Visual salience and biological motion interact to determine camouflaged target detectability

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ABSTRACT

Target visual salience and biological motion independently influence the accuracy and latency of observer detection. However, it is currently unknown how these target parameters might interact in modulating the detectability of camouflaged human targets. In two experiments, observers performed a visual target detection task. In a pilot experiment, observers detected a static human target with parametrically varied visual salience, superimposed on a complex background scene. As expected, results demonstrated varied target detectability as a function of salience, with observers showing higher hit rates and faster response times as a function of increased salience. In the Main Experiment, observers detected simulated human targets walking across a complex scene at five different speeds and three different levels of visual salience (as validated in the pilot experiment). We found strong effects of both movement rate and visual salience, and the two parameters interacted. Specifically, increasing the rate of biological motion increased detectability for even the least salient camouflage patterns. In other words, biological motion can "break" even the least conspicuous camouflage pattern. In contrast, a very salient pattern was highly detectable under static and moving conditions. Results are considered in relation to theories of camouflage detectability, and trade-offs between camouflage development efforts versus advanced training in military maneuvering.

1. Introduction

Camouflage is intended to reduce the detection and recognition of both predators and prey by reducing their visual signature against background scenes (Cuthill et al., 2005; Merilaita et al., 2017; Merilaita and Stevens, 2011). There are a wide variety of camouflage principles that have been explored, such as background pattern matching and disruptive coloration, and each has independently demonstrated its value in altering target detectability (Cott, 1940; Skelhorn and Rowe, 2016; Stevens and Merilaita, 2011; Thayer, 1918). The military has adopted many such principles in the design and development of environment-specific and environment-general (i.e., transitional) camouflage patterns (Santos et al., 2004). However, in order to test the effectiveness of camouflage patterns, much of the research done by U.S. and foreign military has only considered static camouflage patterns superimposed on complex background images (Augustyn et al., 2008; Brunyé et al., 2017; Brunyé et al., 2012; Friškovec, Gabrijelčič, & Simončič, 2010; Gretzmacher et al., 1998; Lin et al., 2014; Todd, 2009). In contrast, decades of research have demonstrated that the human perceptual system is highly sensitive to biological motion (Johansson, 1973; Neri et al., 1998; Simion et al., 2008; Thornton and Vuong, 2004), and military personnel are expected to constantly move between points of cover and concealment (Army, 2010). Thus, there is presently a gap in knowledge related to how movement of a camouflaged human target might interact with manipulations of target salience. For instance, could even the least conspicuous camouflage patterns become detectable under conditions of biological motion? The present research represents a first step in filling that knowledge gap, by examining the independent and interactive influence of target biological motion on camouflage pattern detectability.

2. Target detectability & biological motion

The mechanisms underlying target visual detectability are of great interest to zoologists, biologists, perceptual scientists, and pattern designers alike. In general, camouflage considers the colors and patterns characteristic of a target, as well as its morphology relative to a background scene (Merilaita et al., 2017). Colors, patterns, and morphology can vary in systematic ways to independently and interactively influence detectability, and several decades of work have identified several

fundamental principles driving detectability. These include background pattern matching, disruptive coloration, masquerade, and countershading. Background pattern matching or "crypsis" involves a target's coloration, lightness and patterning consisting of a random sampling of its immediate background (Cuthill et al., 2005; Stevens and Merilaita, 2009). An example of background pattern matching is adorning a target with foliage of a background scene (e.g., a Ghillie suit), which can provide a target with similar coloration and patterning as adjacent vegetation. Disruptive coloration involves the fractionation of a target's outline to create the perception of false edges and boundaries, for instance by introducing high contrast patterns near the edge of a target (Schaefer and Stobbe, 2006; Stevens and Merilaita, 2009). Masquerade involves a target taking on the resemblance of an uninteresting object (non-target), for instance a caterpillar masquerading as a twig can reduce the likelihood that it is recognized as an edible target by a predator (Skelhorn et al., 2010). Finally, countershading works by counteracting the shadow gradient on the body introduced by directional light, making the body appear relatively flat, as seen in fish with a dark-to-light gradient from the top to bottom of their bodies (Cuthill et al., 2016; Kiltie and Laine, 1992).

Most camouflage research has considered either static targets superimposed on background scenes (e.g., Cuthill et al., 2005), or abstract non-biological targets (e.g., rectangles) moving across a complex scene (e.g., Stevens et al., 2011). In the animal literature, only in the past decade was it established that motion can interact with background matching to influence visual detection (Ioannou and Krause, 2009). In that study, researchers examined whether chironomid larvae need to background-match and/or remain motionless to avoid predation by three-spined sticklebacks. Results showed that both background matching and motion contribute to detection, and that they interact such that even highly background-matching prey become detectable when moving. More recently, similar results have been found with cuttlefish faced with predation risk by sharks (Bedore et al., 2015). These findings provide empirical support for earlier anecdotal evidence that the "sit and wait" and "freezing" behaviors observed in diverse animal species are effective tool for avoiding detection by both predators and prey (Eilam, 2005; Théry et al., 2005).

While these studies have demonstrated innovative independent and interactive effects of multiple camouflage principles, including background matching and motion, they have largely neglected how human biological motion might influence target detectability. Human biological motion has received considerable attention in the perceptual sciences and neurosciences literature. Biological motion describes the movement patterns of animals, which are very different from the simple mechanical motions of other moving objects such as vehicles (Johansson, 1973). In the classic setup, biological motion is simulated by illuminating the joints in walking human figure. The more realistic the walking figure in terms of its movement biomechanics and number of illuminated joints, the more sensitive observers are to detecting its presence (Neri et al., 1998). Even infant observers are inherently very sensitive to detecting biological motion (Simion et al., 2008), and the neurosciences have identified a network of adult brain regions, including the occipitotemporal junction, that are selectively responsive to the presence of biological motion (Grèzes et al., 2001; Grossman et al., 2000). Given the inherent sensitivity of human observers to detecting biological motion, it is important to understand how this sensitivity might interact with more traditional conceptualizations of target visual salience.

3. The present study

The present research seeks to provide an initial examination of how the visual salience of a human-shaped target interacts with the rate of biological motion to influence the accuracy and latency of observer detection. We conducted two experiments. The first was a pilot experiment examining the influence of static (non-moving) human-

shaped target visual salience on observer detection. Target salience was systematically altered by varying the opacity of a target's background-matching camouflage pattern relative to a red image layer that was highly salient relative to the background scene. Opacity in this context describes the extent to which the salient layer was visible through the camouflage pattern. We hypothesized a linear influence of opacity shifts on observer detection: as target pattern opacity is parametrically reduced to reveal the red image layer, observer detection rates would increase, along with faster response times. Data from this pilot experiment helped establish a set of salience conditions that reliably influence observer detection in static target conditions. The second experiment used these salience conditions and, in a factorial design, crossed them with the speed of target biological motion. We hypothesized independent influences of target salience and biological motion speed, but also a possible interaction wherein even the least salient patterns would become conspicuous under conditions of fast biological motion.

3.1. Pilot experiment method

3.1.1. Participants and design

Thirty-five male (n = 14) and female (n = 21) adults (M_{age} = 21.7, SD_{age} = 3.7) were recruited to participate in the study for monetary compensation. Participants were consented in accordance with human use approvals issued by Tufts University and the U.S. Army. To qualify for participation, they had to pass a visual acuity (Snellen eye chart) and color vision test (Ishihara pseudoisochromatic plates (Birch, 1997);); five of the 35 did not qualify, leaving 30 complete data sets for analysis. We used a single-factor within-participants design, manipulating the salience of a target camouflage pattern relative to the background scene.

3.1.2. Materials

Materials consisted of targets embedded within a background image.

3.1.3. Background images

A set of 60 background images was created. A single image was developed by pixel-scrambling (10 × 10 squares) a high resolution (1920 × 1080) urban color photograph. The image had an average color of 132, 131, 136 in RGB space (55, 1, −3 in Lab), and primary red (255, 0, 0 in RGB space) was not represented in the image. Multiple versions of this image were created by randomly selecting and re-scrambling 25% of the image's 10 × 10 squares. In this manner, background images were highly similar (75% overlap) to one another, with subtle random alterations across images. Fig. 1 (top panel) depicts a single version of the pixel-scrambled background image.

3.1.4. Target images

We developed a sprite sheet animation using a walking human developed via full-body motion capture. A sprite sheet is comprised of two-dimensional bitmap images, with each image depicting a single frame of an animated movement. The sprite sheet had 26 frames, depicting a normal walking gait cycle, starting at right heel strike and continuing through the entire gait cycle. The gait cycle frames had an average target surface area of 3043 pixels (138 h × 50w); this size was intended to emulate a human target at 50 m from observer, a distance chosen due to a high probability of hit (0.95) with standard weapons, based on Army doctrine (Army, 2004). Using Photoshop CC (Adobe Systems, Inc.), each target frame was layered with the same random sample of a unique version of the pixel-scrambled urban photograph. In this manner, each target frame was identically patterned and a nearly perfect background pattern match. Behind this patterned layer, we placed a primary red (255, 0, 0 in RGB space) layer on each target frame. In this manner, at 100% opacity of the patterned layer, the red was imperceptible; systematically decreasing the percentage opacity