American Psychological Association

Journal of Experimental Psychology:
Human Perception and Performance

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0096-1523/18/$12.00

2018, Vol. 44, No. 12, 1865–1883
http://dx.doi.org/10.1037/xhp0000574

How Feature Relationships Influence Attention and Awareness: Evidence From Eye Movements and EEG

Aimee Martin and Stefanie I. Becker
The University of Queensland

Many everyday tasks require selecting relevant objects in the visual field while ignoring irrelevant information. A widely held belief is that attention is tuned to the exact feature value(s) of a sought-after target object (e.g., color, shape). In contrast, subsequent studies have shown that attentional orienting (capture) is often determined by the relative feature(s) that the target has relative to other irrelevant items surrounding (e.g., redder, larger). However, it is unknown whether conscious awareness is also determined by relative features. Alternatively, awareness could be more strongly determined by exact feature values, which seem to determine dwelling on objects. The present study examined eye movements in a color search task with different types of irrelevant distractors to test (a) whether dwelling is more strongly influenced by exact feature matches than relative matches, and (b) which of the processes (capture vs. dwelling) is more important for conscious awareness of the distractor. A second experiment used an electrophysiological marker of attention (N2pc in the electroencephalogram of participants) to test whether the results generalize to covert attention shifts. As expected, the results revealed that the initial capture of attention was strongest for distractors matching the relative color of the target, whereas similarity to the target was the most important determiner for dwelling. Awareness was more strongly determined by the initial capture of attention than dwelling. These results provide important insights into the interplay of attention and awareness and highlight the importance of considering relative, context-dependent features in theories of awareness.

Public Significance Statement

Our conscious perception is severely capacity-limited, causing manifold failures in noticing important changes, which can lead to mishaps and accidents. What factors determine what we will be consciously aware of? The current study shows that we are most likely to notice items that match the relative features of a sought-after target (e.g., bluest item), as these attract attention most strongly. By contrast, items that perfectly match the target (e.g., greenish-blue item) lead to prolonged dwelling on an item, but these processes do not have a large impact on awareness. These results are at odds with current feature-based accounts, which predict attention and awareness from the exact feature values of items—specifically, by assessing how similar items are. Instead, the current results support a relational account of awareness, which proposes that attentional capture and awareness are both determined by the relative, context-dependent features of items (e.g., bluest, greenest).

Keywords: attention, relational account, awareness, eye movements, N2pc in EEG

Our visual system is constantly subjected to more stimuli that can be processed at any given moment in time. Attention determines which subset of stimuli is processed further and gates access to awareness. Thus, it is important to understand what guides this selection process. Previous studies have shown that attention can be guided by two different processes: First, salient stimuli (i.e., stimuli with a high feature contrast) can automatically attract attention in a purely stimulus-driven manner, irrespective of the observers' goals (Anderson, Ort, Kruijne, Meeter, & Donk, 2015; Parkhurst, Law, & Niebur, 2002; Siebold & Donk, 2014; Theeuwes, 2010). Second, task demands (such as the intention to find a particular item) can modulate allocation of attention in a top-down manner. For instance, when searching for a predefined target, items that match the sought-after target feature will usually attract attention more strongly than salient irrelevant items that do not match the target (Becker, Harris, Venini, & Retell, 2014; Chen & Zelinsky, 2006; Folk, Remington, & Johnston, 1992; Hwang, Higgins, & Pomplun, 2009; Wolfe, 1994). Apparently, we can "tune" attention to the target feature, or a mental representation of the target (target template), which guides attention to items that match the target feature (Ansorge & Becker, 2014; Bacon & Egeth, 1994; Duncan & Humphreys, 1989; Irons, Folk, & Rem-

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Aimee Martin and Stefanie I. Becker, School of Psychology, The University of Queensland.

This research was supported by an Australian Research Council (ARC) grant to Stefanie I. Becker, DP170102559, and an ARC Future Fellowship awarded to Stefanie I. Becker, FT130101282. In addition, Aimee Martin was supported by the Australian Government Research Training Program.

Correspondence concerning this article should be addressed to Aimee Martin, School of Psychology, The University of Queensland, McElwain Building, St Lucia, QLD 4072, Australia. E-mail: aimee.martin@uqconnect.edu.au

ington, 2012; Müller, Heller, & Ziegler, 1995; Navalpakkam & Itti, 2005).

Tuning Attention to Specific Features Versus Relations

According to the currently prevalent theories of attention, attention will usually be tuned to the target feature value in visual search. Hence, if we are searching for an orange, attention will usually be tuned to the features of "orange" and possibly, "round" (Folk & Remington, 1998; Martinez-Trujillo & Treue, 2004). According to this feature-similarity view, only stimuli that share the feature values of the target should attract attention (Born, Ansorge, & Kerzel, 2012; Everaert, Spruyt, & De Houwer, 2013; Folk & Remington, 1998; Treue & Martínez Trujillo, 1999). In line with this view, multiple visual search studies found that an irrelevant distractor only attracted attention when it was similar to the target, not when it was dissimilar. For instance, in search for a red item, a red distractor was regularly reported to capture attention and the observers' gaze, whereas an equally salient green or blue distractor failed to attract attention (e.g., Becker, Lewis, & Axtens, 2017; Becker & Lewis, 2015; Becker, Ansorge, & Horstmann, 2009; Folk & Remington, 1998; Ludwig & Gilchrist, 2002). These findings clearly show that visual selection, as mediated by attention and gaze shifts, are strongly modulated by the search task and the top-down goals of the observer.

However, attentional capture by target-matching items is also consistent with a slightly different mechanism of top-down tuning. In fact, tuning attention to the exact target feature value may not be the most successful strategy, as the exact color, size and orientation of an item varies a lot with the lighting conditions and perspective and distance to the observer. In a more variable environment, it may be more beneficial to tune attention to context-dependent features and select the stimulus that is the largest, reddest, or darkest item in the visual field. Such a context-dependent tuning mechanism has been proposed by Becker (2010) within the framework of a relational account of attention and eye movements. According to the relational account, attention is not necessarily tuned to a particular feature value but can instead be tuned to the relative target feature, that is, the feature that the target has relative to other stimuli in the surrounding area (e.g., larger, redder, darker; Becker, 2010; Becker, Folk, & Remington, 2010). As a consequence, even a target-dissimilar distractor can strongly attract attention, provided that it matches the relative feature of the target (e.g., reddest, darkest, or largest item). For example, if an observer is searching for a blueish green (aqua) colored car in a parking lot containing mostly green other cars, attention would be tuned to bluer or the bluest item (as the aqua car differs in the direction of bluer from the other green cars). As a consequence, a deep blue car would attract attention most strongly, as it is the bluest item in the visual field.

In line with this prediction, several studies showed that a target-dissimilar distractor that matches the relative features of the target (e.g., bluest) can attract attention and the gaze more strongly than target-similar distractors that have the same attributes as the target (e.g., aqua; e.g., Becker, 2010; Becker et al., 2010, 2014; Harris, Remington, & Becker, 2013). Critically, a target-similar cue also fails to attract attention if it does not match the relative attributes of the target (e.g., Becker, Folk, & Remington, 2013; Becker, Harris, York, & Choi, 2017; Harris et al., 2013). These results indicate that attention is usually tuned to the relative feature of the target, and that capture by target-matching items is really because they usually (also) match the relative attributes of the target (Becker et al., 2010, 2013, 2014).

A limitation of previous studies that tested the relational account is, however, that the effect of top-down tuning was assessed only on early, attentional processes, as indexed by the probability of selecting an irrelevant distractor as the first item (or with the first eye movement; e.g., Becker, 2010; Becker, Grubert, & Dux, 2014). The processes determining visual selection could however differ from later, postattentional selection that determine how long we dwell on an object. The dwell time presumably reflects the time needed to perceptually process and identify an object (Becker, 2011; Duncan, 1980; Horstmann, Becker, & Ernst, 2016; Theeuwes, 2010; Venini, Remington, Horstmann, & Becker, 2014) and may depend more on the exact feature value of an object and its match to a sought-after object rather than its relative, context-dependent features.

In fact, there is some tentative evidence that later, postattentional processes operate on exact feature values, as distractors that match the exact feature value of the target were occasionally found to hold attention for longer (as reflected in prolonged dwell times of eye fixations; Becker et al., 2014). Specifically, an eye tracking study reported that dwell times tended to be longer for a target-similar distractor than for a relationally matching, target-dissimilar distractor (Becker et al., 2014). Importantly, this result was observed despite the fact that the relationally matching distractor attracted the observer's gaze more strongly than the target-similar distractor, indicating that attention was tuned to the relative color of the target (e.g., bluer) rather than its specific feature value (e.g., aqua).

This is an interesting finding, because it implies that transient, fast orienting of attention (i.e., capture) may be determined by factors that are different from those that determine feature processing (i.e., dwelling). Importantly, most previous studies cannot distinguish between initial capture and dwelling, as they predominantly measured distractor interference by response times (RTs), which reflect the combined effects of selection and dwelling on the distractor (Becker et al., 2013; Folk & Remington, 1998; Harris et al., 2013). Given that attention has a gatekeeper role for conscious awareness, one important question arising from the possible dissociation of orienting versus dwelling is whether our awareness of visual stimuli is more strongly determined by initial attention shifts or postattentional selection?

Attention and Awareness

Awareness usually refers to the totality of contents (internal and external) that we are conscious of at any given time, and it is typically measured by probing the observer's knowledge of specific stimuli or events (i.e., "reportability"; e.g., Most, Scholl, Clifford, & Simons, 2005; for a review on different states of awareness see Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008). As it is often impossible or impractical to probe an observer's knowledge at the same time that a specific event occurs, the observer's reports often most directly reflect the contents of memory (visual short-term memory [VSTM]; Luck & Vogel, 2013). However, as reportability of past events is often still the best available method to probe (past) contents of awareness, we will use these notions interchangeably here.

Previous studies have shown that attention gates access to awareness, such that attended stimuli are remembered much better than unattended stimuli, which are often not reportable (Markant & Amso, 2014; Rutman, Clapp, Chadick, & Gazzaley, 2010; Schmidt, Vogel, Woodman, & Luck, 2002; Zanto, Rubens, Thangavel, & Gazzaley, 2011).

Higher awareness of attended stimuli is believed to predominantly involve VSTM (e.g., Gayet, Paffen, & van der Stigchel, 2013), with attention modulating the likelihood of stimuli being encoded (Schmidt et al., 2002; Williams & Woodman, 2012; Zhang & Luck, 2008), and/or facilitating their transfer to VSTM (e.g., Schmidt et al., 2002). Some researchers even proposed that attention and VSTM is part of a common mechanism (e.g., Cowan, 2001; Gazzaley & Nobre, 2012; Olivers, Meijer, & Theeuwes, 2006; Rensink, 2002; Schmidt et al., 2002; Wheeler & Treisman, 2002), and it is widely assumed that attending to an item leads automatic encoding of it into VSTM (e.g., Olson, Moore, & Drowos, 2008; but see Tas, Luck, & Hollingworth, 2016). Although the latter claim is still debated, there is a large consensus that VSTM plays a pivotal role for awareness, and that attention and VSTM are closely linked, in that attending to an item will often lead to it being encoded into VSTM (e.g., Gazzaley & Nobre, 2012; Tas et al., 2016). However, so far it is unclear which attentional processes mediate awareness. Specifically, we can ask whether the fleeting, short-lived act of selecting an item is already sufficient for it to be encoded into VSTM, or whether this requires sustained feature processing, as reflected in dwelling.

A study by Schmidt and colleagues (2002) showed that attending to a stimulus will increase awareness for it even when attention was reflexively deployed (captured) in a stimulus-driven manner (e.g., Schmidt et al., 2002). This result indicates that selection of a stimulus, however briefly, is already sufficient to mediate awareness. However, the study did not compare fast transient selection to more sustained processing of the item, and, therefore, the possible contribution of dwelling to awareness is still unclear.

Other studies reported that awareness rates are higher for task-relevant items and higher for task-irrelevant items that are similar to targets than for target-dissimilar items (e.g., Eitam, Yeshurun, & Hassan, 2013; Most et al., 2005; but see Störmer & Alvarez, 2014). In addition, it has been shown that inhibition of task-irrelevant features can block access to awareness and lead to higher rates of inattentional blindness (IB; e.g., Drew & Stothart, 2016). Again, however, these studies did not distinguish between transient selection of an item (capture) and postattentional selection (dwelling), so that it is unclear whether awareness is mediated by early processes that operate mostly on the relative features of objects, or postselectional processes that could potentially rely more on feature-based processes and depend on feature similarity.

The similarity manipulations in previous studies also did not distinguish between relative feature matches or similarity and are therefore consistent with attention being tuned to the relative features of an object rather than its exact feature value (e.g., Drew & Stothart, 2016; Most et al., 2005). Only a single study tested whether awareness could be better predicted by a feature-based account or the relational account. Goldstein and Beck (2016) used a dynamic IB task and compared awareness rates of an unexpected item that could either match the exact feature value of the to-be-attended items or their relative feature. They found that an unexpected item that was dissimilar from the to-be-attended items but matched their relative feature (i.e., darker) was noticed significantly more frequently than all other items (Goldstein & Beck, 2016; see also Drew & Stothart, 2016 and Most et al., 2005). This led Goldstein and Beck (2016) to propose that awareness of unexpected items is more strongly mediated by the relative features of the unexpected item rather than by the physical similarity of the unexpected item with the to-be-attended items.

Another interesting finding of the IB studies was that the unexpected item was noticed with higher frequency when it was visually salient (i.e., when it had a high feature contrast such as a red item among black-and-white other items; Goldstein & Beck, 2016; Most et al., 2005). As previous studies asserted that salient items can automatically attract attention even without a top-down set to search for salient items (e.g., Theeuwes, 1992), the authors concluded that awareness of the unexpected item depended strongly on whether it attracted attention or not (Goldstein & Beck, 2016; Most et al., 2005). Thus, awareness of the item was hypothesized to depend on whether it initiated a fast attention shift to its location. Critically, however, this cannot be asserted with certainty, as the studies could not distinguish between attentional orienting and prolonged dwelling on the item (e.g., after it was accidentally selected). Moreover, in the IB studies, the test object is always an unexpected item, and there is evidence that an unexpected item is always processed at a greater depth and for longer durations than familiar items (e.g., Horstmann et al., 2016). Thus, the two questions of whether awareness is more strongly mediated by visual selection or postattentional selection, and whether these are mediated by the same or different factors, are still unresolved.

The Present Study

The aims of the present study were multifold. In a first experiment, we sought to establish whether attentional capture and postattentional selection are indeed sensitive to different factors (relational matches vs. exact feature matches). As mentioned above, a previous study (Becker et al., 2014) found tentative evidence for such a dissociation, but the effects did not reliably occur across all conditions and the effect size was quite small, so that it is still an open question whether dwelling is indeed determined by feature-specific processes. A second major aim of Experiment 1 was to assess whether awareness of an irrelevant item depends more on initial attentional capture or dwelling. To address these research questions, we tracked the eye movements of observers during a visual search task with an irrelevant distractor that could match either the relative or exact features of the target (or failed to match either property). To distinguish between attentional capture and dwelling, we measured the proportion of first eye movements to the distractor and the distractor dwell times, respectively (for a similar procedure, see, e.g., Becker et al., 2014; Hwang et al., 2009). Awareness of the distractor was measured on a small subset of rare trials, and awareness scores were correlated with the initial attentional capture and dwelling measures to identify the best predictor for awareness.

In a subsequent experiment (Experiment 2), we measured the N2pc in the electroencephalogram (EEG) of observers in a similar, covert attention task in which observers were not allowed to make any eye movements. The N2pc is defined as an enhanced contralateral negativity over posterior scalp electrodes (PO7/8) that occurs ~200–300 ms after stimulus onset, and has been established as the primary electrophysiological marker for spatial attention (e.g., Eimer, 1996; Luck & Hillyard, 1994). The purpose of Experiment 2 was to test whether the results of Experiment 1 generalize to conditions of covert attention shifts, when observers are not allowed to move their eyes and to determine whether the N2pc can act as a predictor for awareness. To assess possible effects of bottom-up saliency on attentional capture, dwelling, and awareness, we also included a salient red distractor in the present study (e.g., Theeuwes, 1992).

Experiment 1

In Experiment 1, we tracked the observers' eye movement during visual search for a color target. In different blocks, the search target was either aqua and presented among olive nontargets (e.g., bluer target), or it was olive and presented among aqua nontargets (e.g., greener target). Observers were asked to make a fast and precise eye movement to the target. To encourage observers to make eye movements to the target and avoid saccadic undershoot (e.g., Findlay, 1997), all search items contained a small letter (x or o); observers were asked to report the letter inside the target with a manual response (i.e., press the left mouse button for "o," right mouse button for "x").

To assess whether attention was biased to the exact target color (e.g., aqua) or its relative color (e.g., bluer), we systematically varied the color of an irrelevant distractor, which differed in shape (i.e., square) from the remaining search items (i.e., disks). The distractor could have one out of five possible colors: blue, aqua, olive, green, or a salient red. With these distractor colors, the bluer (aqua) target was often the bluest item in the search display (i.e., when the distractor was olive, green or red), and the greener (olive) target was often the greenest item in the search display (i.e., when the distractor was blue, aqua, or red), so that observers could find the target by tuning attention to the relative color of the target (i.e., search for the bluest or greenest item; e.g., Becker et al., 2014). A corresponding relational search strategy would result in the strongest capture by the blue distractor (in search for aqua) or the green distractor (in search for olive), as these distractors are in fact the bluest or greenest items in the search display (e.g., Becker et al., 2013, 2014). The target-similar (aqua or olive) distractors should also still attract attention (and the observers' gaze), as they are bluer or greener than the majority of nontarget items. However, if attention is biased to the relative color of the target (bluer, greener), capture by the blue or green distractor should be significantly stronger than capture by these target-similar distractors. On the other hand, if observers tune attention to the exact target feature value (aqua or olive), the target-similar distractors should be selected more frequently than the relationally matching (blue or green) distractors (e.g., Becker et al., 2014; Harris et al., 2013).

As observers have a strong preference to tune attention to the relative rather than the exact color of the target (e.g., Becker et al., 2013, 2014; Harris et al., 2013), we expected that selection would depend on the relative color of target and distractor (bluer, greener) rather than its exact color. The interesting question was whether attention dwelling would also depend on the relative color of the target, or its exact feature value (i.e., similarity to the target). We hypothesized that postselective attentional processes may depend more strongly on whether the distractor physically matches the target color (rather than whether it matches the relative attributes of the target; e.g., Becker et al., 2014). If this is correct, then dwell times should be significantly longer for distractors that match the target color than for distractors that match only the relative color of the target.

The second aim of Experiment 1 was whether awareness of the distractor would be mediated more strongly by (a) initial attentional selection, (b) dwelling (e.g., prolonged feature processing of the distractor), (c) a combination of both, or (d) the saliency of the item. To address this question, we included awareness trials on a small subset of trials, in which the search stimuli were presented only briefly (200 ms) and quickly masked by purple-white pattern masks that contained numbers from 1 to 6. On awareness trials, participants were instructed to report the location of the irrelevant distractor. Awareness trials were only infrequently presented during the experiment (on 5% of all trials) to discourage participants from actively attending to the distractor.

To assess whether awareness is more strongly mediated by initial capture or later attentional processes, we correlated the awareness rates (i.e., the proportion of accurate reports of the distractor location) with the proportion of first eye movements to the distractor (as an index for initial attention shifts to the distractor), and the dwell times on the distractors (to index elongated feature processing of the distractor). In addition, awareness rates were correlated with the mean RT to the target, which served as a joint measure for early capture and later feature processing, and we computed linear regressions of all of these predictors (proportion of first eye movements, dwell times, and mean RTs), to identify the best predictor for awareness. If awareness of the distractor depends most strongly on initial attentional selection to the distractor, awareness rates should correlate most strongly with the proportion of first eye movements on the distractor. On the other hand, if awareness depends more strongly on in-depth processing of the distractor, the distractor dwell times should correlate most highly with awareness. If both processes together determine awareness, a joint measure such as the mean RT, which include both early and later components of attention, should correlate most highly with awareness. In turn, if awareness of the distractor depends most strongly on its saliency and is largely independent of whether the distractor is attended (and for how long), then the salient red distractor should have the highest awareness rates, and awareness rates would not necessarily correlate with any index for distractor processing.

Method

To determine the appropriate sample size for Experiments 1 and 2, we first conducted a pilot study with eight separate participants (whose data were not included in Experiment 1), using the same methods and procedures as specified above. The results showed a significant difference between the distractor conditions in the proportion of first eye movements and the distractor dwell times. The smaller effect size for the dwell times ($\eta_p^2 = .67$) was entered into the G*Power program (Faul, Erdfelder, Lang, & Buchner, 2007) and showed that $N = 15$ participants were necessary to detect significant effects ($p < .05$) with a power $>.80$ in the dwell times. To allow counterbalancing the blocked conditions in Experiment 1, we opted for a sample size of 16 for both Experiments 1 and 2.

Participants. Sixteen participants with normal, or corrected-to-normal vision, and normal color vision, from the University of Queensland completed Experiment 1. Participants were reimbursed with AU$10 for participating in Experiment 1. Fourteen participants were female, and their mean age was 23 years (*SD* = 3.63; range = 20–31 years). The methodology used in Experiment 1 and 2 were approved by the Human Ethics Committee at The University of Queensland.

Apparatus. Experiment 1 used a personal computer with an Intel Core i7-4790 CPU 3.60 GHz processor, equipped with an Nvidia GeForce GTX 645 graphics card and controlled by Presentation software (Neurobehavioral Systems, Albany, CA). All stimuli were displayed on a 19" color LCD monitor with a resolution of 1280 × 1024 pixels and a refresh rate of 60 Hz. All participants were tested individually in a small, normally lit laboratory, with their head resting against the eye tracker's chin rest and forehead support, and they viewed the screen at a distance of 60 cm. Responses were recorded with a standard USB mouse and keyboard. Eye movements were tracked using a video-based infrared eye-tracking system (Eyelink 1000, SR Research, Ontario, Canada) with a spatial resolution of <0.1° and a temporal resolution of 500 Hz.

Stimuli. All stimuli were presented against a white background. Each trial began with a black central fixation cross (0.38° × 0.38°) to ensure participants were attending to the center of the screen. The search display consisted of five target or nontarget disks (2.39°) and one distractor square (2.20° × 2.20°) that were presented equidistantly on the outlines of an imaginary ellipse (diameters: 14.5° × 16.4°) (see Figure 1A). All search items (disks and square) contained a small black "x" or "o" inside (Arial 10 pt) that constituted the response-related items. The target was always an olive or aqua disk, presented among four nontarget disks of the opposite color (aqua or olive, respectively). The distractor square had one out of five possible colors: (a) a relationally matching color (Rel; for an olive target, green would be relationally matching; for an aqua target, blue would be relationally matching), (b) the same color as the target (Tsim; olive or aqua depending on the blocked target condition), (c) the nontarget color

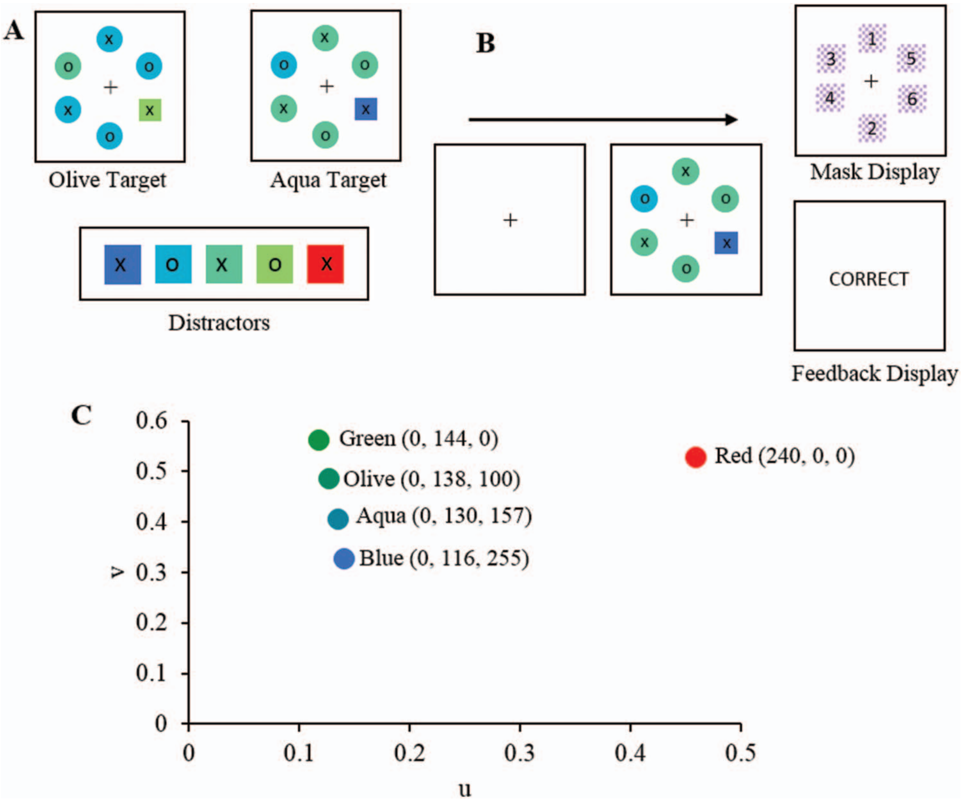

Figure 1. A: Example of the search displays used in Experiment 1 (top left: olive target among aqua nontargets and aqua target among olive nontargets), with the different distractors depicted below. Observers had to make a fast eye movement to the predefined color target and to respond to the stimulus inside the target (i.e., X or O) while ignoring the irrelevant square distractor. B: Example of a trial: Participants had to fixate on the central fixation cross to start the trial. The visual display was presented until a manual response was entered, and immediately succeeded by a feedback display. On awareness trials, the stimuli were shown only for 200 ms, then masked and observers had to indicate the location of the irrelevant distractor square. C: The positions of the colors used in Experiment 1 in the CIE (Commission International de l'Éclairage 1976 color space), with the RBG (red, green, blue) values of the colors listed in parentheses (bottom graph). See the online article for the color version of this figure.

(NonT; olive or aqua depending on the color of the nontargets in the blocked conditions), (d) a relationally opposite color (Opp; for a relationally bluer target this would be green; for a relationally greener target it would be blue) or (5) a very salient red color (Red).

All colors were rendered equiluminant using a ColorCal MKII colorimeter (green: 63.75 cd/m^2, olive: 62.29 cd/m^2, aqua: 62.60 cd/m^2, blue: 63.60 cd/m^2, red: 62.07 cd/m^2). The red-green-blue values and position of the colors in Commission International de l'Éclairage 1976 color space (1976) are depicted in Figure 1C. The mask display was used only on awareness trials and consisted of six purple-and-white checkerboard masks with black numbers from 1 to 6 corresponding to the six locations on the screen (Figure 1B).

Design. The experiment primarily consisted of a 2 × 5 design. The two-possible target/nontarget color pairs were presented in separate blocks, with the order of blocks counterbalanced across participants, whereas the color of the distractor was chosen pseudorandomly on each trial, such that each distractor was presented an equal number of times (80 times within each block). The locations of target and distractor and the response-defining items (x or o) were chosen randomly on each trial, with the limitations that the target and distractor never appeared directly adjacent to each other, and that each display contained an equal number of x and o characters.

Each block contained of 400 trials, of which 20 were awareness trials (four awareness trials for each distractor color), for a total of 800 trials.

Procedure. Prior to each block, participants were shown an example of the search display and instructed to make a fast and precise eye movement to the target and to report whether the target contained an "x" (by pressing the left mouse button) or an "o" (by pressing the right mouse button). Participants were encouraged to make their eye movements as precise and fast as possible, and to take their time with the manual response, to ensure a high accuracy of the manual response.

Participants were also fully informed about the awareness trials. Specifically, they were shown an example of the mask display and told that the search display would only be visible for 200 ms on these trials, after which they would be asked to report the location of the distractor square (by pressing the number key corresponding to the masked positions 1–6 in the mask display, see Figure 1A).

At the start of each block, a 9-point calibration was performed. To ensure stable and accurate eye tracking, each trial started with a fixation control: Participants were instructed to fixate on the fixation cross at the center of the screen, and the search display was only presented when the gaze was within a 1.26° × 1.26° region around the fixation cross (for 500 ms, within a time window of 2,000 ms). On search trials, the search display was presented until the manual button response, and a feedback display consisting of the words "correct" (500 ms) or "wrong" (1,000 ms; Arial, 10 pt) informed participants whether their response in the x/o task had been correct or wrong.

On awareness trials, the search display was presented for only 200 ms and then replaced with a mask display. The masks remained on screen until participants had pressed one of the 1–6 keys to indicate the location of the distractor and was followed by a display displaying the word "Thanks" presented centrally in black writing (Arial, 10 pt). This display and the feedback displays were always followed by a blank display (250 ms), and the next trial started again with the fixation control. The entire experiment took approximately 40 min to complete.

Results

Data. Eye movements were parsed into saccades, fixations, and blinks using the standard parser configuration of the Eyelink software, which classifies an eye movement as a saccade when it exceeds a velocity of 30°/s or an acceleration of 8,000°/s fixations were assigned to a stimulus (target, distractor or nontarget) when the gaze was outside the fixation region (1.52° from the center of the fixation cross), and within a region of 5.04° of the center of the nearest stimulus. When the first fixation could not be assigned to a stimulus, the respective trial was excluded from all analyses, which led to a loss of 9.00% of all data. Furthermore, trials were excluded when the start of the first saccade was delayed by more than 1,000 ms, leading to a further loss of 0.07% of the data, or when RT were below 200 ms or above 2,000 ms, which accounted for 1.41% of the data

Unless specified differently, data were analyzed by within-subjects' analyses of variance (ANOVAs) and two-tailed t tests, whereby we always compared the adjacent pairs of distractor conditions for the t tests to avoid excessive comparisons. Where appropriate, the Greenhouse-Geisser corrected p values and effect sizes (η_p^2) were reported, together with the uncorrected degrees of freedom. To avoid computing too many t tests, and because the data were ordered in a clear fashion, pairwise t tests were only computed between the directly adjacent stimulus pairs, which included the theoretically important comparisons: Rel versus Tsim, Tsim versus NonT, NonT versus Opp, and Opp versus Red. Data were analyzed using SPSS, JASP and R statistical programs (JASP Team, 2017; R Core Team, 2017).

Proportion of first eye movements to the distractor. Figure 2A shows the proportion of first eye movements to each distractor when the target was aqua (bluer) versus olive (greener). First, to assess whether and to what extent the different distractors attracted the observer's gaze, we computed a 2 (Target: Olive, Aqua) × 5 (Distractor: Rel, Tsim, NonT, Opp, Red) repeated-measures ANOVA over the proportion of first eye movements to the distractor. The results revealed a significant main effect of the distractor, $F(4, 60) = 314.49$, $p < .001$, $\eta_p^2 = .95$ (Greenhouse-Geisser corrected), but no main effect of the target color or interaction, $Fs < 1.83$, $ps > .172$ (Figure 2A). Hence, for the following analyses, the data were pooled across the (bluer and greener) target conditions. As shown in Figure 2A, the relatively matching Rel distractor (i.e., blue distractor when the target was aqua; and green when the target was olive) attracted the gaze most strongly and was selected significantly more frequently than the target-matching Tsim distractor by 23.34% (i.e., either aqua or olive distractor to match the target color), $t(15) = 9.94$, $p < .001$, $\eta_p^2 = .87$. Tsim distractors moreover attracted a significantly higher proportion of first eye movements than NonT distractors with a difference of 36.66% (i.e., either aqua or olive distractor to match the color of the nontargets), $t(15) = 22.11$, $p < .001$, $\eta_p^2 = .97$. Selection of a NonT distractor and Opp distractor (i.e., green distractor when the target was aqua/bluer; and blue when the target was olive/greener) was rare and there were no differences between the proportion of first eye movements made to either distractor, $t <$

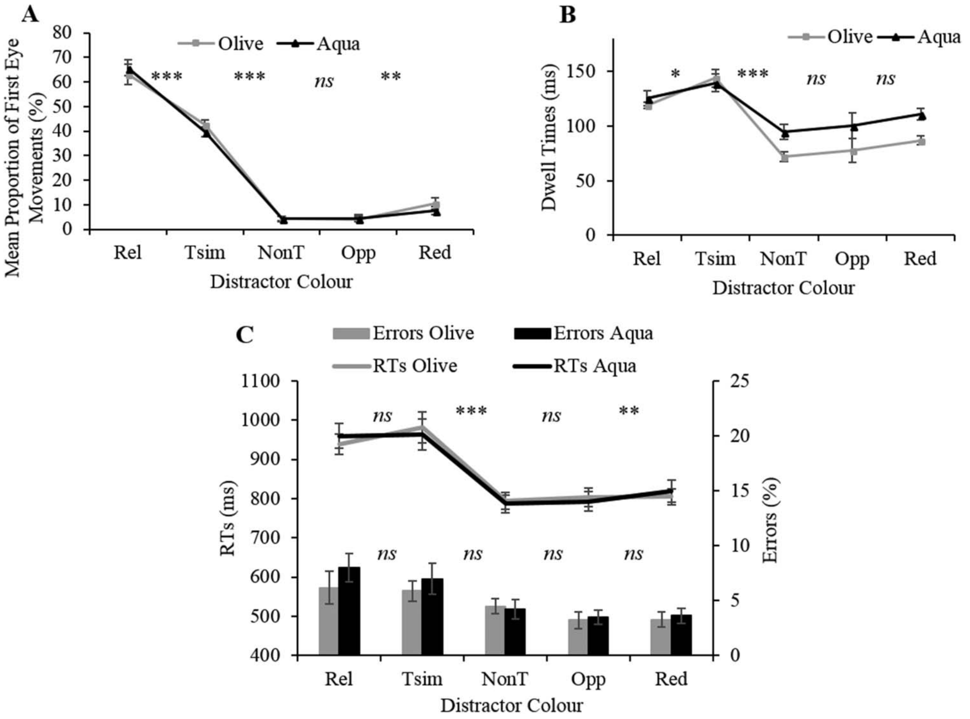

Figure 2. A: The mean proportion of first eye movements to each distractor in search for an olive (greener) or aqua (bluer) target in Experiment 1 (top left). Relationally better (Rel) distractors captured the gaze more frequently than target-similar (Tsim) distractors, which in turn captured the gaze more frequently than non-target-similar (NonT) distractors. Capture rates did not differ between nontarget similar and relationally opposite distractors (Opp), while the red salient distractor (Red) captured the gaze more strongly than the Opp distractor. B: The mean distractor dwell times, depicted separately for the olive (greener) target and the aqua (bluer) target of Experiment 1 (top right). Tsim distractors held the gaze longest, followed by Rel distractors and the other target-dissimilar distractors. C: The mean RTs (linegraph) and error scores (histrograms) of Experiment 1 (bottom), depicted separately for each distractor color and target condition. Rel and Tsim distractors interfered equally with the task, significantly more than the NonT, Opp and Red distractors, which did not differ significantly from each other. For all figures, asterisks indicate the results of pairwise comparisons across the different distractor conditions and error bars represent +/− 1 SEM and may be smaller than the plotting symbol. * $p < .05$, ** $p < .01$, *** $p < .001$, as per two-tailed t test.

1. The salient Red distractor was selected significantly more frequently than the Opp distractor by 6.79%, $t(15) = -3.51$, $p = .003$, $\eta_p^2 = .45$. Taken together, these results show that distractors that match the relative color of the target can attract the gaze more strongly than target-similar distractors, in line with the relational account. Moreover, a salient Red target-dissimilar distractor also weakly attracted the gaze.

Distractor dwell times. To assess whether sustained dwelling on the distractor depended on target similarity or relative matches, we next compared the mean dwell times across the different types of distractors. Data were excluded from this analysis if they contained less than four trials per cell, which left eight participants only for the comparisons between Tsim and NonT, NonT and Opp, and Opp and Red (e.g., all cells contained values for Rel and Tsim distractors).[1] Contrary to the capture results, dwell times were longest on target-similar Tsim distractors, significantly 19.38% longer than on Rel distractors, $t(15) = -2.51$, $p = .024$, $\eta_p^2 = .30$ (see Figure 2B). Furthermore, Tsim distractors were dwelled on significantly longer then NonT distractors by 59.66%, $t(7) = 5.52$, $p = .001$, $\eta_p^2 = .81$. There were no differences in dwell times between NonT and Opp distractors, or between Opp and Red distractors, all ts < 1. Collectively, these results show that distractor dwell times were most strongly modulated by target similarity.

Mean RTs and errors.

Mean RT. To assess distractor effects on a joint measure of transient and postattentional selection, we next analyzed the mean

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[1] The results remained the same when no participants were excluded (which still resulted in three missing values for the Tsim vs NonT and Opp vs Red comparisons and five missing values for the NonT vs Opp comparison, due to the distractor not being selected). Furthermore, to rule out that the results were due to individual differences between participants who selected all distractors sufficiently often (>4 times) to be included in this analysis versus those who did not (and were therefore excluded from this analysis), we computed a range of independent samples t tests. The results showed that the participants did not significantly differ from each other in terms of their mean accuracy ($t < 1$, $p > .515$), mean RT ($t < 1.44$, $p > .177$), or awareness rates ($t < 1$, $p > .442$). Thus, interpretation of the current findings is not complicated by individual differences between participants.

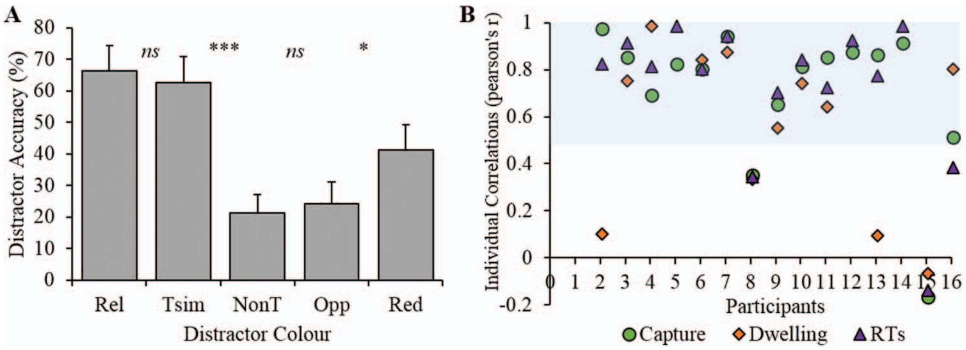

Figure 3. A: The mean awareness rates of Experiment 1 (left) showed that observers were most accurate in identifying the location of the Rel and Tsim distractor, followed by the salient Red distractor, and the NonT and Opp distractors. Error bars represent +1 SEM; $^{*}\ p < .05$, $^{**}\ p < .01$, $^{***}\ p < .001$, as per two-tailed t test. B: Individual correlations of awareness with capture (as indexed by the proportion of first eye movements to the distractor), dwelling (as indexed by distractor dwell time), and mean RT. A linear regression analysis showed that capture was the best predictor of awareness, followed by mean RTs (e.g., combined measure of capture and dwelling), while dwelling was not a significant predictor. See the online article for the color version of this figure.

RT, which should reflect distractor effects due to both capture and dwelling. The same 2 × 5 ANOVA computed over the mean RT revealed a significant main effect of distractor conditions, $F(4, 60) = 55.34$, $p < .001$, $\eta_p^2 = .79$ (Greenhouse-Geisser corrected; see Figure 2C). RTs did not differ between the two possible target colors, nor was there any interaction between the target color and distractor color, all $Fs < 1.89$, all $ps > .125$.

As shown in Figure 2C, mean RT were elevated for both relationally matching and target-similar, Rel and Tsim, distractors, and did not differ between these, $t < -1.05$, $p > .311$. RTs were significantly longer by 181.90 ms with a Tsim distractor than with a NonT distractor, $t(15) = 7.86$, $p < .001$, $\eta_p^2 = 80$. There was no difference in RTs between NonT and Opp distractors, $t < -1.26$. RTs were significantly longer in the presence of a Red distractor, than a Opp distractor by 14.05ms, $t(15) = -1.27$, $p = .005$, $\eta_p^2 = .42$. Overall, the results pattern of the mean RTs reflects additive costs for capture (i.e., shifting the gaze to the distractor) and dwelling on distractors, with both of these processes contributing about equally to the interference effect across different distractor conditions.

Mean errors. An analysis of the mean errors revealed a significant main effect of the distractor color, $F(4, 60) = 6.36$, $p < .001$, $\eta_p^2 = .30$, and no significant main effect of the target color or interaction, $F < 1.88$, $p > .191$. Paired, two-tailed t tests revealed that errors did not differ between any of the distractor conditions, all $ts < 2.00$, all $ps > .064$. The nonsignificant trends in the mean errors followed a similar pattern of results as observed in the mean RTs, showing no signs of a speed–accuracy trade-off.

Awareness trials. Comparing the awareness scores to chance performance (16.7%) revealed that the Rel, Tsim and salient Red distractors were all reported with accuracies significantly above chance level, $t(15) = 6.24$, $p < .001$, $\eta_p^2 = .72$, $t(15) = 5.41$, $p < .001$, $\eta_p^2 = .66$, and $t(15) = 3.17$, $p = .006$, $\eta_p^2 = .40$, respectively. Accuracies for reporting the position of NonT and Opp colored distractors were not significantly above chance, all $ts < 1.10$, all $ps < .436$.

The same 2 × 5 ANOVA computed over the awareness rates revealed that awareness of the distractor was significantly modulated by the color of the distractor, $F(4, 60) = 20.05$, $p < .001$, $\eta_p^2 = .57$, whereas there was no main effect of target color, $F < 1$, or interaction between the two variables, $F < 1$ (see Figure 3A). Pairwise t tests computed over the pooled data of both target conditions revealed that awareness rates were highest for the Rel (66.41%) and the Tsim (62.50%) distractors and did not differ significantly between these distractors, $t < 1$. Awareness rates of the Tsim distractor were 41.15% significantly higher than for the NonT distractor, $t(15) = 5.97$, $p < .001$, $\eta_p^2 = .70$, which in turn did not differ significantly from the Opp distractor, $t < 1$. Awareness rates for the Red distractor were significantly higher by 17.19%, compared to the Opp distractor, $t(15) = -2.67$, $p = .018$, $\eta_p^2 = .32$.

Overall, observers were more likely to indicate the correct location of the distractor when the distractor matched the relative or exact feature of the target. With this, the results from the awareness trials followed a similar pattern as observed in the mean RT, which comprised the additive effects of capture and elongated dwelling.

Regression. To assess whether initial capture versus dwelling attentional processes, or a combination of both (e.g., RTs) is an important predictor for awareness, we next computed a linear regression over the data of Experiment 1, with awareness entered as the dependent variable, and the predictors of (a) the proportion of distractor fixations (to index attentional capture), (b) the mean dwell times (to index postselectional feature processing), and (c) the mean RT (as a joint measure) in each distractor condition, averaged across all participants. The regression showed a significant association between awareness and the three predictor variables (e.g., capture, dwelling and RTs), $F(3, 56) = 7.45$, $p < .001$, $R^2_{\text{adj}} = .25$.[2] Capture rates explained a significant proportion of awareness, $t = 4.28$, $p < .001$, with a one-point increase in capture rates leading to .79 increase

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[2] To assess possible collinearity between the predictors, we computed the variance inflation factor (VIF) values, which were all well below 5 (Capture VIF: 1.28, Dwell VIF: 2.18, RT VIF: 2.32), indicating that our predictors were not highly correlated with each other.

in awareness rates. RTs constituted another significant predictor, $t = -2.26$, $p = .028$, with a 1ms increase in RTs resulting in an .11 decrease in awareness. In turn, dwell times were not a significant predictor of awareness, $t = 1.52$, $p = .133$.[3] These results indicate that the probability of selecting the distractor was the best predictor of awareness, followed by RTs, whereas dwelling was not a significant predictor of awareness.

To test whether the implicit attention measures can also predict awareness at the level of individual participants, we next correlated the mean awareness score with each of the implicit attention measures per participant using Pearson's *r*. One participant had to be excluded due to zero scores on all awareness trials, and three individual correlations could not be computed for dwell times due to too few observations. Therefore, in Figure 3B the data points are missing for Participant 1, along with three data points for dwelling from Participants 5, 12, and 14. The results of the individual correlations are shown in Figure 3B, with the blue shaded area indicating high correlations ≥.50 (Cohen, 1992). As shown in the figure, awareness can be predicted most accurately by the capture rates, followed by mean RTs and dwell times, also at the level of individual participants. Taken together, these results suggest that awareness is determined predominantly by early (relational) processes that determine selection, as these attentional processes have a larger effect on awareness than elongated feature processing.

Discussion

The results of Experiment 1 clearly demonstrate, for the first time, a dissociation between early processes that determine visual selection and later, elongated processes that determine dwelling on selected items. Specifically, we found that relationally matching distractors are more likely to capture attention and the gaze, indicating that early processes of visual selection strongly depend on the relative feature of target and distractor (e.g., Becker, 2010; Becker et al., 2013, 2014). At the same time, however, target-similar distractors held the gaze for longer than relationally congruent distractors, indicating that later, elongated processes of attention depend more strongly on exact feature matches. Possibly, relationally matching distractors can be more readily rejected on the basis of mismatching the target color, whereas identification of the target-similar distractor requires additional processing (e.g., of its shape) to discriminate it from the target. Whereas this explanation needs to be examined further, the present results demonstrate that initial transient shifts of attention and subsequent distractor processing are determined by different factors (i.e., a match in relative vs. exact features).

Second, we found that a joint measure of the mean RT, which includes both early and later attention effects, was approximately equally influenced by the costs of selecting a distractor and elongated dwelling. These findings highlight the need to use measures that can separate between these two variables to safeguard conclusions about the factors driving attention (as relying on the mean RT or other joint measures confounds these early effects with later processes of disengaging attention; e.g., Theeuwes, Atchley, & Kramer, 2000). This seems all the more important, because the frequently reported similarity effect (e.g., Duncan & Humphreys, 1989) was found only in the mean dwell times on the distractor, whereas selection of the distractor was determined by a match in the relative color (e.g., Becker, 2010).

Still, it is noteworthy that both early selection of the distractor and subsequent dwelling depended on top-down processes and were only weakly modulated by stimulus-driven, bottom-up processes. The salient red distractor, despite being extremely salient and obvious, attracted the gaze only weakly, and was not dwelt on for longer than the nonsalient, nontarget similar distractor. Taken together, these results show that both capture and subsequent dwelling depend largely on top-down processes that optimize selection for the task at hand.

The fourth and perhaps most important finding of the present study was that awareness was modulated both by the probability of selecting a distractor, and the combined effects of capture and dwelling, as reflected in the mean RT. By contrast, dwell times on the distractor did not modulate awareness. These results were obtained both in a linear regression and a correlation analysis of individual data, showing that awareness was more strongly determined by the probability of selecting a distractor rather than by subsequent dwelling on the distractor.

This was also reflected in the results for the salient red distractor, which showed slightly higher capture rates and awareness rates, but no elongated dwell times, compared to the nontarget similar or relationally opposite distractors. Taken together, these findings clearly show that the probability of selecting a stimulus has a larger impact in promoting awareness than the time spent processing an item. Apparently, early processes of attention that are sensitive to the relative features of target and distractor are already sufficient to gate access to awareness.

Experiment 2

Experiment 1 yielded a number of important results concerning the factors that modulate initial capture versus later elongated attentional processes, and their effects on awareness, as well as the interplay of top-down versus bottom-up processes on capture versus dwelling and their effects on awareness. The aim of Experiment 2 was to test whether the same results could be obtained in a covert attention task in which participants are not allowed to move their eyes, and attention to the distractor is indexed by the N2pc in the EEG of participants.

The N2pc is defined as a higher contralateral than ipsilateral negativity at posterior electrodes and is currently regarded as the prime electrophysiological marker for covert attentional selection (e.g., Eimer, 1996; Eimer & Grubert, 2014; Luck & Hillyard, 1994; Wascher & Wauschkuhn, 1996). Several studies have shown that a target-similar distractor will reliably elicit a significant N2pc, whereas target-dissimilar items usually produce no or a much reduced N2pc, even when they are salient (Kiss, Jolicoeur, Dell'acqua, & Eimer, 2008; Schubö & Müller, 2009). In some cases, a contralateral distractor positivity (Pd) can be elicited by nonmatching distractor items, which has been linked to distractor inhibition (e.g., Kiss, Grubert, Petersen, & Eimer, 2012; Liesefeld,

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[3] Computing the regression only with the eight participants that contributed solid dwell time data yielded the same results, with capture rates still explaining a significant proportion of awareness, $p = .004$, and dwelling still not being a significant predictor, $p = .904$. The regression analysis was also conducted with all the participants and conditions (with missing values), and only with the subset of distractors that included all participants (e.g., Rel, Tsim, and Red), and consistently showed the same results as above.

Liesefeld, Töllner, & Müller, 2017; Sawaki, Geng, & Luck, 2012; Sawaki & Luck, 2013). Thus, nonmatching distractors may produce a Pd component instead of the N2pc. Furthermore, a Pd component may be observed after the N2pc component, reflecting an initial shift of attention followed by suppression (e.g., Kiss et al., 2012; Sawaki et al., 2012).

A previous study by Schönhammer, Grubert, Kerzel, and Becker (2016) tested whether the N2pc to target-similar items was due to a match in the relative features or exact feature values. They used a spatial cueing paradigm to compare the N2pcs of target-similar and target-dissimilar cues that either matched or mismatched the relative color of the target and found that a relational match was both necessary and sufficient to elicit a significant N2pc (i.e., target-similar and dissimilar cues both elicited an N2pc when they matched the relative feature of the target, and a target-similar cue that did not relationally match the target failed to elicit a significant N2pc). These results suggest that the N2pc indexes the initial orienting of attention, which is usually determined by a match in the relative features of the item and target (e.g., Schönhammer et al., 2016; but see Theeuwes, 2010).

The major aim of Experiment 2 was to assess whether the N2pc may provide a better predictor for awareness than the mean RT or eye movement parameters (see Experiment 1) when observers are not allowed to move their eyes. To address this research question, we again included a small proportion of awareness trials in Experiment 2 (3.82%), in which observers had to report the location of the distractor (as in Experiment 1). Individual and overall correlations with awareness were computed as in Experiment 1, whereby the mean N2pc amplitude to the distractor served as our implicit measure for covert selection, and the mean RT served as a proxy for joint early and later attentional processes.

As the N2pc is defined as a larger contralateral than ipsilateral negativity in response to a stimulus, measuring the N2pc in response to the distractor requires presenting a lateralized distractor (on the right or left side of the display), together with a midline target (to prevent the emergence of a target-related N2pc; e.g., Eimer, 1996; Hickey, Di Lollo, & McDonald, 2009). These conditions were implemented on 66.7% of all trials in Experiment 2, whereas on the remaining trials, the target was lateralized while the distractor was presented on the midline. As in previous studies, N2pc amplitudes were measured over posterior scalp electrodes (PO7, 8), separately for each different distractor. To optimize the conditions for the measurement of the N2pc, the number of trials was increased (to 1,440). Moreover, to avoid eye movement artifacts, we tried to discourage participants from making eye movements by shortening the presentation duration of the search display to 200 ms, moving the stimuli closer to the central fixation cross and increasing the size of the response-defining x and o stimuli.

Method

Participants. Twenty new, neurologically normal participants from the University of Queensland with normal, or corrected-to-normal vision, and normal color vision were recruited for Experiment 2. Informed signed consent was obtained from participants prior to testing and participants were reimbursed with AU$20 for their participation. Four participants were excluded from further analysis, three because of excessive alpha activity and one because their regression value was identified as an outlier (according to a multivariate model to screen for outliers using Cook's Distance; see Irons & Leber, 2016 for a similar procedure). Of the remaining participants, 10 were females and six were males, and they had a mean age of 22.25 years (range = 18–31 years, *SD* = 3.26).

Apparatus. EEG data were recorded using a 64-channel BrainProducts EEG system (Gilching, Germany) with a BrainAmp DC amplifier connected to a personal computer. The personal computer contained an Intel Core i5-4790 CPU 3.50 GHz processor, equipped with an Intel(R) HD Graphics 4600 card and controlled by Presentation software (Neurobehavioral Systems, Albany, CA). All stimuli were displayed on a 19" color LCD monitor with a resolution of 1,280 × 1,024 pixels and a refresh rate of 60 Hz. All participants were tested individually in a small, normally lit laboratory, with a viewing distance of approximately 60 cm. Responses were recorded with a standard USB mouse and keyboard.

Stimuli, design, and procedure. The search stimuli were the same as in Experiment 1. The stimulus size and distance were adjusted for the covert attention task, such that the items were positioned closer to the center on the outlines of an imaginary ellipse with a diameter of 1.91° × 2.20°. The size of the search stimuli and masks were similarly adjusted, so that the square distractor measured 1.15° × 1.15°, the target and nontarget disks had a diameter of 1.24°, and the postmasks used on awareness trials measured 1.1° × 1.4°.

The same design was used as in Experiment 1, except that the target color (aqua, olive) was varied between subjects, and the number of trials was increased to 1,440 trials in total (55 awareness trials), to optimize conditions for the measurement of the N2pc.

The procedure was similar to Experiment 1: Each trial started with the presentation of the central fixation cross. The search display was then presented (together with the fixation cross) for 200 ms, after which the search stimuli disappeared and only the fixation cross remained visible (to aid participants in the task of remaining fixated). When participants entered an incorrect button response to the x/o task, a short beep was elicited (1,000 Hz, 100 ms) with a recovery period for 1,000 ms with a blank screen, and the next trial started again with the presentation of the fixation cross. On correct trials, the intertrial interval was randomly determined to be between 1,200 and 1,500 ms. On awareness trials, the search display was replaced with the mask display after 200 ms, and participants were instructed to indicate the location of the distractor.

EEG data recording and analysis. The continuous EEG was recorded from 29 scalp electrodes mounted in an elastic cap (Fpz, F7, F3, Fz, F4, F8, FC5, FC6, T7, C3, Cz, C4, T8, CP5, CP6, P7, P3, Pz, P4, P8, PO9, PO7, PO3, PO4, PO8, PO10, O1, Oz, and O2). Impedances were kept below 5kΩ. All electrodes were referenced online to the left earlobe and were rereferenced offline to the average of the linked earlobes. Data was sampled at a rate of 500 Hz and online filtered with a high cut-off filter of 40 Hz and notch filter of 50 Hz. EEG data were analyzed with the Brain Vision Analyzer 2.0 software (Brain Products, Gilching, Germany).

Trials that contained artifacts (i.e., blinks exceeding ±60 μV in the Fpz channel; horizontal eye movements exceeding ±30 μV in the HEOG; muscular movements exceeding ±80 μV in all other channels) were excluded from EEG analysis (see Becker et al., 2014; Eimer & Grubert, 2014; Grubert & Eimer, 2016, for similar exclusion criteria). The remaining data were segmented into epochs ranging from 100 ms prior to stimulus onset, to 400 ms poststimulus onset, and adjusted relative to a 100-ms prestimulus baseline. Event related potential (ERP) waveforms were computed separately for each distractor type (i.e., Rel, Tsim, NonT, Opp, Red), and separately for contra-versus ipsilateral distractor conditions. The mean N2pc amplitudes were computed from the lateral posterior electrodes PO7 and PO8 in the 210–270 ms poststimulus window (see, e.g., Kiss et al., 2012, for a similar time window).

The N2pc onsets and offsets were computed by locating the negative peak within the 200–300 ms poststimulus time window, and traveling backward and forward, respectively, to determine the point in time when 50% of the peak value had been reached, separately for each distractor and participant. For the statistical analysis of the N2pc onset and offset latencies, we used the jack-knifing procedure of Ulrich and Miller (2001), with the corresponding statistical corrections.

Results

Behavioral results. Trials that contained anticipatory responses (e.g., less than 200 ms) or delayed responses (e.g., greater than 2,000 ms) were excluded from further analysis, leading to a loss of 1.35% of all trials.

Mean RT. As shown in Figure 4A, the results of the covert attention task mimicked those obtained in Experiment 1, with relationally matching, Rel, distractors and target-similar, Tsim, distractors, interfering most strongly, as reflected in longer mean RTs. A 2 × 5 mixed ANOVA with the within-subjects factor of distractor type (Rel, Tsim, NonT, Opp, Red) and the between-subjects factor of target color (aqua, olive) on the mean correct RT correspondingly showed a significant main effect of the distractor color, $F(4, 56) = 95.87$, $p < .001$, $\eta_p^2 = .87$ (Greenhouse-Geisser corrected), but no main effect of the target color, or a significant interaction between the target color and distractor, both Fs < 2.79, both $ps > .117$.

Paired, two-tailed t tests showed that RTs were similarly elevated and did not differ between the Rel and the Tsim distractor, $t < 1$. RTs were significantly elongated for the Tsim distractor, compared to a Nont distractor by 143.84 ms, $t(15) = 15.87$, $p < .001$, $\eta_p^2 = .94$. RTs were also significantly delayed for the Opp distractor compared with a Nont distractor by 22.87 ms,

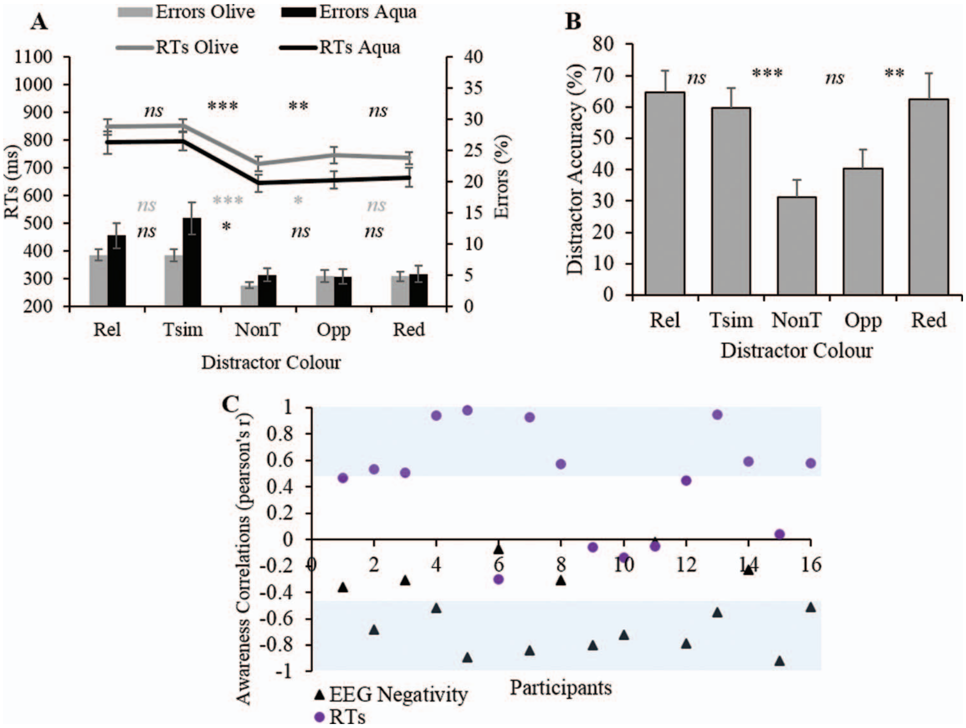

Figure 4. A: Mean RTs (linegraph) and errors (histograms) for each distractor color in search for an olive (greener) or aqua (bluer) target in Experiment 2 (top left). The Rel and Tsim distractors interfered to the same extent with the task, and significantly more than the other distractors. Deviating from Experiment 1, the NonT, Opp and Red distractors had higher accuracy rates above chance. B: Results of the awareness trials, in which observers had to indicate the location of the irrelevant distractor (top right). Observers were more accurate in localizing Rel, Tsim and Red distractors than Opp or NonT distractors. Deviating from Experiment 1, the NonT, Opp and Red distractors had higher accuracy rates above chance. For A and B, error bars represent 1 SEM. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$, as per two-tailed t test. C: Individual correlations between awareness and N2pc amplitude and RTs across the five distractor conditions of Experiment 2. A linear regression showed that the N2pc amplitudes were a good predictor of awareness, in that a larger N2pc was associated with a higher probability of being aware of the distractor. By contrast, the mean RTs were not a significant predictor of awareness. See the online article for the color version of this figure.

$t(15) = -3.17$, $p = .006$, $\eta_p^2 = 40$, but did not differ between the Opp and the salient Red distractor, $t < 1$.

Mean errors. An analysis of the mean errors revealed a significant main effect of the distractor color, $F(4, 56) = 20.69$, $p < .001$, $\eta_p^2 = .60$ (Greenhouse-Geisser corrected, Figure 4A), with higher error rates in the presence of an aqua colored target ($M = 8.07\%$, $SEM = 1.13$), compared to an olive target ($M = 5.89\%$, $SEM = .69$). A significant interaction between distractor color and the target color $F(4, 56) = 3.00$, $p = .026$, $\eta_p^2 = .18$, but no significant effect of the target color, $F < 3.00$, $p > .104$. Because of the significant interaction, errors were examined for each target type separately.

Paired, two-tailed *t* tests showed that across both target types, errors did not differ between Rel and Tsim distractors, all ts < 1. Similarly, across both target types, significantly more errors were made when a Tsim distractor was present, compared to Nont distractors (aqua target by 1.58%: $t(6) = 3.31$, $p = .016$, $\eta_p^2 = .65$; olive target by 4.77%: $t(8) = 6.76$, $p < .001$, $\eta_p^2 = .85$). Significantly more errors were made in the presence of a Opp distractor than a NonT color in search for the olive target by 1.49%, $t(8) = -2.96$, $p = .047$, $\eta_p^2 = .41$, but not in search for the aqua target, $t < .55$, $p > .606$. Error rates did not differ between the Opp and Red distractors in either target condition, all ts $< .03$, all ps $> .525$. With this, the results error scores mimicked the results pattern of the mean RT in demonstrating a distractor cost with Rel and Tsim colors.

ERPs in response to a lateral distractor with a midline target.

Mean N2pc amplitude. Figure 5A displays the grand mean ERPs separately for the five different lateral distractors. The N2pc analysis included only trials in which the distractor was located laterally with a midline target, which occurred on 66.67% of all trials. Furthermore, trials were excluded from the N2pc analysis when they contained artifacts (8.03% blinks and 17.84% horizontal eye movements).

A 5 (distractor: Rel, Tsim, NonT, Opp, Red) × 2 (laterality: contra- vs. ipsilateral) mixed ANOVA with the between-subjects factor of target color computed over the mean N2pc amplitude within the 210–270 ms poststimulus time window revealed a significant main effect of contralaterality, $F(1, 14) = 6.41$, $p = .024$, $\eta_p^2 = .31$, and a significant interaction between the distractor color and contralaterality, $F(4, 56) = 22.73$, $p < .001$, $\eta_p^2 = .62$ (Figure 5A). No other main effects or interactions were significant, all Fs < 1.66, all ps $> .205$; hence, data were pooled across target colors to increase statistical power.

Paired *t* tests revealed a significant N2pc (i.e., a significantly larger negativity on contra-than ipsilateral trials) for the Rel distractor, $t(15) = 5.74$, $p < .001$, $\eta_p^2 = .69$, and the Tsim distractor, $t(15) = 3.73$, $p = .002$, $\eta_p^2 = .48$. No significant N2pc was found for the NonT, $t(15) = -1.58$, $p = .135$, Opp, $t(15) = -1.93$, $p = .072$, or the Red distractor, $t < 1$.

To compare the N2pc amplitudes between the different distractor conditions, we next computed the mean difference waves for each distractor condition (contralateral minus ipsilateral waveforms). The results (see Figure 5B) revealed a significantly larger N2pc for the Rel distractor than the Tsim distractor, $t(15) = -2.67$, $p = .018$, $\eta_p^2 = .32$. Furthermore, the Tsim distractor had a larger mean amplitude than the NonT distractor, $t(15) = -6.34$, $p < .001$, $\eta_p^2 = .73$. There was no difference between NonT and Opp distractors, $p < .476$. However, the Opp distractor showed a larger positivity than the Red distractor, $t(15) = 2.32$, $p = .035$, $\eta_p^2 = .26$.

Onset and offset latencies. Comparing the jack-knifed onset and offset latencies of the N2pc between the Rel and Tsim distractor revealed that the N2pc for the Rel distractors (211ms) had a significantly earlier onset, compared to the Tsim distractor (234ms), $t(15) = -50.65$, $p_{cor} < .001$, $\eta_p^2 = .99$. Furthermore, the Rel distractor also had an earlier N2pc offset (272 ms) than the Tsim distractor (282 ms), $t(15) = -41.94$, $p_{cor} < .001$, $\eta_p^2 = .99$, indicating that the N2pc for the Rel distractor was shifted relative to the N2pc to the Tsim distractor.

Other effects. Visual inspection of the individual N2pcs revealed a contra-lateral positivity following the N2pc in a subset of the conditions. To formally analyze the potential Pd in the data set, we computed paired *t* tests over the 300–360 ms poststimulus time window. The results revealed a significant Pd component only for the Rel distractor, $t(15) = -2.83$, $p = .013$, $\eta_p^2 = .35$.[4] No significant positivity was found for Tsim, NonT matching, a Opp color, or a salient Red distractor, all ts < 1.73, all ps $> .106$.

Awareness trials. The mean awareness rates are depicted in Figure 4B. As in Experiment 1, awareness rates were high for the Rel and Tsim distractor, but deviating from Experiment 1, they were also high for the Red distractor, and seemed generally higher than in Experiment 1 (for all distractors). In line with the latter impression, all distractors were localized with above-chance accuracy (16.7%; Rel: $t(15) = 7.19$, $p < .001$, $\eta_p^2 = .78$, Tsim: $t(15) = 6.80$, $p < .001$, $\eta_p^2 = .76$, NonT: $t(15) = 2.82$, $p = .018$, $\eta_p^2 = .32$, Opp: $t(15) = 3.84$, $p = .002$, $\eta_p^2 = .50$, and Red: $t(15) = 5.55$, $p < .001$, $\eta_p^2 = .67$).

A mixed ANOVA with the within-subjects factor distractor (Rel, Tsim, NonT, Opp, Red) and the between-subjects factor of target color (aqua, olive) showed that awareness of the distractor was significantly modulated by the distractor color, $F(4, 56) = 11.01$, $p < .001$, $\eta_p^2 = .44$, but not by the target color or an interaction, Fs < 1.55, ps $> .234$.

As shown in Figure 4B, awareness rates did not differ significantly between the Rel and Tsim distractor, $t(15) = .80$, $p = .439$. Awareness rates were significantly higher for the Tsim distractor compared to the NonT distractor by 28.41%, $t(15) = 5.11$, $p < .001$, $\eta_p^2 = .64$, and did not differ between Opp and NonT distractors, $t = -1.94$, $p = .072$. The Red salient distractor showed significantly higher awareness rates than the Opp distractor, by 22.16%, $t(15) = -4.39$, $p = .001$, $\eta_p^2 = .56$. In fact, the awareness rates for the Red distractor were so high that they did not differ significantly either from the relationally matching or target-similar distractors, ts < 1, ps $> .725$.

Correlations with awareness. To assess which implicit measures of attention best predicted awareness, a linear regression was calculated over the data, with the average of the awareness score as the dependent variable, and the mean N2pc amplitude and mean RT for each distractor condition entered as predictors. The results of the regression showed a significant association between awareness and

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[4] In Figure 5A, for the Rel distractor there appears to be a slight contralateral negativity following the Pd component. Analyzing the data within a longer, 400–900 ms poststimulus time window however yielded no further ERP components after the Pd component.

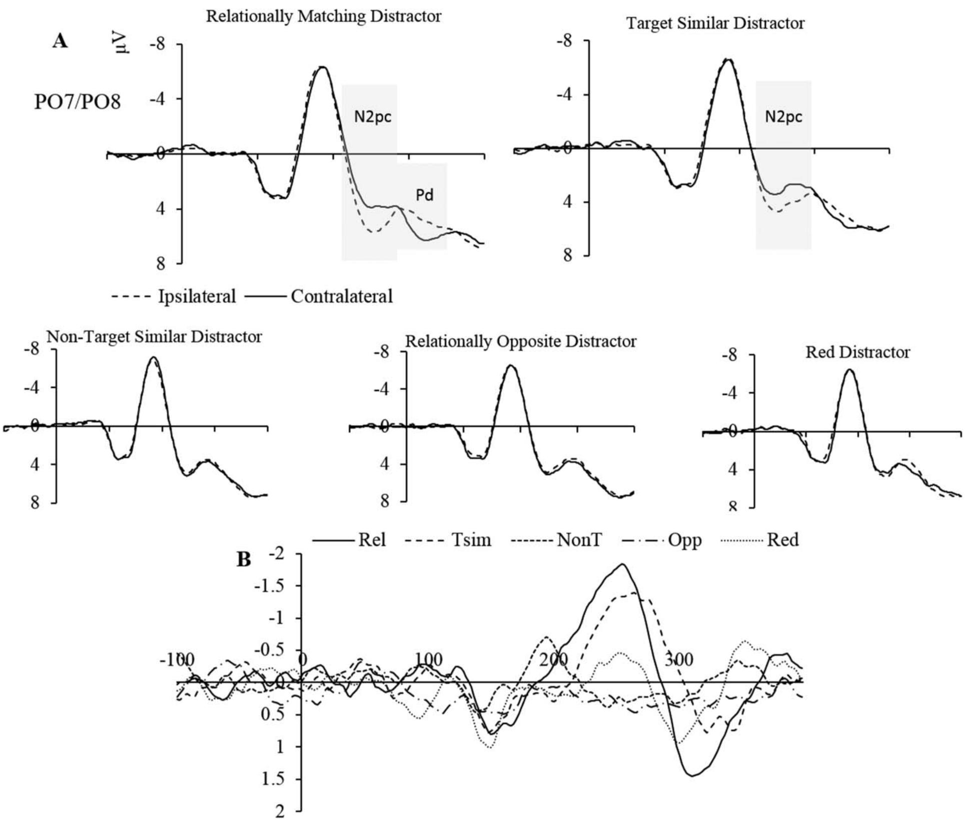

Figure 5. A: ERPs elicited at electrodes sites PO7, PO8 in response to the distractor, displayed separately for each distractor type and contralateral (solid lines) versus ipsilateral (dashed lines) distractor conditions (with a midline target; top and middle). A significant N2pc was observed only for the Rel and Tsim distractors (210—270 ms poststimulus onset). In a later time window (300 ms to 360 ms poststimulus onset), a significant positivity (Pd) was observed only for the Rel distractor. B: Differences waves obtained from contralateral minus ipsilateral ERPs (PO7/PO8) for each distractor in Experiment 2 (bottom). The N2pc of the Rel distractor was significantly larger and had a significantly earlier onset and offset, compared to the Tsim distractor.

the two predictors, $F(2, 77) = 10.70$, $p < .001$, $R^2_{\text{adj}} = .20$.[5] However, only N2pc amplitude was a significant predictor of awareness, $t = -4.32$, $p < .001$, with every one-point decrease in negativity for the N2pc amplitude leading to a 14.59 increase in awareness rates. RTs were not a significant predictor, $t < 1$, $p = .973$.

As in Experiment 1, we also computed the individual correlations across the variables for each participant individually. As shown in Figure 4C, the mean N2pc were more strongly correlated with awareness than mean RT. However, correlations were overall lower than in Experiment 1, especially for the mean RT, which did not reliably predict awareness. At first, one may be tempted to explain the failure of mean RT to predict awareness with the Red distractor being an outlier, in that the Red distractor had high awareness rates yet did not show elevated RT. However, when the regression was rerun without the Red distractor, the results were very similar. This indicates that the mean RT may generally be a poor predictor for awareness in covert attention tasks (at least when compared with the N2pc).

We also compared the mean N2pc amplitudes and mean RT between high noticers (awareness $M = 69.10\%$, $SEM = 1.97$) and low noticers (awareness $M = 34.32\%$, $SEM = 5.39$) using a median split, and found that high awareness performers had significantly larger N2pc amplitudes ($M = -.58$, $SEM = .12$) compared to low awareness performers ($M = -.07$, $SEM = .18$), $t(14) = -2.32$, $p = .036$, $\eta_p^2 = .28$, whereas the two groups did not differ in terms of their mean RT, $t < .1$, $p = .834$.[6]

Collectively, these results indicate that the mean N2pc amplitude is a better indicator for awareness than mean RT, probably because the N2pc more directly indexes attentional capture, which may also be the most important determiner for awareness in covert attention tasks.

Discussion

Experiment 2 yielded several important insights: First, the results showed that a relationally matching distractor elicited a

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[5] VIF values were well below 5 (N2pc VIF: 1.15; RT VIF: 1.15), indicating that there was no collinearity between predictors.

[6] We also compared the mean N2pc amplitudes for high ($M = -.32$, $SEM = .16$) and low ($M = -.42$, $SEM = .23$) RT performers (using median split) and found that N2pc amplitudes did not differ between these two groups, $t < 1$, $p = .709$. Nor were there any differences in the N2pc when high and low performers were defined by their error scores (using median split), $t < 1$, $p = .590$.

significantly larger N2pc than a target-similar distractor that had the same color as the target. Interestingly, we also found differences in the onset and offset of the N2pc, which occurred significantly earlier for the relationally congruent distractor than for the target-similar distractor. In addition, a significant Pd was observed only for the relationally congruent distractor, not for the target-similar distractor, reflecting suppression of the distractor location after it was attended (Liesefeld et al., 2017; Sawaki et al., 2012; Sawaki & Luck, 2013).[7] These results suggest that attention was initially prioritized to the relationally matching distractor, after which the location was quickly suppressed, potentially due to the distractor not matching the target feature (which allowed rejecting the distractor in search for the target). The target-similar distractor did not elicit a Pd component, potentially because it would be counterproductive during the task to inhibit the exact target color and would interfere with selecting the target. Another point of interest is that the salient Red distractor apparently did not attract attention (i.e., did not show a significant N2pc), yet awareness rates were as high as for the relationally matching and target-similar distractors. As will be discussed in more detail below, the high awareness rates for the salient Red distractor may have been mediated by a stronger involvement of VSTM in the covert attention task of Experiment 2, which may also explain the higher awareness rates for all distractor types (which were all above chance).

A third important finding of Experiment 2 was that the N2pc was a better predictor for awareness than the mean RTs. As mentioned above, these results were obtained even when the red distractor was removed, suggesting that the N2pc is generally a better predictor for awareness than mean RT. This could be because awareness is more strongly determined by the initial orienting of attention, which is more directly reflected in the N2pc than in the mean RT. The mean RT are presumably determined both by attentional capture and subsequent (attentional) dwelling, with the possible addition of other decisional or response-related processes (e.g., conflict resolution; Becker, Horstmann, & Remington, 2011; Becker et al., 2014; Norman, 1981; Reason, 1990; Scheffers, & Coles, 2000), which could compromise its ability to reliably predict awareness. In line with this possibility, previous studies also often failed to find significant correlations of these coarse-grained behavioral measures with awareness (Horstmann & Becker, 2008; Most et al., 2005; Rausei, Makovski, & Jiang, 2007). The two findings that the mean N2pc amplitude was a better predictor for awareness than mean RT, and that the mean N2pc was higher for noticers, highlight the importance of earlier processes for awareness, in line with the findings of Experiment 1.

General Discussion

The present study yielded several important findings. First, the eye movement results showed that relationally congruent distractors captured attention and the gaze most strongly, while observers tended to dwell longer on target-similar distractors. These findings provide converging evidence that attention is typically biased to the relative color of a target, rather than its particular color value (Becker et al., 2010, 2014; Harris et al., 2013; Meeter & Olivers, 2014). Moreover, the present study showed, for the first time, a dissociation between processes that determine selection and post-selectional dwelling. Specifically, although selection was determined by processes operating on the relative, context-dependent features of target and distractor, the time needed for perceptual processing was determined by target similarity, independent of the context (e.g., Duncan & Humphreys, 1989; Horstmann, Becker, & Ernst, 2017; Wolfe, 1994). Presumably, it is easier to reject and disengage attention from a relationally matching distractor because it noticeably differs from the target (due to it having a different color), whereas distinguishing between two same-colored items requires further in-depth processing of the item (e.g., of the shape, which adds processing time).

These findings indicate an important shift in processing modes during visual search: Attention is initially tuned to the relative target feature, which leads to selection of all relationally matching distractors (including the target-similar distractor; Becker, 2010). The subsequent identification or classification of the selected item (as target or distractor) in turn engages feature-specific processes that operate on the exact feature values of target and distractor (or a comparison of both).

In line with this account, the N2pc amplitude was larger (and occurred earlier) for a relationally congruent distractor than for the target-matching distractor. Furthermore, following the N2pc component toward the relationally congruent distractor was a Pd component, indicating that selection of relationally matching distractors is quickly followed by suppression and disengagement of attention. However, there was no disengagement of attention for target-similar distractors (as evidenced by a lack of the Pd component), reflecting that target-similar distractors are more difficult to identify and reject than relationally matching (but differently colored) distractors. Of note, the target-similar distractor differed only in one feature dimension (e.g., shape) from the target, whereas the other distractors differed in both color and shape, which may have aided fast rejection of the relationally matching distractor (Müller et al., 1995). The difficulty of rejecting the target-similar, same-colored distractor presumably reflects that later distractor identification processes that commence after selection are feature-based, in the sense that these processes operate on the exact feature values of target and distractor, in a largely context-independent manner (e.g., Duncan & Humphreys, 1989). As the similarity between target and distractor only plays a role at this later stage of attentional dwelling and object identification, the results suggest that current feature similarity accounts should be modified, or limited to later processes (e.g., Duncan & Humphreys, 1989; Martinez-Trujillo & Treue, 2004; Navalpakkam & Itti, 2005).

Attention and Awareness

The most important findings of the present study probably relate to awareness. In line with previous studies, the present results showed that awareness of the distractor was strongly modulated by the top-down task demands, in that stimuli matching the task-relevant stimuli were more likely to be reported accurately (Markant & Amso, 2014; Rutman et al., 2010; Zanto et al., 2011).

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[7] The EEG data also showed a significant N2pc to the target, across all distractor conditions, in the 250–290 ms poststimulus interval, all $ps < .024$. However, as the corresponding display condition was realized on only 34% of all trials (displays with a lateralized target and the distractor on the mid-line), the target-related N2pc was not analyzed further.

Importantly, we found that awareness of the distractor did not depend much on extended feature processing, which, in turn, depended on feature similarity but was primarily determined by whether the distractor matched the relative features of the target and would be selected.

Previous studies also mostly attributed awareness to the initial orienting of attention to the probe stimulus ("attentional capture," e.g., Most et al., 2005), but often failed to establish the theoretically important link between orienting and awareness, as the implicit attention measure was not, or only very weakly, correlated with awareness (e.g., Horstmann & Becker, 2008; Most et al., 2005). The present study allowed distinguishing between attentional capture and, later, postattentional selection. Hence, we were able to demonstrate that awareness depends more strongly on initial attentional capture than elongated feature processing. Moreover, the finding of significant correlations between early attentional measures and awareness provides the theoretically important link and confirms the role of attention as a gatekeeper for awareness (Most et al., 2005; Zanto et al., 2011). With this, the results corroborate the findings of the IB study by Goldstein and Beck (2016), that awareness is mediated by relative feature matches rather than feature similarity, suggesting that attentional capture is a more important predictor for awareness also in other paradigms (Goldstein & Beck, 2016; see also Drew & Stothart, 2016; Most et al., 2005).

The present findings can also contribute to current debates of VSTM, as they suggest that transient selection of an item already leads to encoding of it into VSTM. Specifically, we demonstrated that an item is encoded into VSTM even when it is quickly rejected immediately after selection, as evidenced by short dwell times and a significant Pd in the EEG of participants (see the relationally matching distractor in Exp. 1 and 2). These results are in line with the wide-spread view that attention and VSTM are tightly linked, and that selection of an item will automatically lead to VSTM encoding (e.g., Cowan, 2001; Gunseli, van Moorselaar, Meeter, & Olivers, 2015; Kiyonaga & Egner, 2013; Olson et al., 2008; Schmidt et al., 2002). Moreover, our findings suggest that irrelevant items are encoded into VSTM both in an overt selection task, when participants are instructed to move the eyes to the target, and in a covert selection task, when the target is selected without moving the eyes.

In apparent contradiction to these findings, Tas and colleagues (2016) recently reported that only overt selection leads to VSTM encoding, whereas covert selection of an irrelevant item is not sufficient for it to be encoded into VSTM. However, in their experiment VSTM encoding was indexed by measuring interference of the selected item with memorized items. Moreover, the covert attention task did not encourage processing of the features of the item, but only selection and encoding of its position. Given the relative independence of spatial and feature-based attention and associated VSTM systems, the failure to observe interference could have been because the task encouraged only encoding of a position, which does not necessarily interfere with memory of colors (Tresch, Sinnamon, & Seamon, 1993).

In the present study, we measured VSTM encoding more directly, by asking participants to report the position of the distractor (on rare probe trials). Participants were asked to report the position rather than the color of the distractor because we reasoned that recall of colors would likely be influenced by differences in task-relevance and feature processing (i.e., dwell times), which would have contaminated this measure of VSTM/awareness. In addition, probing for distractor colors could also result in the measure being rather insensitive, as it seems possible to be aware of something without being able to accurately recall its attributes. Finally, reporting of the position of the distractor ensured that the task affordances in visual search and on probe trials both tapped into the same, spatial attention/VSTM system. In line with this logic, our results showed that items that attracted attention were also more likely to be encoded into VSTM.

Still, it could be argued that the present results are not conclusive, because the distractor was not completely task-irrelevant. Although this is true, probe trials were presented only very rarely, to avoid participants to strategically attend to the distractors. Moreover, a bias to attend to the distractor would have increased awareness for all distractors, yet, in Experiment 1, distractors that failed to attract the gaze were also not reported with above-chance accuracy. This indicates that the probe trials did not induce participants to strategically attend to the distractors. Thus, although the present results cannot strictly rule out that it is possible to select distractors without encoding them into VSTM (Tas et al., 2016), it seems safe to conclude that the position of an irrelevant distractor will usually be encoded in VSTM if it attracts attention, both in covert and overt selection tasks, and even when the distractor can be quickly rejected as irrelevant.

One interesting difference between Studies 1 and 2 was that awareness rates were generally higher in the covert attention task of the EEG study (Study 2). Apparently, observers adopted a different strategy in the covert attention task, possibly in response to the rather brief presentation of the target display (200 ms). With these briefly presented displays, selecting a distractor may produce costs that prevent successful selection and identification of the target (after distractor selection). To compensate, participants may have followed a strategy of registering or encoding multiple possible candidate targets in VSTM, which led to generally higher awareness rates for all distractors (see also Makovski, Sussman, & Jiang, 2008; Williams & Woodman, 2012; Schmidt et al., 2002; Zhang & Luck, 2008).

Saliency and Awareness

Another noteworthy finding of Experiment 2 was that the red salient distractor showed very high awareness rates, despite the fact that it was not covertly selected (as evidenced by the absence of a significant N2pc and RT increase). This is an important finding, because it shows that salient items can reach high levels of awareness even without similar levels of spatial attention being deployed to them. On reflection, this is a plausible outcome, as attentional selection of an item will usually enhance attributes that a salient item already possesses; namely, (a) detectability (Carrasco, Penpeci-Talgar, & Eckstein, 2000; Baldassi & Verghese, 2005), (b) spatial resolution (He, Cavanagh, & Intriligator, 1996; Yeshurun & Carrasco, 1998), (c) feature discrimination (Posner, 1980; Lee, Itti, Koch, & Braun, 1999), and (d) perceived contrast (i.e., appearance; Liu, Fuller, & Carrasco, 2006). In this regard, it is not too surprising that salient stimuli enjoy a systematic advantage in explicit awareness or memory tests, and corresponding results have been obtained in previous studies (e.g., Goldstein & Beck, 2016; Most et al., 2005), as well as in our Experiment 2.

Collectively, these findings indicate that bottom-up saliency may not have a large effect on selection per se, which seems to be largely top-down controlled (e.g., Folk & Remington, 1998). Rather, bottom-up saliency seems to confer an advantage at a later stage of visual processing, in that salient items are more likely to enter awareness.

The question is then why the salient distractor did not show such high awareness rates in the first experiment. A first possible explanation is that awareness of the salient distractor in Experiment 2 depended on participants adopting the strategy to encode multiple candidate targets into VSTM (because of the brief presentation durations of the target; see above). If this is correct, awareness of salient items would not be purely automatic, but—similar to attention—depend on the strategies used by observers (e.g., Bacon & Egeth, 1994).

A second possible explanation is that the requirement to make an eye movement interfered with awareness of the salient distractor. We consider this rather unlikely, as previous studies usually permitted eye movements and yet found high awareness rates for salient items (e.g., Goldstein & Beck, 2016; Most et al., 2005). However, the differences in awareness of the salient item could also be due to differences in the search displays: Of note, the stimuli were further spread out in the eye tracking task of Experiment 1, which could have reduced the impact of the salient distractor; either because it was further in the periphery, or because it lacked a strong local feature contrast. According to current theories of attention, saliency is often computed as a function of *local* feature contrasts, so that stimuli with a high feature contrast are only salient, or more salient, when they are densely packed (e.g., Guided Search; Wolfe, 1994; Nakayama & Martini, 2011). As the stimuli in Study 1 were spread out more widely than in the covert attention task, it is possible that the red distractor was not as readily detectable or radically different, and was therefore not encoded preferentially in VSTM.

Conclusions

The present study yielded several important findings. First, relational rather than feature-specific processes determine early attentional capture, whereas a match in the exact feature values (rather than the relative features) determines later postselectional dwelling. Second, the best predictors for awareness were measures that indexed early attentional capture rather than subsequent dwelling (i.e., the probability of selecting an item and the mean N2pc amplitude rather than dwell times or mean RT). Third, we showed that very salient items can yield high awareness rates despite not being attended to the same extent.

Taken together, these results confirm the tight link between attention and awareness or VSTM and indicate that current models of attention and awareness or VSTM would need to be modified in at least two ways: First, accounts of VSTM, awareness and IB would need to implement feature relationships to accurately predict awareness. Second, models may have to be modified to accurately predict attention to and awareness of salient items. Or, to put it a different manner: Current theories of awareness probably need to account for the possibility that salient items have stronger effects on awareness than can be explained by attention alone.

Further research on attention and awareness will probably profit from carefully assessing the saliency of all tested items and entering saliency as an additional predictor for awareness (while reducing its impact on earlier stage; e.g., Wolfe, 1994). Furthermore, given that traditional measures of attention conflate the effects of attention and saliency (e.g., improved detection/discrimination accuracy or speed; Posner, 1980), future studies would need to use spatially specific measures to differentiate between attended and unattended items.

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Received December 10, 2017
Revision received June 1, 2018
Accepted June 4, 2018 ■

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