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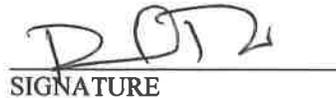
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Running Head: EXAMINING SNAKE DETECTION THEORY

Examining Snake Detection Theory: Conscious and Unconscious Responses to Snakes

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EXAMINING SNAKE DETECTION THEORY

Abstract

According to Isbell's (2006) Snake Detection Theory, the need to rapidly detect and thus avoid snakes had a major impact on the evolution of the primate visual system. Snake Detection Theory rests on the assumption that there are both cortical (conscious) and subcortical (unconscious) brain structures and mechanisms that are responsible for rapid visual detection of and quick avoidance reactions to snakes. Evidence in support of Snake Detection Theory comes from a variety of studies that assess speed and accuracy of snake detection, evaluate neurophysiological responses to snakes, and measure arousal reactions in response to snakes compared to other stimuli. However, evidence for Snake Detection Theory primarily comes from visual search tasks and presentations of images on a computer screen. There are no studies that look for physiological evidence of pre-attentive awareness of a snake in a naturalistic context. If Snake Detection Theory applies to primates in natural conditions, we should see evidence of both preferential detection of snakes and evidence of physiological reactions to snakes (heart rate, HR, and galvanic skin response, GSR) even when there is not conscious awareness of the snake's presence. Therefore, I proposed the following five hypotheses by having participants take a virtual hike in which a realistic model of a snake, rabbit, or bottle has been placed on the trail. I predicted that: 1) snakes would be reported as seen more often than rabbits or bottles; 2) among participants who reported seeing the stimulus, larger GSR responses would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions; 3) among participants who did not report seeing the stimulus, larger GSR responses would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions;

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4) among participants who reported seeing the stimulus, greater decelerations over baseline heart rate would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions; 5) among participants who did not report seeing the stimulus, greater decelerations over baseline heart rate would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions. I also asked a research question about the relationship, if any, between self-reported snake fears and detection/reaction in the snake condition. I found that hypotheses 1- 4 were supported, and hypothesis 5 showed similar trends but failed to reach significance. There was no relationship between snake fears and detection or HR or GSR changes. The results of my study provide evidence in support of Snake Detection Theory by being the first to show that snakes are detected more often than controls, and elicit conscious and unconscious physiological responses, in a naturalistic context.

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Examining Snake Detection Theory: Conscious and Unconscious Responses to Snakes

The earliest primates appeared about 60 million years ago (Ma) (Ross, 2000; Eizirik, 2004). From this time forward, snakes and primates have coexisted (Prasad, Jaeger, Sahni, Gheerbrant, & Khajuria, 1994; Rage, Prasad, & Bajpai, 2004). Fossil evidence suggests that carnivores such as lions evolved around 62-42 Ma, whereas snakes emerged around 100 Ma (Van Valkenburgh, 1999; Polly, 2006). Therefore, snakes were the first predators of primates. Snakes continue to live in the same environments as all primates, inhabiting all but the coldest parts of the world (Shine, 1981), and they continue to present a threat to nonhuman and human primates today (Chippaux, 1998).

The co-evolution of snakes and primates led to adaptations that reflect the hunting strategies of snakes, and the anti-predator strategies of primates. Snakes have evolved a variety of adaptations to attack their prey. Snakes were initially burrowers who used constriction to kill their victims (Wiens, Brandley, & Reeder, 2006). Venomous snakes emerged around 60 Ma, making them even deadlier. The envenomation adaptation coincided with the appearance of fast-moving mammals who were harder to catch by constriction alone (Greene, 1983). Further, the evolution of camouflaged skin helped snakes ambush their prey while avoiding detection by their own predators. For example, geometrical scaling patterns help conceal the contours of the body which make a snake less distinguishable (Spinner, Kovalev, Gorb, & Westhoff, 2013). But, like many other mammals to whom snakes pose a serious threat, primates have evolved counter-adaptations related to snakes. Isbell's (2006) Snake Detection Theory focuses on snake-related adaptations to the primate visual system.

Evidence for Snake Detection Theory

According to Isbell's (2006) Snake Detection Theory the need to rapidly detect and thus avoid snakes had a major impact on the evolution of the primate visual system. Evidence in support of Snake Detection Theory comes from a variety of studies that assess speed and accuracy of snake detection, evaluate neurophysiological responses to snakes, and measure arousal reactions in response to snakes versus other kinds of stimuli. For instance, Shibasaki and Kawai (2009) found that macaque monkeys (*Macaca fuscata*) who had no prior experience with snakes produced faster reaction times when detecting photos of snakes, compared to a non-threatening stimulus such as flowers, in a computer-based visual search task. In similar tasks, snake-naïve monkeys detected snakes quicker than other threatening stimuli such as spiders (Kawai & Koda, 2016; Öhman, Soares, Juth, Lindstrom and Esteves, 2012; Shibasaki & Kawai, 2011). This suggests that non-human primates have an innate ability to detect snakes more quickly than other threatening and non-threatening objects.

Similarly, a number of studies have shown that humans detect snakes more quickly than other stimuli. Ruling out the possibility that dangerous threats other than snakes evoke equally quick detection, Soares and Esteves (2013) found that participants detected snakes more quickly than spiders in a computerized visual search paradigm.

Snakes are detected quickly under visually taxing conditions. Human participants detected snakes more accurately than birds, cats, and fish in a fragmented photograph in which the image was slowly revealed (Kawai & He, 2016). Soares, Lindstrom, Esteves and Öhman (2014) found that snakes were detected more quickly than spiders and mushrooms when the stimulus was presented at the periphery of a grid consisting of multiple photo distractors. The authors suggest that when there is a higher perceptual load placed on the visual system, snakes, unlike spiders, are still given attentional priority.

Certain physical characteristics of snakes may be responsible for rapid detection of and increased physiological responses to snakes. Snakes have long curvilinear bodies with patterned or unpatterned scales. LoBue (2014) discovered that simple curvilinear lines were detected faster than simple rectangular shapes by adults in a visual search task. She suggests that humans may have perceptual biases to look for curvilinear shapes, perhaps because of their relationship to snakes. In addition, when presented with a rapid series of 450 images of snakes, worms, beetles, and spiders, participants showed higher early posterior negativity (EPN), an event-related potential indicator of early visual processing of emotionally impactful information, to snakes than they did to the other stimuli (Van Strien, Christiaans, Franken, & Huijding, 2016). Additionally, worms elicited higher EPN responses than beetles, which suggests that although it poses no threat, the curvilinear shape of the worm may have been responsible for the greater reactivity.

Further, snake scales may contribute to increased detection of and physiological responses to snakes. Van Strien and Isbell (2017) presented participants with a rapid series of photos consisting of snake scales, lizard skin, and bird feathers. As predicted, snake scales elicited larger EPN responses than lizard skin and bird feathers. Wombolt and Caine (2016) investigated common marmosets' (*Callithrix jacchus*) behavioral reactions to stimuli within their naturalistic environment that included triangles and serpentine shapes with varying scale patterns. The stimuli were presented to the marmosets on a platform located under an elevated portion of their enclosure; the monkeys could see the stimulus only when directly looking down upon it. Results indicated that marmosets spent more time visually inspecting serpentine shapes with patterns than serpentine shapes without patterns, or triangles with or without patterns

(Wombolt & Caine, 2016). The authors suggest that shape and scales are attended to and perceived as more threatening than the control stimuli.

Cortical and Subcortical Visual Pathways

Snake Detection Theory rests on the assumption that there are underlying brain structures and mechanisms that are responsible for rapid visual detection of and quick avoidance reactions to snakes. There are two main visual pathways from the retina to the brain: the geniculostriate path from the retina to the lateral geniculate nucleus (LGN) of the thalamus to the visual cortex (hence a cortical pathway), and the tectopulvinar pathway from the retina to the superior colliculus (SC) and the pulvinar of the thalamus (hence a subcortical pathway). Together these pathways provide the basis for all of the well-known features of the primate visual system (acuity, discrimination, color, etc.), but also rapid attention and reaction to threats (Kolb, Wishaw & Teskey, 2016). In cognitive psychology, these cortical and subcortical pathways are usually described as generating attentive and pre-attentive perception, respectively. Cave and Batty (2006) describe pre-attentive perception as the largely unconscious processing of visual information that precedes more focused and conscious processing of a visual stimulus. Pre-attentive perception is fast, automatic, and signaled even under high perceptual loads. Pre-attentional processes rely on subcortical structures to extract basic information such as location and orientation; subsequently, attentive processes select relevant stimuli from the visual field for further analysis involving the cortex.

Three types of cells in the visual system populate the geniculostriate and tectopulvinar pathways. Input to the LGN from the retina includes the magnocellular (M) and parvocellular (P) visual pathways. The M path forms a major part of the dorsal visual processing stream specialized for visually guided reaching and grasping (Goodale & Westwood, 2004). The P

pathway is the part of the ventral visual processing stream that allows us to recognize and identify objects (DeYoe & Essen, 1988). The M and P pathways are routed from the LGN to the primary (striate) visual cortex and then on to the parietal and temporal lobes, respectively. Thus, these visual pathways are considered to be “cortical” and they are associated with conscious perception.

The koniocellular (K) pathway has received the most attention in Snake Detection Theory. The K pathway has three different routes from the retina to brain structures that process visual information, two of which are subcortical. One of these subcortical routes does not track through the LGN at all, but goes directly from the retina to the SC, which is located in the midbrain below the thalamus, and is separated into superficial and deep layers. Superficial layers are involved in the visual detection of moving stimuli, whereas the deeper layers are involved in motor movements, such as freezing and darting, when reacting to a threat (Isa, 2002). Macaques with damage to their SC display odd eye and head movements, and often express defensive behaviors to non-threatening objects (Zarbalian, Leung, Lower, Malkova & Gale, 2003). The second subcortical route of the K pathway leads to the pulvinar, a nucleus in the thalamus that is unique to primates. The pulvinar is involved in controlling quick eye movements toward objects of interest and sends information to the amygdala (Bonda, 2000). Together these two subcortical pathways produce pre-attentive awareness of threats such as snakes.

Studies involving nonhuman primates and humans have found electrophysiological evidence for populations of cells in the pulvinar that are tuned to snake perception. Specifically, Van Le et al. (2013) revealed that macaques (*M. fuscata*) displayed higher amplitudes and faster neuronal activity in the medial and dorso-lateral pulvinar in response to images of snakes compared to monkey hands, faces, and geometric shapes. Additionally, Van Le et al. (2016)

found stronger gamma oscillations at stimulus onset in pulvinar neurons of macaques (*M. fuscata*) during visual presentations of snakes compared to monkey faces, hands, and geometric shapes. Gamma oscillations are associated with attention-holding and working memory (Jensen, Kaiser, & Lachaux, 2007), both of which are important for subsequent activation of cortical awareness.

Evidence of cells tuned to snake perception have also been found in the human visual cortex. Higher EPN amplitudes in the lateral occipital lobe have been found in human participants when viewing a series of rapidly appearing photos of snakes compared to spiders, slugs, crocodiles, and turtles (Van Strien, Eijlers, Franken & Huijding, 2014; Van Strien, Franken & Huijding, 2014).

The visual pathways and structures described above provide a primate with the ability to rapidly detect and move quickly away from snakes. The subcortical pathways allow for rapid, largely unconscious, initial reactions to snakes and cortical pathways become involved with finer-grained analysis of the stimulus and context. But there is another important component to this system, the amygdala, which is responsible for fear that may accompany threat detection. Together the amygdala, SC, and pulvinar form the so called “fear module” (Öhman & Mineka, 2001). Evidence suggests that the amygdala is responsible for fear conditioning and is necessary for appropriate reactions to threatening stimuli (Amaral, 2006; Morris, Friston & Dolan, 1997). Öhman, Carlsson, Lundqvist, and Ingvar (2007) concluded that the amygdala can be activated from potentially accessible, but unattended, fear stimuli. In fact, it is believed that individuals with phobias are unable to control their fear voluntarily because the amygdala is only weakly responsive to input from the cortex once the initial fear reaction has been initiated and sympathetic arousal is underway.

Galvanic Skin Response and Heart Rate

Physiological measures can offer evidence of a reaction to a stimulus even if it is not reported as having been detected. To test Snake Detection Theory, which relies in part on the assumption that the primate visual system is uniquely tuned to the pre-conscious detection of snake stimuli, using such physiological measures can be very useful.

The galvanic skin response (GSR) and heart rate (HR) have been widely used in research investigating arousal. GSR is a sympathetic nervous system response (Braithwaite, Watson, Jones, & Rowe, 2015) in which sweat is produced in reaction to a stressful stimulus to reduce the body's temperature, restoring homeostasis to the nervous system. This sweat contains cortisol that has been released in association with the perception of the stressor, and cortisol molecules carry an electrical charge (Cross, 2017). Therefore, as sweat increases, cortisol increases, which produces more electrical conductance.

GSR is categorized in two ways: skin conductance level (SCL), which reflects overall baseline changes in autonomic arousal over time in the absence of a particular arousing stimulus, and skin conductance response (SCR), which reflects a change in skin conductance in response to such a stimulus (Braithwaite et al., 2015). SCRs create upward deflecting peaks; a peak with a magnitude of at least 0.05 micro Siemens that occurs 1-3 s after the onset of the stimulus is typically considered to indicate a response. SCRs typically amplify for 2-10 s before returning to the baseline SCL (Braithwaite et al., 2015).

Heart rate, usually reported as beats per minute, is another commonly used measure of fear and arousal. Heartbeats are produced from the sinoatrial node within the heart, creating a rhythmic pace of about 60 beats per minute when at rest (Gordon, Gwathmey, & Xie, 2015). Heart rate may either accelerate or decelerate in response to certain arousing stimuli. Heart rate decelerations are associated with focused attention to an external stimulus, such as when viewing

an emotionally arousing visual stimulus. Thrasher and LoBue (2016) found that infants who watched videos of snakes and elephants showed decreased heart rate in response to the former but not the latter, which the authors interpret as an attentional response that is indicative of a preparedness to learn about a potentially threatening stimulus. In contrast, heart rate accelerations occur in response to internalized emotional states, such as fear, in which one has a defensive reaction to an arousing stimulus (Palomba, Angrilli & Mini, 1997). For example, Globisch, Hamm, Esteves, and Öhman (1999) found that people who are highly fearful of snakes or spiders showed heart rate acceleration to snake/spider photos, whereas people with low snake/spider fear showed decelerations. Further, heart rate has been shown to elicit greater deceleration to unpleasant stimuli than to pleasant and neutral stimuli (Anttonen & Surakka, 2005; Palomba et al., 1997; Codispoti & De Cesarei, 2007; Lang, Greenwald, Bradley & Hamm, 1993). Most studies measured HR decelerations by finding the difference between the mean heart rate before the stimulus onset and the average HR when the stimulus was in view.

As indicated in the aforementioned studies, HR and GSR react when people are consciously aware of a threatening stimulus, but these measures can also be used to indicate pre-attentive perception of threat. Globisch et al. (1999) found heart rate decelerations and SCRs to snake and spider photos whether the stimuli were presented for 6 sec or 150 ms, suggesting that changes to HR and GSR can be elicited even without full perceptual awareness of the stimulus. Subjects who had below-average snake fears, like those with high snake fears, demonstrated greater SCRs to snake/spider than to neutral (e.g., household items) objects.

The Current Study

As described in the forgoing literature review, Snake Detection Theory has amassed support from behavioral and physiological research. These studies have shown that snake-related

stimuli are detected more quickly than a variety of other stimuli by human and nonhuman primates alike (Kawai & Koda, 2016; LoBue & Deloache, 2008; Öhman, Soares, Juth, Lindstrom & Esteves, 2012; Shibasaki & Kawai, 2011; Soares & Esteves, 2013). Relative to various other stimuli, including threats such as spiders, snake stimuli elicit greater physiological responses (LoBue, 2014; Van Strien & Isbell, 2017; Van Strien, Eijlers, Franken & Huijding, 2014; Van Strien, Franken & Huijding, 2014), and there are cells within the visual pathways that respond strongly and preferentially to images of snakes (Van Le et al., 2013). But there is a relative paucity of empirical research in Snake Detection Theory that examines snake detection in natural or seminatural conditions. That is, do primates who are navigating the natural world respond rapidly and preferentially to snakes? Are snakes detected more often than other sorts of objects, and is there evidence of pre-attentive processing when snakes are detected under natural conditions? Research on snake detection comes largely from visual search paradigms in which the monkey or human is asked to find a stimulus on a computer screen (Kawai & Koda, 2016; LoBue & Deloache, 2008; Öhman, Soares, Juth, Lindstrom & Esteves, 2012; Shibasaki & Kawai, 2009; Shibasaki & Kawai, 2011; Soares, 2012, Soares & Esteves, 2013). Furthermore, in these cases the subject or participant is actively searching for the snake stimulus, but the real threat posed by snakes to primates does not arise when the individual is looking for the snake, but when s/he is engaged in other activities (e.g., searching for food) that take attention away from possible sources of threat. Physiological responses to snakes are usually tested with a presentation of rapid photographs (Langeslag & Van Strien, 2018; Soares, 2012; Soares et al., 2014; Van Strien et al., 2014; Van Strien, Franken & Huijding, 2014; Van Strien & Isbell, 2017) but physiological responses to snakes in a more natural context have not been measured.

I addressed these gaps by assigning participants to conditions in which they viewed a video, recorded in the first-person using a GoPro, that was taken along a hiking trail located in Riverside County, California. Along the trail was either a realistic model of a coiled rattlesnake or another animate (a rabbit model) or inanimate (a bottle) stimulus. Participants were instructed to imagine themselves as the person taking the hike, creating an immersive, naturalistic, yet controlled experience. Rather than instructing them to search for a particular stimulus, they were instructed to simply enjoy the hike by imagining that they were hiking. In addition to testing the hypothesis that snakes are detected more readily than many other stimuli (in this case, a rabbit or a bottle), I tested the assumption that our visual system is designed to detect snakes even in the absence of conscious detection. If this is the case, there should be a physiological response (GSR and/or HR) even when the participant reports that s/he did not see the stimulus.

In sum, the following hypotheses and one research question were tested in my thesis research: 1) Snakes would be reported as seen more often than the rabbits or bottles. 2) Among participants who reported seeing the stimulus, larger SCR responses would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions. 3) Among participants who did not report seeing the stimulus, larger SCR responses would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions. 4) Among participants who reported seeing the stimulus, greater decelerations over average baseline heart rate would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions. 5) Among participants who did not report seeing the stimulus, greater decelerations over baseline heart rate would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions. Lastly, I posed a research question that asked if self-reported snake fear is associated with detection and physiological responses in the snake condition.

Method

Participants

Participants were undergraduate college students ($N = 160$) at California State University San Marcos (CSUSM) recruited through the Psychology Department human participant pool (HPP). Participants included 119 females and 41 males. Age and ethnicity data were not collected, but according to www.csusm.edu, the average age of CSUSM undergraduate students is 22.7 years old (<18: 12.4%, 19-22: 51.8%, 23-25: 19.1%, 26-35: 13.4%, >36: 3.3%). Ethnicities are as follows: Hispanic/Latino: 47.3%, White: 26.7%, Asian: 8.7%, African American: 3.0%, Native American: 0.3%, Pacific Islander: 0.2%, Other: 3.9%, Non-Citizen: 4.8%, Two or More Races: 5.2%. Participants who noted having an extreme fear of snakes, color blindness, or any other uncorrected vision problem on the pre-screening form for HPP registration were not eligible for participation in this study.

Stimuli

Stimuli consisted of two snake models (7 x 8 in, 7 x 9 in), two rabbit models (4 x 9 in, 5 x 9 in) and two glass bottles (7 ½ x 2 ½ in, 9 x 2 ½ in) placed along two hiking routes. The snake models were made of ceramic and realistically painted with acrylic to represent a Southern Pacific Rattlesnake (*Crotalus oreganus helleri*) and a Western Diamondback Rattlesnake (*Crotalus ruber*). The two ceramic rabbit models represented light and dark brown versions of Desert Cottontails (*Sylvilagus audubonii*). The two glass bottles were made of amber and green glass. Using two versions of each stimulus type reduced the chance that the results of my experiments are limited to one particular model. (see Figure 1).

Hike Videos

The hike videos were two minutes long and were recorded with a Go-Pro strapped on a head mount at a 50-degree angle while I walked at a pace of 80 steps per minute (maintained by a metronome recording, not audible on the videos) along two trails located near Canyon Hills Community Park in Menifee, CA, in the winter of 2018. As is the case for the stimuli, using two different hiking routes reduced the chance that my results are limited to one particular context. All videos were filmed between 12:30 and 1:30 pm for optimal lighting and minimal shadows.

In each hike video, one of the stimuli was visible for exactly 5 s along the side of the trail. The curves of the trail and strategic position of rocks and bushes hid the stimulus until it came into view of the camera. The location in which the stimulus appears is the same for all six stimuli (2 snakes, 2 rabbits, 2 bottles) on route 1, and for all six stimuli on route 2. In each video the stimulus appears in view after one minute of hiking. This allowed me to collect baseline GSR and HR prior to the appearance of the stimulus. Participants continued on the hike for the second minute, but data from the last 50 sec of the hike is not relevant to the hypotheses of the current study and is aimed at other research questions in our laboratory.

Participants were randomly assigned to one of twelve conditions (one of the six stimuli on one of the two routes). To determine sample size, I conducted a power analysis and obtained an effect size of .46 from a previous study (Weimer, Gerdes & Pauli, 2013) that measured physiological reactions to seen and unseen images of spiders versus flowers. Using G*Power, I determined that 77 participants were needed. I recruited 160 participants to adequately power interaction effects (Giner-Sorolla, 2018) between condition and detection (seen or not seen) on the physiological outcome measures (SCR and HR).

Measures

GSR was measured using the iWorx PK214 (iWorx Systems Inc., Dover, NH, USA) dual channel biopotential amplifier, receiving input from a pair of Ag/AgCL electrode sensors. iWorx A-GSR-GEL, a saline concentration closely resembling sweat, was applied to the ring and middle fingers of the participant's non-dominant hand before applying the electrodes. Heart rate was measured using a PT-104 plethysmograph sensor connected to the biopotential amplifier. The sensor was placed on the participant's index finger on his/her non-dominant hand. The iWorx PK214 amplifier was connected to a laptop computer that recorded the responses using LabScribe 2 software (iWorx Systems Inc., Dover, NH, USA).

Outcome Measures

Stimulus detection. After viewing the video, participants were shown three photographs in a random order, with one of the photos being the stimulus that appeared in the video and the others being the stimuli that appeared in other conditions. Participants indicated which, if any, of the objects they saw “with a high degree of certainty.”

Skin conductance. The largest SCR deflection greater than 0.05 micro Siemens within 10 s following the appearance of the stimulus was calculated for each participant. A deflection typically occurs within 5 s following the appearance of the stimulus; because participants may have seen the stimulus at the end of the 5 s in which it appeared, the greatest deflection during the 5 s of stimulus presentation and the 5 s following was used as my measure. Accordingly, if there were multiple SCR deflections within the 10 s, the largest SCR deflection was recorded as the measure of response. If there was no deflection greater than 0.05 μ S during or up to 10 s after the appearance of the stimulus, the participants' score was recorded as zero (Braithwaite et al., 2015).

Heart rate. The participants' heart rate, measured in beats per minute, was calculated for the period starting when the stimulus was in view and ending 10 s afterwards (BPMe). There seems to be no standard for how long a HR response typically lasts before returning to baseline, but studies measuring HR use intervals of about 20 s between stimuli presentations, and measure HR responses about 6 s following stimulus presentation (Globisch et al., 1999; Palomba et al., 1997). Baseline HR was determined as average BPM in the 20 s preceding the appearance of the stimulus (BPMb). A difference score (BPMe-BPMb) was calculated for each participant and analyzed using a two-way ANOVA to determine differences in HR responses across conditions (hypotheses 3 and 5).

Snake Fear Questionnaire (SNAQ). My research question asked if there is a relationship between self-reported high snake fear with increased detection and physiological responses in the snake condition. The SNAQ is a 30-item self-report scale that assesses snake fear from none to high levels. Klorman, Hastings, Weerts, Melamed, and Lang (1974) reported a mean score of 6.36 based on a sample of 244 undergraduate students. This measure has high test-retest reliability ($r = .84$) and, has been validated to discriminate snake fear only; individuals with a snake phobia exhibit a mean score of 24.44 ($SD = 3.82$) (Fredrikson, 1983).

As described earlier, participants who noted having an extreme fear of snakes were excluded from the study. However, participants' responses to the SNAQ (see Figure 2) were expected to exhibit a range of snake fearfulness, from none to moderate levels. Participants' responses were scored by assigning a "1" for a true response, and a "0" for a false response. Questions 6, 12, 16, 17, 20, 25, 27, and 28 were reverse coded in which a "0" was assigned for a true response, and a "1" was assigned for a false response. Responses to all of the questions were added to create a snake fear score from 0-30, in which higher scores indicated higher snake fear.

Video Immersion. Participants indicated how successful they were at imagining themselves walking along the trail in the video. Level of immersion was assessed by a Likert scale ranging from 1 to 5 (1 = Not at all successful, 2 = A little successful, 3 = Moderately successful, 4 = Highly successful, 5 = Very successful). This served as a manipulation check to be sure that participants felt that they themselves were taking the hike.

General Procedure

The participants were greeted and told that the study was about emotions that people may experience while hiking, and that heart rate and skin conductance measures would be taken to help us understand those experiences. After giving informed consent, participants were escorted to the experimental room, and seated 24" in front of a 27" monitor. Conductive saline gel and sensors were placed on the index, middle and ring fingers of the participant's non-dominant hand and secured with Velcro. My instruction to the participant was as follows: "You are now going to watch a video of a virtual hike. It will last for just two minutes. While you are watching, imagine that it is YOU who is walking on the path. So, for instance, when you yourself are taking a hike you need to make sure to stay on the trail as you walk, and you need to be aware to step around obstacles in your path while you are observing the scenery. It is important that you try to think of this experience as being YOU, walking naturally on the hike, rather than watching someone else hiking. Is that clear?" Note that the participant was not told to specifically look for anything as s/he watched the video. As explained in the Introduction, the goal of the experiment was to determine if snakes are preferentially detected by primates when they are engaged in other activities (i.e., not specifically looking for a snake).

Participants were instructed to look into the blank, black monitor screen, place their hands on the desk gently, and remain still while I monitored baseline skin conductance and heart

rate for 30 s. This served two purposes: 1) to make sure the equipment was running properly and was actively recording the participant's physiological data, and 2) to habituate the participant to the equipment before the experiment began.

After confirming that the equipment was working, I started the two-minute video. I remained in the room, behind and to the side of the participant, to be sure s/he was attending to the screen and that GSR and HR were recording. Once the video was over, I showed the participant three photos, in a random order, one of which was the stimulus shown in the video, and the other two being the other stimuli in the study. After each photo the participant was asked whether or not the stimulus in the photo "was seen with a high degree of certainty." If the participant answered in the affirmative to any of them, s/he was asked to recall on which side of the trail it was seen. This served as a check on the validity of the participant's affirmative response.

Following the photo presentation, participants were asked, "As you watched the video, how successful were you at imagining that it was you walking along the trail, with a 5 being very successful and a 1 being not at all successful." This served as a manipulation check to be sure that participants felt immersed on the hike. Then, participants were given the Snake Fear Questionnaire (SNAQ) to assess their snake fearfulness. Finally, the participant was debriefed, given contact information for campus Student Health and Counseling Services if needed, and thanked for his/her participation.

Results

Pilot Results

A pilot study was implemented during the Fall 2018 semester using the same procedures and measures described above. The main purpose of the pilot study was to determine if there was variability in whether or not the stimuli were seen, and if GSR and HR variations were measurable.

Sample size was small ($N = 28$) but descriptive statistics revealed results in support of my hypotheses. First, more participants reported that they correctly saw the snake ($n = 6$) than the rabbit ($n = 5$) or bottle ($n = 4$). Among participants who reported seeing the stimulus, larger SCRs occurred in the snake condition than in the rabbit or bottle conditions. Also, among participants who correctly reported seeing the stimulus, larger HR decelerations occurred in the snake condition than in the rabbit or bottle conditions. Similarly, among participants who did not correctly report seeing the stimulus, larger SCRs occurred in the snake condition than in the rabbit or bottle conditions. And, among participants who did not correctly report seeing the stimulus, larger HR decelerations occurred in the snake condition than in the rabbit or bottle conditions.

Main Study

A total of 54, 53, and 53 participants viewed the videos that included the snake, rabbit, and bottle stimuli, respectively. All participants who reported seeing a stimulus were able to correctly identify the side of the trail on which they saw it, and no participant reported seeing a stimulus that was not in the video he or she saw. Participants reported a moderate level of immersion ($M = 3.70$ out of a maximum of 5, $SD = 0.73$). My results provide support for my hypotheses, as follows.

Hypothesis 1: Snakes will be reported as seen more often than the rabbits or bottles. A 2 (seen or not seen) x 3 (snake, rabbit, bottle) Chi-square test of independence was conducted to

determine if snakes were reported as seen more often than rabbits or bottles. A significant relationship was found between detection and condition ($\chi^2(2) = 19.08, p < .001$). Snakes were detected in 70% ($n = 38$ of 54) of the trials (95% CI [.57, .81]). In contrast, both rabbits and bottles were detected in 34% ($n = 18$ of 53) of the trials (95% CI [.34, .66]) (See Figure 3). When examining the adjusted standardized residuals, results indicated that the observed count was significantly higher than expected for the snake condition ($z = 4.4$) and lower than expected for the rabbit ($z = -2.2$) and bottle conditions ($z = -2.2$).

Hypotheses 2 and 3. Hypothesis 2 stated that participants who reported seeing the stimulus would have larger SCRs in the snake compared to the rabbit or bottle conditions. Hypothesis 3 stated that participants who did not report seeing the stimulus, would have larger SCRs in the snake compared to the rabbit or bottle conditions.

A two-way ANOVA (stimulus condition x detection) was conducted to examine SCRs. There were five missing values: one when the stimulus was seen (rabbit condition), and four when the stimulus was not seen (one in the rabbit, three in the bottle). The predictors significantly improved the model fit ($F(5, 149) = 9.01, p < .001, partial \eta^2 = .23$). Specifically, there was a significant main effect of stimulus condition ($F(2, 149) = 14.31, p < .001, partial \eta^2 = .16$). There was no significant main effect of detection (seen or unseen) ($F(1, 149) = 2.45, p = .120, partial \eta^2 = .02$), nor was there a significant interaction for SCR between stimulus condition and whether or not the stimulus was seen ($F(2, 149) = 0.64, p = .528, partial \eta^2 = .01$).

Helmert planned contrasts were conducted to compare the snake condition to the rabbit and bottle conditions, and the rabbit and bottle conditions to each other. The snake condition ($M = .31, SD = .39$), compared to the rabbit ($M = .07, SD = .16$) and bottle ($M = .02, SD = .05$) conditions, produced larger SCRs ($b = 0.23, SE = 0.05, p < .001, 95\% CI(b) [0.15, 0.32]$). There

was not a significant difference in SCRs between the rabbit and bottle conditions ($b = 0.07$, $SE = 0.05$, $p = .215$, $95\% CI(b) [-0.04, 0.17]$).

Additionally, comparisons revealed that when the stimulus was seen, snakes ($M = 0.35$, $SD = 0.42$) produced significantly larger SCRs than rabbits ($M = 0.12$, $SD = 0.23$) ($b = 0.22$, $SE = 0.07$, $p = .002$, $95\% CI(b) [0.08, 0.37]$, $d = 0.65$), or bottles ($M = 0.02$, $SD = 0.06$) ($b = 0.33$, $SE = 0.07$, $p < .001$, $95\% CI(b) [0.18, 0.47]$, $d = 1.08$). There was not a significant difference in SCRs between the rabbit and bottle conditions ($b = 0.10$, $SE = 0.08$, $p = .225$, $95\% CI(b) [-0.06, 0.27]$, $d = .70$). (See Figure 4).

When the stimulus was not seen, snakes ($M = 0.23$, $SD = 0.31$) produced significantly larger SCRs than rabbits ($M = 0.05$, $SD = 0.11$) ($b = 0.18$, $SE = 0.07$, $p = .017$, $95\% CI(b) [0.03, 0.33]$, $d = 1.03$) or bottles ($M = 0.02$, $SD = 0.04$) ($b = 0.21$, $SE = 0.07$, $p = .007$, $95\% CI(b) [0.06, 0.36]$, $d = 1.62$). There was not a significant difference in SCRs between rabbit and bottle conditions ($b = 0.03$, $SE = 0.06$, $p = .659$, $d = .40$, $95\% CI(b) [-0.09, 0.15]$, $d = .40$). (See Figure 5).

A post-hoc two-way ANOVA was conducted to assess differences in baseline GSR reactivity in order to determine if random assignment was successful in distributing individual differences in GSR reactivity across conditions. The predictors did not improve significantly improve model fit ($F(5, 149) = .08$, $p = .36$, $partial \eta^2 = .04$). There was no significant main effect of condition ($F(2, 149) = 2.33$, $p = .101$, $partial \eta^2 = .03$) or detection ($F(1, 149) = .01$, $p = .936$, $partial \eta^2 = .00$), nor was there an interaction between condition and detection ($F(2, 149) = .26$, $p = .774$, $partial \eta^2 = .00$).

Hypotheses 4 and 5. Hypothesis 4 stated that participants who reported seeing the stimulus, would have greater decelerations over average baseline heart rate in the snake

compared to the rabbit or bottle conditions. Hypothesis 5 stated that participants who did not report seeing the stimulus would have greater decelerations over baseline HR in the snake compared to the rabbit or bottle conditions.

A two-way ANOVA (stimulus condition x detection) was conducted to examine HR responses. The predictors significantly improved the model fit ($F(5, 154) = 5.53, p < .001, \text{partial } \eta^2 = .15$). Specifically, a significant main effect of condition was found ($F(2, 154) = 7.26, p = .001, \text{partial } \eta^2 = .09$). There was no significant main effect of detection (seen or not seen) ($F(1, 154) = 3.05, p = .083, \text{partial } \eta^2 = .02$), nor was there a significant interaction ($F(2, 149) = 0.33, p = .723, \text{partial } \eta^2 = .01$).

Helmert planned contrasts were conducted to compare the snake condition to the rabbit and bottle conditions, and the rabbit and bottle conditions to each other. The snake condition ($M = -1.11, SD = 2.22$), compared to the rabbit ($M = .79, SD = 2.35$) and bottle ($M = .65, SD = 2.15$) conditions, produced significantly greater HR decelerations ($b = -1.54, SE = 0.41, p < .001, 95\% CI [-2.34, -0.74]$). There was not a significant difference when comparing HR decelerations between the rabbit and bottle conditions ($b = 0.17, SE = 0.46, p = .718, 95\% CI [-0.74, 1.07]$).

Additional comparisons revealed that when the stimulus was seen, snakes ($M = -1.44, SD = 2.10$) produced significantly greater HR decelerations compared to rabbits ($M = 0.54, SD = 2.00$), ($b = -1.97, SE = 0.64, p = .002, 95\% CI(b) [-3.24, -0.71], d = -0.96$), and bottles ($M = 0.31, SD = 1.57$), ($b = -1.75, SE = 0.64, p = .007, 95\% CI(b) [-3.02, -0.48], d = -0.91$). There was not a significant difference in HR decelerations between the rabbit and bottle conditions ($b = 0.23, SE = 0.75, p = .764, 95\% CI(b) [-1.25, 1.70], d = 0.13$). Note, in fact, that neither the rabbit nor the bottle condition generated HR decelerations at all, as the means were above, not below, the baseline HR. (See Figure 6).

When the stimulus was not seen, snakes ($M = -0.35$, $SD = 2.38$) elicited greater HR decelerations than rabbits ($M = 0.92$, $SD = 2.53$), ($b = -1.27$, $SE = 0.67$, $p = .062$, $95\% CI(b) [-2.60, 0.06]$, $d = -0.51$), or bottles ($M = 0.82$, $SD = 2.41$), ($b = -1.16$, $SE = 0.67$, $p = .088$, $95\% CI(b) [-2.49, 0.17]$, $d = -0.48$) at levels that approached but did not reach statistical significance. There was not a significant difference in HR decelerations between the rabbit and bottle conditions ($b = 0.11$, $SE = 0.54$, $p = .841$, $95\% CI(b) [-0.95, 1.17]$, $d = 0.04$). As was true when the stimulus was seen, neither the rabbit nor the bottle condition generated HR decelerations at all, as the means were above, not below, the baseline HR. (See Figure 7).

Research Question: Is self-reported snake fear associated with detection and physiological responses in the snake condition?

Scores on the SNAQ ranged from 0 to 21 out of a maximum score of 30 ($M = 6.57$, $SD = 4.12$), and Cronbach's alpha indicated high test-retest reliability ($r = .78$). These scores are similar to the mean score reported by Klorman et al. (1974), and the test-retest reliability reported Fredrikson (1983). Participants in the snake condition detected snakes in 38 out of 54 trials, and produced a mean SCR score of 0.31 ($SD = 0.39$) and mean HR deceleration score of -1.11 ($SD = 2.22$).

A binary logistic regression indicated a non-significant relationship between snake detection and snake fearfulness ($\chi^2(1) = 2.01$, $p = .156$, $OR = 1.13$, $95\% CI(OR) [0.96, 1.34]$). Two Pearson bivariate correlations revealed a non-significant relationship between snake fear and SCRs ($r(54) = -0.08$, $p = .546$), and a non-significant relationship between snake fear and HR decelerations ($r(54) = -0.15$, $p = .290$).

Discussion

The goal of my study was to contribute to Snake Detection Theory by investigating preferential detection of and physiological arousal to snakes in a naturalistic environment even during the absence of conscious awareness. I tested five hypotheses by having participants take a virtual hike in which a realistic model of a snake, rabbit, or bottle were placed on a hiking trail. H 1 predicted that snakes would be reported as seen more often than rabbits or bottles. H 2 predicted that among participants who reported seeing the stimulus, larger SCR responses would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions. H 3 predicted that among participants who did not report seeing the stimulus, larger SCR responses would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions. H 4 predicted that among participants who reported seeing the stimulus, greater decelerations over average baseline heart rate would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions. H 5 predicted that among participants who did not report seeing the stimulus, greater decelerations over average baseline heart rate would occur during stimulus exposure in the snake compared to the rabbit or bottle conditions. I also asked a research question: is self-reported snake fear associated with increased detection and physiological responses in the snake condition?

The results of my study provide strong support for Isbell's (2006) Snake Detection Theory. My data are the first to show that people a) detect snakes more often than control objects and b) show physiological responses indicative of detection and arousal even if the snake was not reported as seen, in a controlled but naturalistic experimental context. I also found that self-reported fear of snakes is not related to snake-related physiological arousal or the likelihood of detecting snakes.

Snake Detection

The central prediction of Snake Detection Theory is that the primate visual system evolved in order to increase the likelihood that we will detect snakes in our environment (Isbell, 2006). This prediction was supported by my data (H1). The participants in the snake condition were more likely to report seeing a snake than not, whereas the reverse was true for rabbits and bottles.

Snakes are the oldest and one of the most ubiquitous threats to primates, posing danger as predators of primates and/or as deliverers of venom in response to being threatened themselves. Past research has shown that human and non-human primates detect snakes more quickly than animate and inanimate controls (Kawai & Koda, 2016; LoBue & DeLoache, 2008; Öhman, Soares, Juth, Lindstrom & Esteves, 2012; Shibasaki & Kawai, 2009; Shibasaki & Kawai, 2011; Soares, 2012; Soares & Esteves, 2013). These studies used visual search paradigms in which the subject was tasked with identifying a target stimulus on a computer screen. Kawai and Huachen (2019) constructed photographs of natural scenes in which snakes or lizards appeared in a flicker paradigm study. Participants were more likely to report that they detected a change in the environment when a snake appeared in the photo compared to when a lizard appeared. These methodologies have participants look at still photographs and ask them to search for an object (the visual search studies) or attend to an event (e.g., change). In contrast, in my study participants were not instructed to look for or notice anything in particular, and they were moving (virtually) through a changing environment. These are the very circumstances in which an ability to detect a snake is probably most important, and Snake Detection Theory relies on the assumption that snakes are detected in natural environments even when attention is directed elsewhere (e.g., looking for landmarks or food, or attending to a companion). My data provide

important new evidence in support of Snake Detection Theory by showing that snakes are detected more often than another animate object (a rabbit) or an inanimate object (a bottle) under circumstances that are more naturalistic than those described in the literature thus far.

In contrast to my results, data from inattentional blindness studies have not supported the presumed superiority of snakes in capturing preattentive awareness (Calvillo & Jackson, 2014). Calvillo and Hawkins (2016) found that, while attending to a word search on a screen, participants were less likely to notice the presentation of a snake image than that of a spider, bird, cow, chair, or gun. In a second experiment, the authors found that, overall, non-threatening animate objects were detected more often than threatening objects. It is unclear why threats would be less often noticed than nonthreatening objects, and why snakes in particular were so infrequently detected in this paradigm, but it should be noted that the inattentional blindness research has not yet corroborated Snake Detection Theory.

Arousal Reactions to Detected Snakes

Another central component of Snake Detection Theory is that detection of a snake is accompanied by arousal that will motivate a primate to quickly react to the snake in a way that reduces the chance of attack. I predicted that among participants who reported seeing the stimulus, larger SCRs would occur in association with exposure to the stimulus in the snake condition compared to the rabbit or bottle conditions (H2). I also predicted (H3) that there would be greater heart rate decelerations to snakes than to rabbits or bottles (recall that highly fearful participants, who would be expected to show HR accelerations, were excluded from the study). These predictions were supported. Participants who saw snakes produced significantly larger SCRs and significantly greater HR decelerations than those who saw rabbits or bottles.

To avoid direct contact with a detected snake, primates should show startle reactions, selective attention, and enhanced vigilance (Wombolt & Caine, 2016). These reactions are likely to be evoked by arousal, and evidence of arousal can be found in measures of galvanic skin response (GSR), heart rate (HR) changes, and brain activity (e.g., Globisch et al., 1999; Thrasher & LoBue, 2016; Van le et al., 2013; Van le et al., 2016; Van Strien, Christiaans, Franken, & Huijding, 2016; Van Strien, Eijlers, Franken, & Huijding, 2014; Van Strien, Franken, & Huijding, 2014; Van Strien & Isbell 2017). In support of Snake Detection Theory, Globisch and colleagues (1999) found that photos of snakes produced larger skin conductance responses than control objects. The photos also elicited heart rate decelerations, indicative of focused attention (Palomba, Angrilli & Mini, 1997; Thrasher & LoBue, 2016), although highly snake-fearful participants responded with HR accelerations instead. Higher EPN amplitudes in the lateral occipital lobe, which are indicative of early visual processing, were found in human participants when viewing a series of rapidly appearing photos of snakes compared to spiders, slugs, crocodiles, or turtles (Van Strien, Eijlers, Franken & Huijding, 2014; Van Strien, Franken & Huijding, 2014). My research is yet another demonstration that snakes are preferentially responded to by primates in such a way that reduces injurious or even fatal encounters with snakes, and the first such demonstration in a naturalistic context.

Unconscious Responses to Snakes

Perhaps even more important to Snake Detection Theory than evidence of physiological responsiveness to seen snakes is the prediction that primates have the ability to respond with arousal and avoidance to snakes even before conscious awareness of the snake's presence. I predicted that there would be greater SCRs and HR decelerations in the snake versus rabbit or bottle conditions even when those stimuli were not reported as having been seen (H4 and H5).

My predictions were supported for SCRs; differences in the predicted direction were also apparent for HR but they failed to reach statistical significance ($p = .06$ and $.088$ for comparisons with bottle and rabbit conditions, respectively).

Given their ambush hunting strategies and camouflaged skin, a snake may not be detected until it is virtually under foot. The tectopulvinar pathway of the primate visual system is a subcortical pathway that travels from the retina directly to the superior colliculus of the midbrain and then to the pulvinar of the thalamus. In this pathway, the superior colliculus is specialized for the detection of moving stimuli and the triggering of the fight or flight response; the pulvinar is specialized for rapid eye movements and sending visual information to the amygdala. The TTP transmits visual information more quickly than the geniculostriate pathway, which is responsible for true sight and conscious awareness of visual information. The tectopulvinar pathway, has, therefore, received attention in Snake Detection Theory for its likely role in mediating quick, unconscious reactions to snakes. In fact, there are neurons in the pulvinar that seem to be specially tuned to snakes. These neurons respond quicker and produce higher magnitudes in response to images of snakes compared to other controls (Van le et al., 2013; Van le et al., 2016).

There is ample evidence in psychology that physiological reactions to stimuli can occur even when the viewer is not aware of having seen the stimulus. For instance, Globisch et al. (1999) found greater SCRs and HR decelerations to snake/spider photos compared to controls when stimuli were presented for 150 ms. Also, Weimer and colleagues (2012) found greater SCR responses to spider stimuli compared to flowers at durations (200 ms) that would not allow participants to consciously detect the stimulus. These studies provide evidence that physiological responses can be elicited even without full perceptual awareness of a stimulus. Therefore, I predicted that if the tectopulvinar pathway is involved in the detection of snakes there should be

evidence of it in physiological arousal even when a snake in the individual's visual field is not reported as having been seen. My study reinforces the likely role of the tectopulvinar pathway, as it is the first to reveal physiological reactions indicative of arousal in a naturalistic context even when a snake is not consciously detected.

Relationship of Self-Reported Snake Fear to Detection and Arousal

Using the Snake Fear Questionnaire (Klorman, Hastings, Weerts, Melamed, & Lang, 1974) I expected, and found, a range of snake fearfulness from none to moderate levels in my participants. This allowed me to determine if degree of fearfulness was associated with detection of the snakes in my videos. My results showed no such relationship. Also, I found no relationship between degree of self-reported snake fear and SCRs or HR decelerations. The fact that my participants were not highly fearful and showed, on average, decelerations of HR, corroborates their self-reports; highly fearful people tend to show HR acceleration to the feared stimulus, not deceleration.

Limitations and Further Considerations

In order to account for individual differences of physiological reactivity within GSR measurements, it is recommended that SCRs produced to a stimulus be standardized by comparing event-related SCR deflections to baseline SCR deflections. According to Braithwaite et al. (2015), the best practice is to measure each of a participant's SCR deflections up to and including the stimulus deflection, transforming them into a z-score distribution for that participant. This standardization accounts for individual differences in overall GSR responsiveness and allows researchers to more accurately compare the event-related SCR deflections. However, this procedure is only applicable to research questions that produce data

sets with frequent baseline SCRs and a measurable SCR to the stimulus for each participant. My hypotheses were addressed with procedures that are unlikely to produce that sort of data. Indeed, many of my participants did not produce a SCR deflection when the stimulus was in view ($n = 95$). Others produced a limited number of baseline SCRs (e.g., 25 participants produced just one baseline SCR, and 3 produced no baseline SCRs). This made it impossible to calculate a standard deviation, which in turn made it impossible to calculate a z-score for many of my participants and prevented me from accounting for a participants' overall GSR reactivity. However, random assignment to group makes it likely that there was a range of GSR reactivity across the participants in all three conditions (snake, rabbit, bottle). In fact, a post hoc two-way ANOVA revealed that there was no difference between average baseline SCR deflections across stimulus conditions.

It should also be noted that my GSR data was positively skewed, which violates the assumption of normality for a parametric test. However, ANOVA is a robust statistical test that is relatively immune to this violation.

For reasons having to do with ethical concerns about psychological distress, and in order to make the interpretations of HR changes clearer, I excluded participants from my study who noted on a pre-screening form that they had an extreme fear of snakes. By excluding participants who were highly fearful of snakes, my conclusions only pertain to those with none to moderate snake fears. Öhman, Flykt, and Esteves (2001) found that participants who scored in the 90th percentile on the SNAQ detected snakes and spiders quicker than non-fearful participants, but Lipp, Derakshan, Waters, and Logies (2004) were unable to replicate this finding. Both studies indicated that, regardless of fear levels, participants identified snakes and spiders significantly

quicker than control stimuli. Thus, it seems unlikely that including participants with an extreme fear of snakes would have altered my results regarding detection (Hypothesis 1).

One may argue that fear could motivate a person to be vigilant for snakes. Nonetheless, my data suggest that fear is not necessary for snake detection, and arousal (HR decelerations and SCRs) is not dependent on fear. There is little evidence that humans are innately afraid of snakes; rather, humans are predisposed to carefully attend to snakes (Lobue & Adolph (2019)). The HR responses of my participants (i.e., decelerations) suggest that I captured these attentional responses. LoBue and Adolph (2019) argue that it is often more adaptive to evolve a cognitive bias toward careful attention to certain classes of stimuli than it is to be automatically fearful of those stimuli. Fitness is enhanced by the most efficient expenditures of energy, and unnecessary expressions of fear are not efficient (Caine, 1998).

I chose to use two non-threatening control objects (rabbit and bottle) to test my hypotheses about the special role that snakes play in visual attention and perception. My data do not allow me to claim that snakes are detected more often and with greater arousal than other control stimuli. Also, I did not use another threatening stimulus as one of my controls because of difficulties in presenting a realistic threat that was not either much smaller (e.g., a spider) or much larger (e.g., a mountain lion) than the snake stimulus. It will be important in future research to compare snakes to additional stimuli in naturalistic contexts. Likewise, using additional replicates of the stimuli will reduce the threat of pseudoreplication in this research. The animate monitoring hypothesis states that animate objects capture attention because of their importance for detecting predators and prey in ancestral hunter-gatherer societies (Calvillo & Hawkins, 2016). Although I was only interested in comparing snakes to my control objects, and not the control objects to one another, I found that rabbits and bottles were equally often

detected. Calvillo and Jackson (2014) found that when searching for a target word among varying distractor words on a white background, unexpected animate objects were detected more often than inanimate objects under low (three words) but not high (six words) perceptual loads. LaPointe (2010) found that people, but not other types of animals, were detected more often than inanimate controls within natural scenes in a flicker paradigm study. The conditions under which my participants detected (or not) the stimuli would be considered high in perceptual load. The animate monitoring hypothesis may be limited to conditions of low perceptual load, and/or “animate” may be far too broad a category when compared to “inanimate.” In any case, Snake Detection Theory claims that snakes are a special case of animacy, and my data are consistent with that claim.

Future Directions

Researchers might benefit from investigating snake detection through eye tracking. For example, Weimer et al. (2013) found no difference between spider and flower detection rates when asked what stimulus the participants saw, but they found more frequent eye saccades toward spiders compared to flowers in the full attention and inattention trials. The authors suggest that frequent eye movements toward spiders during the inattention trials are the result of activation of the subcortical visual pathway that unconsciously and quickly processes threatening stimuli. Eye tracking measures would be useful in corroborating self-report measures of detection, and would be particularly interesting in cases where physiological reactions are recorded in the absence of conscious awareness. In my study, for instance, eye-tracking could tell me if those who did not report seeing the snake but showed GSR changes did indeed look at the stimulus. Such research would be especially valuable if it could take place under naturalistic circumstances

Coelho, Suttiwan, Faiz, Ferreira-Santos, and Zsido (2019) point out that there are few ecologically valid experiments in the Snake Detection Theory literature. In addressing this criticism, I used videos of a hike that were displayed on a computer screen. Care was taken to encourage participants to immerse themselves in the experience, and participants did report feeling immersed to at least a moderate degree ($M = 3.70$ out of 5, $SD = .73$). However, the experience was not identical to what a person experiences while taking a hike, where other sensory cues (sound, odor, proprioception, etc.) might influence snake detection and arousal. One way to more closely replicate the natural environment is virtual reality. Huff, Zielinski, Facticeau, Brady, and LaBar (2010) report that fear conditioning studies can be effectively performed in an immersive virtual reality environment, and that both snakes and spiders elicited SCRs both in the acquisition and extinction phases. Furthermore, participants in the virtual reality simulation produced larger SCRs during the extinction phase compared to when they viewed the photo images of these stimuli on a computer screen. This suggests that virtual reality could serve as an effective way to test hypotheses developed from Snake Detection Theory.

Conclusions

Snake Detection Theory rests on the assumption that the primate visual system is adapted to detect snakes quickly and promote the avoidance of them, making use of an evolved visual pathway that promotes detection and avoidance even before there is conscious awareness. Research with human and non-human primates has supported Snake Detection Theory using visual search paradigms within a laboratory setting. But the biggest threats posed by snakes appear in natural contexts while individuals are moving through the environment and are not actively searching for snakes. Detection should be accompanied by arousal that reduces the chance of contact with the snake. If Snake Detection Theory is correct, there should be

physiological reactions indicative of arousal that accompany detection of a snake, whether or not the person is consciously aware of seeing a snake in a natural environment. My research has contributed to the Snake Detection Theory literature by showing for the first time that, in a simulation of the natural circumstances under which snakes might be encountered, people detect snakes more often than rabbits or bottles and demonstrate physiological arousal in response to those snakes even in the absence of conscious awareness.

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A.



B.



C.



D.



Figure 1. Photos of the models used in the experiments: A) Southern Pacific Rattlesnake (*Crotalus oreganus helleri*); B) Western Diamondback Rattlesnake (*Crotalus ruber*); C) and D) light and dark brown Desert Cottontail rabbits (*Sylvilagus audubonii*); E) and F) amber and green

glass bottles. These photos were shown to the participants after they view the videos to determine if the stimulus was or was not detected.

TRUE	FALSE	
_____	_____	1. I avoid going to parks or on camping trips because there may be snakes about.
_____	_____	2. I would feel some anxiety holding a toy snake in my hand.
_____	_____	3. If a picture of a snake appears on the screen during a motion picture, I turn my head away.
_____	_____	4. I dislike looking at pictures of snakes in a magazine.
_____	_____	5. Although it may be so, I think of snakes as slimy.
_____	_____	6. I enjoy watching snakes at the zoo.
_____	_____	7. I am terrified by the thought of touching a harmless snake.
_____	_____	8. If someone says that there are snakes anywhere about, I become alert and on edge.
_____	_____	9. I would not go swimming at the beach if snakes had ever been reported in the area.
_____	_____	10. I would feel uncomfortable wearing a snakeskin belt.
_____	_____	11. When I see a snake, I feel tense and restless.
_____	_____	12. I enjoy reading articles about snakes and other reptiles.
_____	_____	13. I feel sick when I see a snake.
_____	_____	14. Snakes are sometimes useful.
_____	_____	15. I shudder when I think of snakes.
_____	_____	16. I don't mind being near a non-poisonous snake if there is someone there with whom I have confidence.
_____	_____	17. Some snakes are very attractive to look at.
_____	_____	18. I don't believe anyone can hold a snake without fear.

- _____ _____ 19. The way snakes move is repulsive.
- _____ _____ 20. It wouldn't bother me to touch a dead snake with a long stick.
- _____ _____ 21. If I came upon a snake in the woods I would probably run.
- _____ _____ 22. I'm more afraid of snakes than any other animal.
- _____ _____ 23. I would not want to travel "down south" or in tropical countries because of the greater prevalence of snakes.
- _____ _____ 24. I wouldn't take a course like biology if I thought I might have to dissect a snake.
- _____ _____ 25. I have no fear of non-poisonous snakes.
- _____ _____ 26. Not only am I afraid of snakes, but worms and most reptiles make me feel anxious.
- _____ _____ 27. Snakes are very graceful animals.
- _____ _____ 28. I think that I'm no more afraid of snakes than the average person.
- _____ _____ 29. I would prefer not to finish a story if something about snakes was introduced into the plot.
- _____ _____ 30. Even if I was late for a very important appointment, the thought of snakes would stop me from taking a shortcut through an open field.

Figure 2. Snake Questionnaire (SNAQ). Participants indicated true (if mostly true or true most of the time) or false (if mostly false or false most of the time) for each statement.

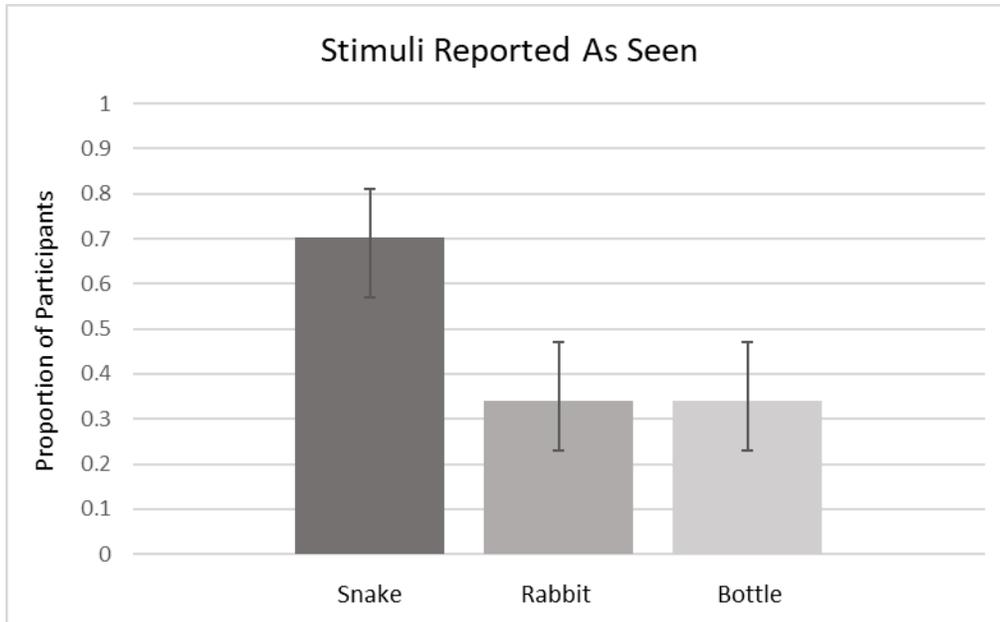


Figure 3. Proportion of participants reporting how often the stimulus was reported as seen.

Snakes were significantly more often reported as seen than rabbits or bottles.

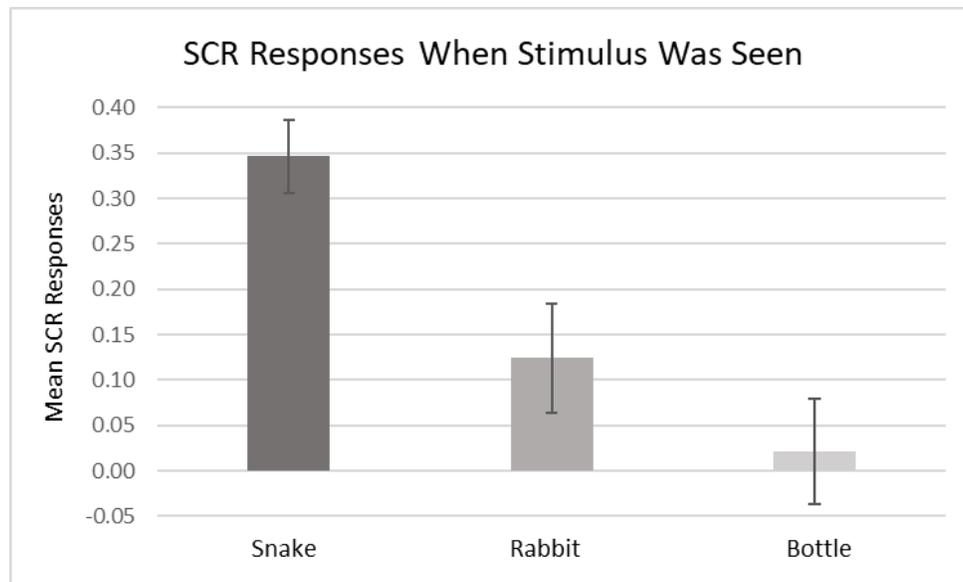


Figure 4. When the stimulus was reported as seen, the average skin conductance response (SCR) produced while the stimulus was in view, was significantly greater in the snake than in the rabbit or bottle conditions. The rabbit and bottle conditions did not differ. Error bars represent standard errors.

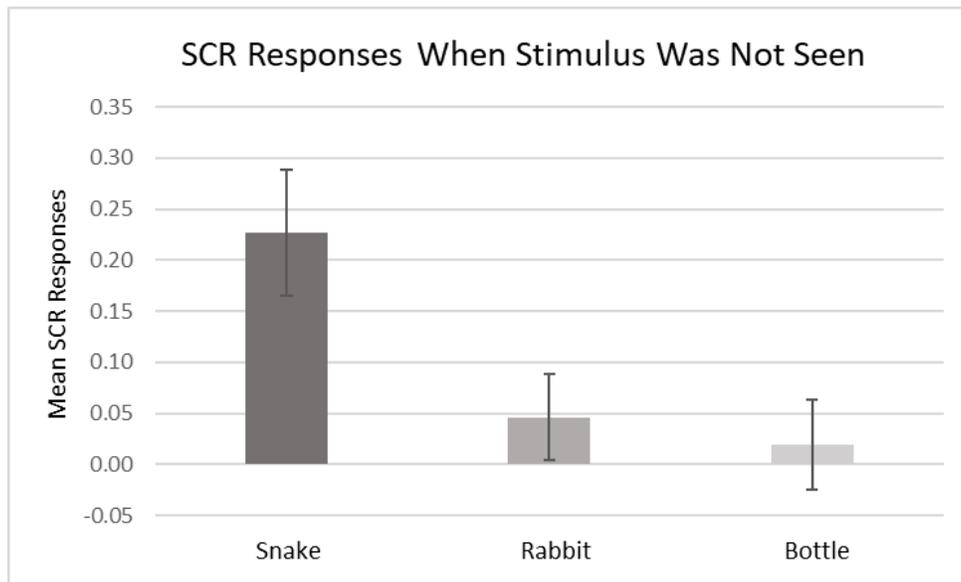


Figure 5. When the stimulus was not reported as seen, the average skin conductance response (SCR) produced when the stimulus was in view, was significantly greater in the snake than in the rabbit or bottle conditions. The rabbit and bottle conditions did not differ. Error bars represent standard errors.

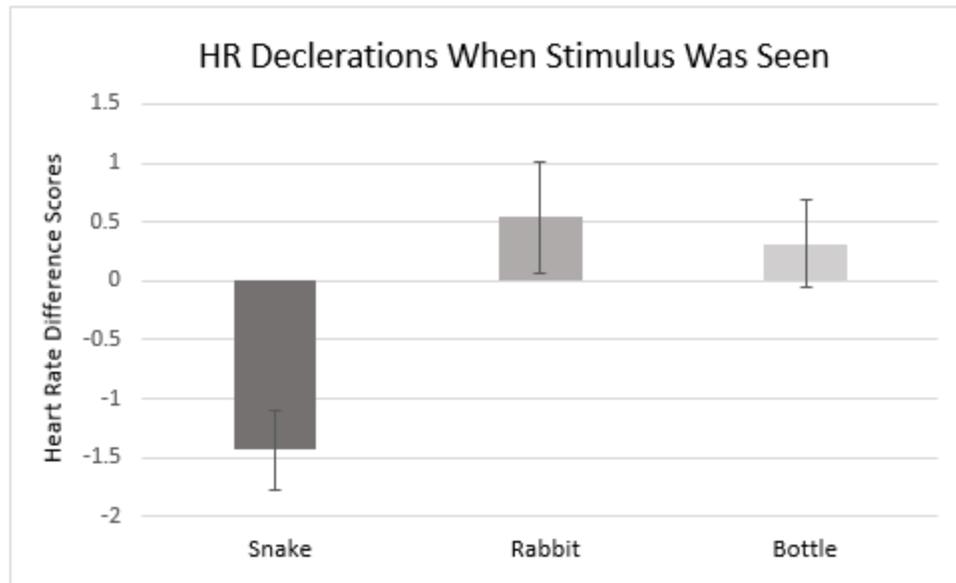


Figure 6. When the stimulus was reported as seen, average HR decelerations, over baseline heart rate, were significantly greater in the snakes than in the rabbit or bottle conditions. The rabbit and bottle conditions did not differ. Error bars represent standard errors.

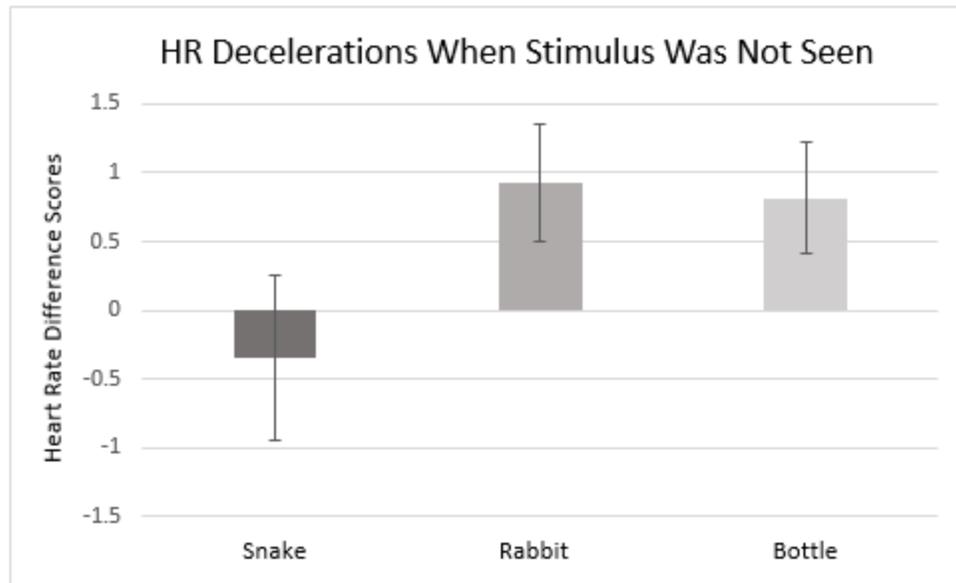


Figure 7. When the stimulus was not reported as seen, differences in average HR decelerations, over baseline HR, approached significance in comparison to the rabbit ($p = .062$) and bottle conditions ($p = .088$) conditions. There was no difference between the rabbit or bottle conditions. Error bars represent standard error for each condition