of attentional limitations, rather than a specific artifact of motion processing.

In Exp. 1A, the scenes came from one of five categories (beach, building, highway, indoor, mountain). In Exp. 1B, the scene images contained animals and vehicles rather than the five categories from Exp. 1A. This was done because previous studies cited to support the claim of scene perception without attention had participants determine whether a scene contained an animal (Li, VanRullen, Koch, & Perona, 2002; Rousselet, Fabre-Thorpe, & Thorpe, 2002; Thorpe, Fize, & Marlot, 1996), or a vehicle (Li, VanRullen, Koch, & Perona, 2002; Fei-Fei, VanRullen, Koch, & Perona, 2005).
Methods

Multiple-Object Tracking (MOT) Task. Each trial began with eight identical discs randomly placed on the screen. Four discs turned red for three seconds to identify them as targets to be tracked. All items then moved for a random duration uniformly distributed between 3 and 6 seconds in 100 ms steps (e.g. 3000 ms, 3100 ms, 3200 ms, etc.). (See Supplementary Methods for information on the motion algorithm.) The background checkerboard changed every 67 ms (Fig. 1A). At the end of the trial, all items stopped moving and participants clicked on each of the targets with the mouse. Feedback on the trial was given immediately. Discs were initially presented with a single checkerboard presented in the background.

Rapid Serial Visual Presentation (RSVP) Task. For Exp. 1B, participants’ task was to count the number of times a digit was presented in a stream of letters. At points where the background and letter overlapped, the pixel value was set to .35 times the background and .65 times the letter so that the letters appeared transparent and the background could be seen through the letters. Whenever a scene was presented, and during the mask that followed it, only a letter could be present, never a target digit. When no target scene was presented, the last two images were always letters. Distractors were randomly drawn from: A, B, C, D, G, H K, M, N, O, P, Q, R, T, U, V, W, X, Y. Target digits were 1, 2, 4, and 5. No target digit was ever drawn twice in a given trial. Thus, there could be between 0-4 target digits presented in a trial. Trials lasted between 1,200 and 1,700 ms with between 12–17 images (100 ms per image) presented on each trial. The length of trials was uniformly distributed so that each trial length occurred the same number of times. At the end of each trial, participants provided their answer to the digit task by pressing the number 0, 1, 2, 3, or 4 on the keyboard. Immediate feedback was given at the end of the trial.

Inattentional blindness procedures. For trials 1-4, participants performed the given task (MOT task in Exp. 1A, RSVP task in Exp 1B) and gave their response at the end of each trial. On
the 5th trial, participants provided no response for the given task and instead were immediately asked about the presence of a scene. On these trials, participants were asked a series of questions from a script (see Supplementary Material for the script that was used).

Participants who accurately identified the scene after being asked if they noticed anything different on that trial were classified as having “immediately saw the scene” (Figs. 1B & 1D). Participants who correctly labeled the scene after being asked any of the following questions were classified as having “classified the scene after questions.” Questioning stopped if the participant classified the scene before the last question was asked. It was only participants who were asked all questions and were not able to classify the scene correctly when given an alternative forced choice task who were classified as having “never saw the scene.” It was from this group that we determined rates of inattentional blindness.

For Exp. 1A, 25 participants were recruited, while another 30 participants were recruited for Exp. 1B. In Exp. 1B, six different images were used as the critical stimuli; three containing an animal, three a vehicle. Each photo was presented to 5 participants (i.e. 5 saw the image with a deer, 5 the image with a bird, 5 the image with a pickup truck, etc.).

Results and Discussion

Experiment 1A: MOT and Scene Detection. In Exp. 1A, 64% of participants experienced complete inattentional blindness (Figs. 1B). Meanwhile, only 18% of participants detected the scene immediately. By using a sustained, attentionally demanding task, we were able to induce inattentional blindness for natural scenes in a large proportion of participants.

After the critical trial, participants completed 20 trials in which they attended to the background while ignoring the moving discs and identified which type of scene, if any, was
present. This was done to ensure that the inattentual blindness rates were not due to the scenes being imperceptible. In this condition, participants successfully detected and classified the scenes 96% of the time.

Experiment 1B: RSVP and Scene Detection. For Exp. 1B, on the fifth trial, a natural scene unexpectedly replaced the second-to-last mask — checkerboards in this case. 50% of participants experienced total inattentional blindness, while 23% of participants were able to identify the category immediately (Fig. 1D).

Participants then completed 20 trials in which they attended to the background and ignored the RSVP stream. This was done to ensure that the rate of inattentional blindness was not due to participants being unable to see the scenes through the letters. In this case, participants successfully noticed and classified the scenes 93% of the time. This strongly suggests that our inattentional blindness results were specifically because of attentional allocation.

The combined results of Exp. 1 stand in stark contrast to Mack and Rock’s results, which did not find a single instance of inattentional blindness for scenes when using a presentation time of only 30 ms (compared to our 67 and 100 ms respectively). It is possible that our use of preceding masks is an important different between our experiments. By not having masks precede the critical stimuli, it is possible that the sudden onset of that stimuli captured attention, allowing them to be perceived. By this logic, our preceding masks minimized the transient/bottom-up signal caused by the presentation of the scene. In addition, it is also likely that their study did not obtain our results because the primary task was not demanding enough. When the task demands are adjusted so that attention is properly and continuously engaged, it becomes clear that natural scene perception is not immune to inattentional blindness.
**Experiment 2: Multiple Object Tracking Impairs Natural Scene Perception**

Previous studies have reported that scene perception is unaffected by dual-task interference (Fei-Fei, VanRullen, Koch, & Perona, 2005; Li, VanRullen, Koch, & Perona, 2002; Rousselet, Fabre-Thorpe, & Thorpe, 2002). Exp. 2 tested the possibility that dual-task interference depends on the demands of the competing task. Thus, we varied the difficulty of the primary task and measured what effects, if any, this had on scene perception. In the dual-task condition, participants performed the MOT task and simultaneously performed a scene detection/classification task. Task difficulty was manipulated by adjusting the speed since object speed has been known to lead to variations in performance (Alvarez & Franconeri, 2007).

If scene perception requires attention, but only a minimal amount, tracking and scene perception should show no interference at slower tracking speeds because the easy tracking task will leave enough resources to complete the scene perception task (Lavie, 2005; Yi, Woodman, Widders, Marois, & Chun, 2004). However, at faster tracking speeds, little or no resources will be available for the scene perception task, and a cost should be observed for one or both tasks.

**Methods**

*Participants.* Eight participants were used for this experiment.

*Procedure.* The methods and parameters of Exp. 2 were identical to those of Exp. 1A. The only difference is that participants knew scenes would be regularly presented and were instructed to detect and classify those scenes. For the tracking only task, participants were instructed to
ignore the background stream, and a scene was never presented in the background.¹ When scene detection was the only task, participants were told to ignore the moving discs and focus only on the background. In the dual-task condition, both were performed simultaneously. This procedure was done twice, with the discs moving at 4.5 deg/s and 10.5 deg/s (for both single and dual-task condition). The masks used in this experiment were colored checkerboards changing every 67 ms. The rate at which the background images changed was held constant throughout and did not change when the speed of the MOT task was adjusted. At the end of dual-task trials, participants first clicked on the target dots and then provided an answer for the scene task using the keyboard. Each condition was comprised of 80 trials with six blocks (480 total trials).

**Results and Discussion**

When the discs moved at the slower speed, scene perception was unimpaired while simultaneously performing the MOT task ($t(7) = 1.17$ $p = 0.28$) (Fig. 2A). Taken alone, this lack of interference would suggest that there is no attentional requirement to scene perception. However, when speed increased, there was a cost for the scene task ($t(7) = 3.5; p < 0.01$). This pattern also held in the MOT task (Fig. 2B). Tracking performance was not different in the single and dual-task conditions at the slower speed ($t(7) = 1.09, p = 0.31$), but was different at the faster speed ($t(7) = 2.9, p < 0.05$).²

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¹ A control experiment was run to ensure that single-task tracking is unaffected by the presence or absence of a scene in the background. A group of control participants completed 60 trials in which half of the trials contained no natural scene in the background stream and the other half had a scene from one of the five categories presented as the second to last image in the stream. In this case, there was no difference in performance for trials in which a scene was present (76% correct SEM = 2.8) from trials when no scene was present (74% correct SEM = 3.6) ($t(7) = .35, p = 0.74$).

² 6 separate participants also performed the MOT and scene task in a dual-task condition. The only change to the procedures was that rather than using the five category scene stimuli, we used a set
The fact that the tracking performance was also affected under dual-task conditions suggests that scenes not only require attention, but these requirements are substantive since attention must be allocated from other tasks in order to complete the scene task. These results suggest that previous research claiming to show that focused attention is not needed for scene perception were likely obtained because attention was not sufficiently engaged.

**Experiment 3: Performing an RSVP Task Impairs Natural Scene Perception**

Here we sought to extend the findings from Exp. 2 using the RSVP paradigm of Exp. 1B. The task was to count the number of digits presented while simultaneously performing either a categorization or detection task on the background scene. For the first categorization condition, observers classified which of five scene categories was presented (mountain, beach, highway, indoor, building). For the second detection condition, participants determined whether the scene did or did not contain animals.

**Methods**

Eight participants performed the RSVP task while simultaneously monitoring the background for a natural scene. Once again, these tasks were done in single and dual-task conditions. For the first condition, the scene stimuli used were the five scene categories from earlier experiments. For the second condition, participants performed a go/no-go categorization task in which they reported whether the presented photograph contained an animal. Scenes without of scenes that either did or did not contain an animal. Participants performed the MOT and scene tasks in both single and dual-task settings with the dots moving at the faster speed (10.5 deg/sec). Once again we found a significant drop in performance from the single to dual-task situations for both the MOT ($t(5) = 3.65, p < 0.05$) and scene tasks ($t(5) = 2.72, p < 0.05$).
an animal were selected so that the scenes could easily contain an animal but simply did not (e.g. a forest or backyard with no animal present – See Supplementary Material for example stimuli).

For both conditions, trials lasted between 1,200 and 1,700 ms (100 ms per item) with a total of between 12-17 images presented on each trial. The length of trials was uniformly distributed so that each trial length occurred the same number of times for each subject. For the three blocks, (single task scene single task RSVP, and dual-task) participants completed 120 trials (360 total) for condition A and 100 trials (300 total) for condition B. The order in which these blocks were completed was counterbalanced between subjects. During the dual-task condition, a scene was presented 50% of the time. For each condition, the type of stimuli presented was uniformly distributed throughout. Thus, within a condition, every scene category was presented equally often.

Results and Discussion

When using the five categories, performance was inferior in the dual-task condition for both the scene task ($t(7) = 7.05, p < 0.001$) and the RSVP task ($t(7) = 4.43, p < 0.01$) (Fig. 3A). When using the animal/no animal task, performance was again inferior in the dual-task condition for the scene task ($t(7) = 4.76, p < 0.01$) and the RSVP task ($t(7) = 4.96, p < 0.01$) (Fig. 3B). Thus, dual-task costs are not only observed when motion processing is involved, but appear to be observed generally when the secondary task is attentionally demanding. Additionally, the use of a go/no-go task here demonstrates that the difference in results between the current study and previous studies (Li, VanRullen, Koch, & Perona, 2002; Rousselet, Fabre-Thorpe, & Thorpe, 2002; Thorpe, Fize, & Marlot, 1996) cannot be attributed to a difference in task used to assess scene perception. In fact, we found here that the five-category task was more resistant to dual-task interference (an 11% decrease in performance) than the animal/vehicle task (a 26% decrease). This
result suggests that the amount of attention required to identify objects in scenes is greater than the amount required for identifying a scene’s gist. However, whether this is generally true cannot be firmly concluded without further research.

**General Discussion**

The relationship between attention and awareness is one of the most hotly debated issues in neuroscience and psychology (Block, 2005; Koch, & Tsuchiya, 2007; Lamme, 2003; Mack & Rock, 1998; O’Regan, & Noë, 2001). The predominant view is that certain classes of stimuli, such as natural scenes, can be perceived without attention — “preattentively.” What reason is there to believe in awareness without attention? The initial result used to support this position stemmed from the fact that basic visual features “pop-out” in visual search (Treisman & Gelade, 1980). However, it has since been shown that attention plays an important role in feature perception since features can be missed during the attentional blink (Joseph, Chun, & Nakayama, 1997) and that pop-out does not occur when spatial cues direct attention away from the target location (Theeuwes, Kramer, & Atchley, 1999).

More recently, natural scene perception has been repeatedly cited as the primary example of awareness without attention (Koch & Tsuchiya, 2007; Lamme, 2004; Rensink, 2007; Tononi & Koch, 2008). Here we tested this view, using multiple types of attentionally demanding tasks and found in several experiments that observers can be rendered inattentionally blind to natural scenes and scene perception can be impaired under dual-task conditions. Thus, natural scenes do require attention to be perceived.

It should be noted that in dual-task situations, while performance with the scenes dropped, they remained well above chance. It is possible that our primary tasks were not sufficiently
difficult and there were still resources that could be directed towards the scene. However, it is also possible that some, but not all, aspects of scene perception require attention and it was those aspects that were affected in the current study. Future research will be needed to identify if there are in fact any particular aspects of scene perception that are systematically immune to attentional interference.

While attention may be necessary for the conscious perception of natural scenes, several pieces of evidence suggest that processing to high levels can still occur in the absence of both attention and/or awareness. Recently, Serre and colleagues (2007) have shown that a purely feedforward architecture can accurately predict the level and pattern with which human observers perform on a rapid animal vs. non-animal categorization task. In addition, it has been repeatedly demonstrated that ultra-rapid saccades towards a scene containing an animal, vehicle, or face can occur after only 100-130 ms (Crouzet, Kirchner, & Thorpe, 2010; Kirchner & Thorpe, 2006). Thus, certain behavioral decisions concerning the nature of a scene can be biased in one way or another without conscious awareness (i.e. the subject is predisposed to looking, say, right, even without awareness of the scene to the right). This idea is consistent with research showing that subconscious information can nevertheless influence subsequent behaviors and decisions (Luck, Vogel, & Shapiro, 1996; Naccache & Dehaene, 2001). It should be stressed that this notion is in no way inconsistent with the present findings: while unconscious, high-level scene processing can occur without attention, attention is necessary for the natural scene to reach conscious awareness.

It is worth stressing that in previous studies (Li, VanRullen, Koch, & Perona, 2002; Rousselet, Fabre-Thorpe, & Thorpe, 2002), task difficulty was set so that primary task performance was well below 100% correct (i.e. ceiling). The logic being that since performance was below ceiling, attention was fully engaged by the task. Therefore, tasks that can be completed in addition to the primary task are completed without attention. However, the present study
questions this logic by showing that adjusting performance to below ceiling in this manner is not enough to ensure that attention is entirely occupied by the primary task. In the low load condition of Exp. 2A, participants always performed below ceiling for both the tracking and the scene detection tasks (Fig. 2A). Nevertheless, it was only with the higher tracking load that there was a mutual cost for both tracking and scene performance. The insight that task performance cannot be used as a one-to-one index of available attentional resources has important implications for future research, particularly if the goal is to understand the attentional requirements of perceptual processes. This suggests that there may be an excess of attentional resources even when the primary task is quite challenging (Norman & Bobrow, 1975). Indeed, it might even reflect an actual inability to allocate more resources to a task despite their availability (Kahneman, 1973). This is merely speculative at this point and future research will have to address this important topic. For our present purposes, the important point is that “below ceiling” might not be sufficient to claim that attentional resources are fully consumed.

In sum, the present results indicate that natural scene perception is so efficient and requires so little attention that the perceptual system must be properly taxed if this attentional cost is to be identified. Models of awareness that seek to dissociate attention and awareness (Block, 2005; Koch, & Tsuchiya, 2007; Lamme, 2003) cannot use gist perception or the perception of objects, such as animals, in a natural scene as an example of awareness without attention. Indeed, without evidence of natural scene perception without attention, no evidence of awareness without attention currently exists. While there is good reason to believe in attention without awareness (Naccache, Blandin, & Dehaene, 2002), there is no evidence for awareness without attention. In conjunction with previous research, the present results support the claim that visual attention is required for visual awareness.
References


Rensink, R.A., O’Regan, J.K., & Clark, J.J. (1997) To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science, 8*, 368-373.


Figure Captions

Figure 1. Experimental design. (A) Example of a critical trial with randomly colored checkerboard masks (presented every 67 ms) with MOT task. (B) Rates of inattentional blindness and percentage correct in perceiving and identifying background scenes when instructed to do so. (C) Example of critical trial with RSVP task (images presented every 100 ms). (D) Rates of inattentional blindness and percentage corrected in perceiving and identifying background scenes per instructions with RSVP task.

Figure 2. Exp. 2 results. Single and dual-task (A) natural scene classification and (B) tracking performance as a function of the speed of the moving discs in MOT task.

Figure 3. Exp. 3 results. Single and dual-task accuracy for the (A) Number task (how many numbers were present?) and scene classification (which, if any, of the scene categories were present ?) using the 5 categories and (B) animal/no animal discrimination task (did the scene contain an animal or not?).
Figure 1

A

B
attend to tracking (ignore background)

attends to background (ignore tracking)

Inattentinal blindness

Immediately saw the scene

C

D
attend to letter stream (ignore background)

attend to background (ignore letter stream)

Classified the scene after questions
Figure 2

**A, dual task scene detection**

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<td>Fast tracking</td>
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n.s., * indicates significance.

**B, dual task MOT**

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n.s., * indicates significance.

Figure 3

**A, 5 categories**

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<tr>
<td>Scene task</td>
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* indicates significance.

**B, animal/vehicle**

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