Disruptive coloration tricks the human eye – a study of detection times of two near-similar targets in natural backgrounds

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ABSTRACT

Our understanding of camouflage, in military as well as in evolutionary perspectives, has been developing over the last 100 years. In that period of time several underlying principles have emerged. It has turned out in the recent decade that background pattern matching alone may not be sufficient to conceal targets because of the ubiquitous and revealing information contained by the edges of a target. In this paper we have studied one concealment strategy, the so-called disruptive coloration, further as it predicts that high contrast patches placed at the target's outline will impede detection, by creating false target edges when exposed to the observer. Such disruptive coloration is contra-intuitive as it may impede detection in spite of the fact that the patches themselves may be poorly concealed. In military environments the "disruptive approach" within camouflage has been textbook material for decades. Still, very little has been reported, supporting this idea, especially when it comes to the concealment of human targets in natural sceneries. We report here experimental evidence from a field study, containing detection data from 12 unique natural scenes (5 testing the disruptive effect, 7 as reference tests), with both human targets and human observers, showing that disruptively colored camouflage patches along a human's outline (its head) may increase detection time significantly as when compared to a similar (human) target concealed only with background matching. Hence, our results support the idea that disruptive coloration may impede detection and similarly that the best concealment is achieved when disruptive coloration is added to a target that matches the background (reasonably) well. This study raises important question to the current understanding of human vision and concealment as well as to any approach to describe the human visual system mathematically.

Keywords: Camouflage, disruptive coloration, search, vision, contrast, human observers, background matching.

1. INTRODUCTION

Knowledge on your own signature, such as how effective concealment can be achieved in natural settings is very important in nature and warfare alike. The primary aim with camouflage is to turn a target into a non-conspicuity object when exposed to some kind of sensor, such as the human eye or other. For camouflage in the visual part of the electromagnetic spectrum, the primary purpose is to reduce a target's contrast relative to its local background [1, 2]. Low contrast relative to a natural background is normally achieved through similar spectral reflectance properties of target and background; hence the two reflect light equally over the visual spectrum. As no local, natural background look entirely alike (spectrally as well as structurally), camouflage patterns normally consist of different colours as such a visual appearance is assumed to be able to operate in a large variety of natural backgrounds and still provide acceptable reductions in contrast [3-5].

In military settings camouflage patterns have been used for decades and the assumption that a camouflage pattern may have the ability to disrupt the shape of a target has been textbook material for decades [6]. A desired concealment effect that often is connected with multi-colored camouflage patterns is that such patterns are assumed to disrupt the shape of the target by disturbing an observer's visual impression of it, and hence make the target more difficult to detect. By placing high contrast (and relatively large) patches, that stand out visually, along the outline of a target it is believed that this creates false edges (as seen by an observer), and hence the shape of the target is disrupted [1]. The concept of enhanced concealment through disruptive coloration was reported at first more than a hundred years ago and was refined during the World War II [7, 8]. Still very little – if any at all – of scientific credibility has been reported on the effect of disruptive camouflage on the concealment effectiveness of a human target.

Disruptive coloration and disruptive camouflage is typically designed so that one or more high contrast (relative to the adjacent parts of the target) patches are located along the contour of a target. This is because the shape of a target is

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believed to be a salient feature in detection of targets [1]. Since the postulation of disruptive coloration as a concealment strategy [7] it took over a hundred years before it was justified through dedicated experiments of birds searching for moth targets [6]. This opened a new field within concealment of prey when subject to predators [9-14] of some kind in the animal kingdom. However, to the best of the author's knowledge, little is reported, of scientific credibility, on the concealment effectiveness of disruptive coloration (or disruptive camouflage patterns) in human shaped targets when searched for in natural scenery, although the effect of disruptive coloration has been shown to hold also for humans searching for flat, artificial insects [10, 11].

Consequently there is no quantitative measure on how large the concealment effect of disruptive coloration, as an add-on effect to an existing pattern that is developed to match the natural background in overall, for camouflage purposes may be under different conditions and sceneries. Neither is it clear under what circumstances disruptive camouflage will be beneficial, and of equal importance, under what circumstances will it not enhance a target's concealment or even reduce it.

This paper intends to give possible explanations to observations of human targets concealed with disruptive coloration on top of a background matching camouflage pattern. The main finding in this study indicates that high contrast disruptive coloration along a target's outline had a positive (and significant) effect on detection times of human shaped targets in various (dry arid) natural backgrounds. This was found to hold as long as the underlying camouflage pattern – on top of which the disruptively colored patch was added – was matching the local background reasonably well, spectrally and structurally, in the visible range of the electromagnetic spectrum.

2. METHOD

Two near-identical (but still slightly different) camouflage patterns, 1 and 2, were compared regarding their visual concealment effectiveness is various arid backgrounds. The two patterns were roller printed onto cotton textile (225 g/m^2 optically opaque, Hol-Tex Gmbh, Germany) intended for combat uniforms in order to ensure a proper colour representation in the visual spectrum. The camouflaged textile was then sewn into two mannequins with hoods, covering the shape of a human torso and head (Figure 1). A styrophoam mannequin was dressed up with the jackets, one at a time, constituting the two targets, T1 and T2, in the camouflage test to be carried out. The two targets are shown in Figure 1 without hood (a and b) and with hood (c and d). Each target was placed in 12 different local backgrounds (scenes) in an arid terrain (Mediterranean, Rhodes).

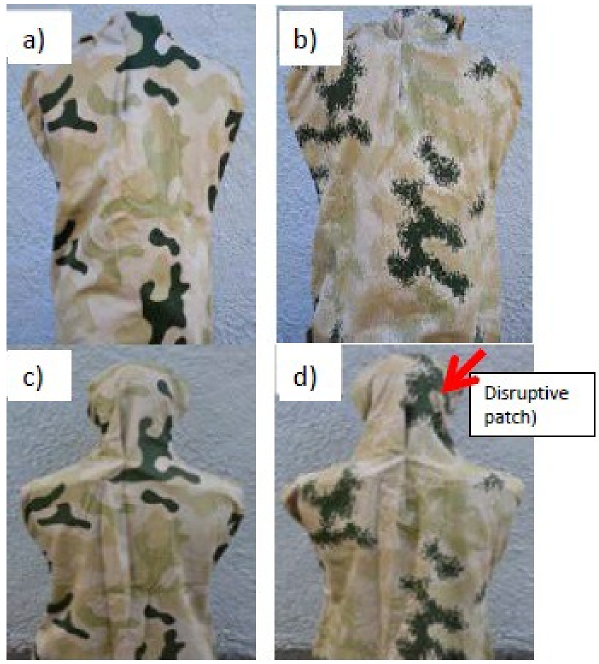

Figure 1. Close-up photographs of the two near-identical targets, shown in a) and b). Image a) shows target 1 without head, b) target 2 without head, c) target 1 with no disruptive patch, and d) target 2 with disruptive patch along the head outline

Background data capture of the targets

The scenes were chosen to contain different types of local backgrounds next to the target. The two targets were, for every single scene, recorded in as identical conditions as we were able to, considering, target orientation, position and area exposed, and as stable illumination conditions as possible, as the latter is very important to the targets' colour representation to the observer. To ensure target position and orientation, target 1 and 2 were, one at a time fixed to the ground with a spear. An illustration of a scene (scene 5 of 12) is given in Figure 2, showing the two individual images of target 1 and target 2 in exact similar natural background. The overall aim during the image capture was to assure that the two targets' camouflage patterns were assessed solely based on their relative camouflage effectiveness. To achieve that, a near-continuous (within minutes) recording of the targets was carried out in each scene. This was done by a digital camera (Nikon D5200). Furthermore, only one target was recorded per image. This was done in order to avoid confusion about which target was actually to be assessed in the trial.

Of great importance was that each of the 12 the scenes were chosen so that no observer should expect where to find the target or to start the search. Targets were therefore located randomly in the image frame (never centered) in order to avoid observers' expectations on where to start to search. The physical distance to the targets in the field was varied between 12 m and 70 m in the 12 different scenes. The scene images were recorded with the intention that the target should be possible to actually be detected, whenever the observer's eye focus was at the target's spot in the image frame. Hence a detection of a target by a human observer was meant to reflect the real camouflage effectiveness and not to be based on observer's making guesses about too distant targets. In 5 of the in total 12 scenes the target was recorded with both torso and head (ref Fig 1), whereas in the 7 of the remaining scenes only the target's torso (no head) was recorded by photography when placed in natural backgrounds.

Figure 2. Illustration of a scene (scene 5), showing how the two targets were located at the exact same spot in the local background and then recorded continuously (two still images recorded within a minute). The upper image shows target 2 (disruptive preference) whereas the lower image shows target 1 (no disruptive preference).

Evaluating the concealment effectiveness of target 1 and target 2 by observer trials

The concealment effectiveness of target 1 (disruptive) and target 1 (non-disruptive) was estimated using human observers in a purpose made search by photo observer trial with humans [15]. The number of human observers that were used per scene varied between 21 (scene no. 10) and 36 (scene no 1) in our observer trial. The spread in number of observers was due to the fact that the trial results to be presented in this paper were a part of a larger camouflage study where a total number of 148 observers were used to assess 9 or 12 (some targets did not facilitate the use of a hood) unique targets in each scene. However, the number of observers was the same for both target 1 and 2 (to an accuracy of one single observer) in each of the 12 scenes presented in this paper, and hence allows for a relative comparison of camouflage effectiveness in each scene.

Preparation of human observers

Prior to the observer trial each soldier was given a word by word *identical* introduction to the observer trial by an instructor. Each observer was then adjusted to have an optimal and identical distance to the widescreen (ca 40 cm), as the screen was intended to fill most of the observers' field of view. Also, the observer's eyes were approximately leveling the center of the pc-screen. Thereafter, each of the observers conducted a test run consisting of two images similar to those in the main trial. During this test run, the observers were allowed to ask questions to the instructors, reducing the risk of misunderstandings before the main trial started [15]. During trial itself, observers were not allowed to ask questions, but were left to search for targets solely by themselves. Finally, the observers were free to choose their own search strategy during the trial.

Conducting the observer trial

During the observer trial each observer was shown a randomized sequence of photographs of the 12 different scenes, one at the time in a high definition (HD) wide screen (2560 x 1600 pixels) in a dimly lit room. Each photograph represented a scene with either one or no target. The observers searched for a target and indicated detection by mouse-clicking at the target as soon as he or she felt confident that it was a proper target and not an anomaly (e.g. a target-shaped bush etc). The corresponding detection time was logged for each detection. There was a small tolerance surrounding each target to avoid that real detections were accidentally recorded as a miss-detection [15]. Hence the observer had to click close to the target to indicate a "hit", but not necessarily spot on the center of the target. This approach was chosen as the primary goal with the observer trial methodology was to assess camouflage effectiveness of various targets, not to test the observer's accuracy regarding clicking on the target spot with a mouse. Of importance was that each human observer was exposed no more than one single target per scene, as targets were identically positioned in each scene.

The total duration of each scene image presentation was limited to 60 seconds in order to give the observer reasonable search time, but on the same time avoid any reduction of the observer's concentration through tedious searches for a well hidden target. Whenever the fixed time limit was exceeded, the target (in that particular scene) was stored as "non-detection". All detection times and all non-detections were stored for further analysis. Finally, we used a purpose-made software tool, showing the scenes in a randomized order as well as storing all data of relevance from the trial.

Statistical analysis of observer data

The detection time data from the human based search by photo observer trial were analyzed thoroughly, searching for significant differences between the two target's concealment effectiveness in each of the 12 scenes. First a Jarque-Bera test for each target per scene was carried out, testing whether the corresponding distribution of detection times was normally distributed or not. Whenever at least one of the target's detection times, in a particular scene, failed to fulfill normality the Wilkoxon on rank test (Mann-Whitney U-test) was chosen as the preferred statistical test as such a non-parametric test has shown to be most reliable in situations where distributions to be compared are a mix of both normal (parametric) and non-parametric [16,17]. Also, the Wilcoxon's rank test, being non-parametric, has the ability to account for all non-detections (i.e. detection times larger than the search time limit set to 60 seconds) which were found for some of the targets in some scenes during the observer trial. In overall, the principal value (p-value) describing the degree of similarity in concealment effectiveness between target 1 and target 2 for each of the 12 scenes was then obtained. A further description on how to handle trial detection data, including the non-detections, can be found in a recent study on camouflage assessment methodologies [15].

3. RESULTS

The results to be presented are divided into two parts. The first part shows the performance of the two targets in the 5 scenes where the disruptive hood was used, and are shown in great detail. The second parts shows the performance of the two targets with no hood used, serving as a reference test of the overall concealment properties of pattern 1 compared with pattern 2, as they were near similar, but not identical (ref Figure 1).

The 5 disruptive scenes

Figure 3 -7 show the detection times of target 1 (non-disruptive) and target 2 (disruptive) in the 5 "disruptive" scenes (scene 1-5) where both targets were evaluated with hood. The figures 3- 7 all show the same kind of information where each mark shows the detection time of a single observer. The red squares associated with each target represent the median time for the corresponding distribution of detection times. It is worth mentioning that the median time associated with a target also accounts for the observed non-detections which are listed as integer numbers in the rectangles right above the detection time distributions themselves. Hence, in Figure 3 (scene 1), target 1 had one, single non-detection, whereas target 2 had 8 non-detections. For the two targets in scene 1 significant ($p = 0.027$) concealment performance in favor of target 2 (disruptive) was with respect to the distribution of detection times (Wilcoxon's rank test).

Figure 4-7 show the similar concealment performance of the two targets in scene 2-5. In scene 2 (Fig. 4) and 4 (Fig. 6) no significant difference between target 1 and target 2 were observed ($p < 0.05$ by Wilcoxon), and that can also be seen from the almost identical median, red squares in Figure 4 and 6. The two figures, 5 and 7, show the detection times obtained for target 1 and target 2 in scene 3 and 5, respectively. We see that there were large differences in concealment effectiveness in favor of target 2, summarized by a near-significant difference (p=0.064) in scene 3 and a significant difference ($p < 0.01$) in scene 5.

Data on whether the targets' distribution times were significantly different, as well as being normally distributed or not are summarized in Table 1.

The 7 non-disruptive (reference) scenes

Table 2 gives the overall results from the 7 scenes where target 1 and target 2 were compared with no hood used, meaning that both targets were without any disruptive preference to the other. The table shows the p-values (obtained by Wilcoxon's rank test) for the 7 scenes, as a measure of the differences in concealment effectiveness of the two targets. We see that in all these 7 "non-disruptive" scenes no significant differences were found ($p > 0.05$).

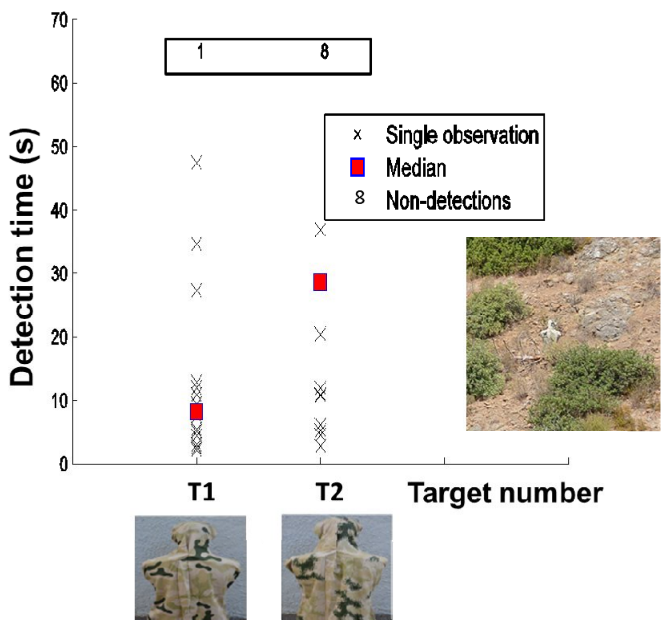

Figure 3. Distribution of detection times for the two targets, T1 (non-disruptive) and T2 (disruptive), in scene 1 where both targets were recorded with head. A close-up image of the target and the local background is shown in the inset image. The red squares show the median detection time for each target. The rectangular box above the time distributions shows the number of non-detections per target in this scene.

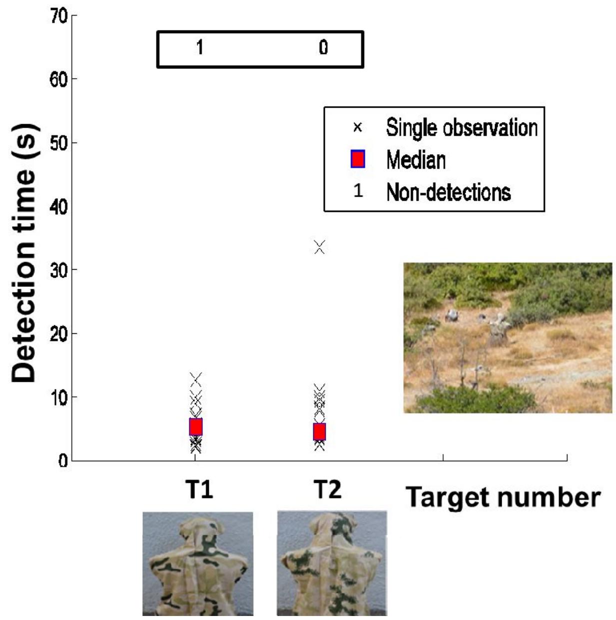

Figure 4. Distribution of detection times for the two targets, T1 (non-disruptive) and T2 (disruptive), in scene 2 where both targets were recorded with head. A close-up image of the target and the local background is shown in the inset image. The red squares show the median detection time for each target. The rectangular box above the time distributions shows the number of non-detections per target in this scene.

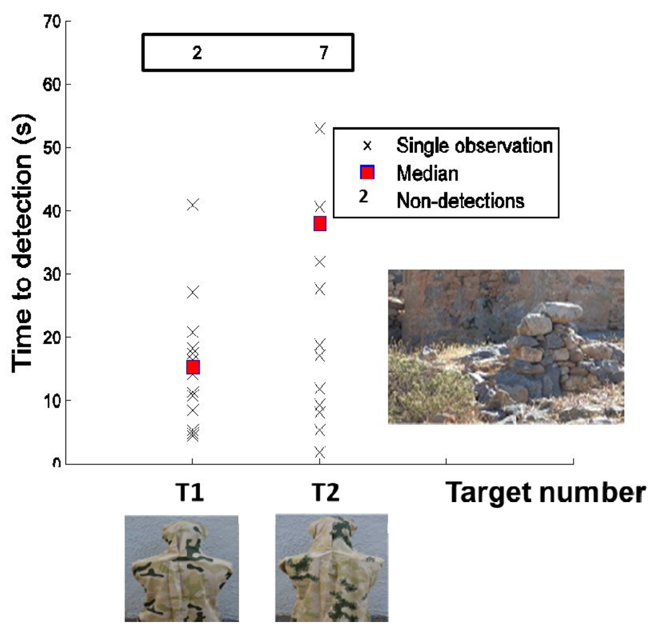

Figure 5. Distribution of detection times for the two targets, T1 (non-disruptive) and T2 (disruptive), in scene 3 where both targets were recorded with head. A close-up image of the target and the local background is shown in the inset image. The red squares show the median detection time for each target. The rectangular box above the time distributions shows the number of non-detections per target in this scene.

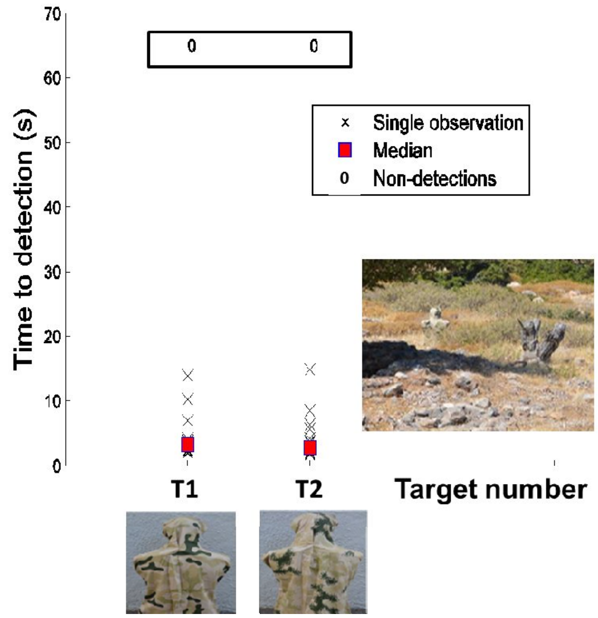

Figure 6. Distribution of detection times for the two targets, T1 (non-disruptive) and T2 (disruptive), in scene 4 where both targets were recorded with head. A close-up image of the target and the local background is shown in the inset image. The red squares show the median detection time for each target. The rectangular box above the time distributions shows the number of non-detections per target in this scene.

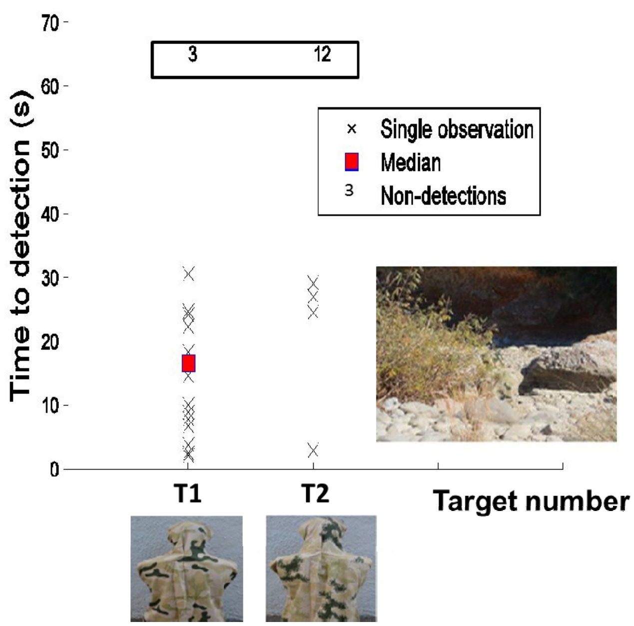

Figure 7. Distribution of detection times for the two targets, T1 (non-disruptive) and T2 (disruptive), in scene 5 where both targets were recorded with head. A close-up image of the target and the local background is shown in the inset image. The red squares show the median detection time for each target. Note that for target T2 the median was some undefined value as the number of non-detections, 12, outnumbered the number of actual detections. The rectangular box above the time distributions shows the number of non-detections per target in this scene.

Table 1. Statistical analysis of the detection times of target A and B in the 5 scenes where target B had a disruptively coloured patch. Each row shows the p-value, normality and image recordings data for a given scene.

Scene number	P	Normality		Distance to target (m)	Focal length (mm)
		Target 1	Target 2 (disruptive patch)		
1	0.027	No	No	41	18
2	0.865	Yes	No	43	24
3	0.064	No	Yes	17	24
4	0.759	No	No	50	35
5	0.001	Yes	No	17	24

Table 2. Statistical analysis of the detection times of target 1 and 2 in the 7 reference scenes (no disruptive patch). Each row shows the p-value, normality and image recordings data for a given scene.

Scene number	P	Normality		Distance to target (m)	Focal length (mm)
		Target 1	Target 2		
6	0.864	Yes	Yes	39	18
7	0.892	No	No	27	24
8	0.248	Yes	Yes	41	35
9	0.326	Yes	No	18	24
10	0.189	No	No	50	24
11	0.707	Yes	Yes	70	35
12	0.665	No	No	12	24

4. DISCUSSION

In this study the concealment effectiveness of disruptive coloration has been investigated by comparing an apparently disruptive target, T2, with an optically near-similar, but non-disruptive, target, T2, of identical shape and size. This was carried out through observer trials in 12 distinct natural sceneries, by obtaining a large data set of detection times for further analysis.

From Table 1 we see that there was a significant ($p < 0.05$) or close-to-significant ($p = 0.064$) difference between target 1 and target 2 in 3 of the 5 scenes (Figure 3, 5 and 7). In each of the 3 scenes target 2, which was disruptive, came out with generally higher detection times, and hence also enhanced survivability compared to the non-disruptive counterpart, target 1. In the two remaining scenes (scene 2, Figure 4 and scene 4, Figure 6) there were not found any significant difference amongst the two targets regarding their distribution of detection times from the observer trial (seen by the high p-values in Table 1). Hence from the 5 disruptive scenes, alone, there is a 3 of 5 scene indication that disruptive coloration along the head outline enhances survivability significantly.

The results given in Table 2 show that target 1 and target 2 were indistinguishable in performance in all 7 of the 7 scenes were the disruptive hood was not used (ref Figure 1) and none of the targets had a disruptive preference to the other. We see this first of all by the fact that all p-values were much above 0.05. The results from these 7 scenes indicate that the two near-similar patterns of target 1 and target 2 were similar in concealment effectiveness over all the 7 distinct scenes. This observation also indicate that the small differences in pattern (target 1 had sharp edges, while target 2 had fuzzy edges on the individual pattern elements) did not affect the overall camouflage effectiveness when exposed to human observers.

By combining the results from Table 1 (targets with head) and Table 2 (targets with no head) we are able to investigate whether the disruptive patch along the head section of target 2 did actually give enhanced survivability or not. In sum we have 3 of 5 positive confirmations that disruptive coloration did make a difference on the survivability from the tests of the disruptive effect. In addition we have 7 of 7 confirmations that the targets were not performing differently by other concealment effects (such as minor differences in pattern patch distributions). The latter rules out the possibility that the difference in performance in the 3 scenes (scene 1, 3 and 5), where a significant difference was found, was induced by the two target patterns not being visually identical.

The results from Table 1 therefore strengthens the assumption that the observed differences in scene 1 (Figure 3), scene 3 (Figure 5), and scene 5 (Figure 7) were due to differences in head pattern design. The most likely explanation on the observed results is that the dark green patch located along the right side of the head of target 2 acts disruptively and thereby conceals the head shape, by creating false edges and eventually disturbing an observer's visual impression of the target. Such an interpretation of the results is in line with the reported studies on disruptive coloration in the animal kingdom during the last 9-10 years. [6, 9-14] which have, one step at the time, confirmed Thayer's 100 year old assumptions on concealing coloration as a tool to enhance survivability.

Interestingly, the results that are reported in this study fit well with previously reported works on disruptive coloration where birds searched for flat-bodied prey [6, 9, 14] as well as human observers searching for prey targets [10-12], indicating a potential correspondence between avian and human perception of camouflage. However, on humans searching for other, concealed human-shaped targets in natural sceneries, there is, to the best of the author's knowledge, sparsely reported on disruptive coloration although a lot is reported on camouflage effectiveness assessments [3-5, 18-21].

Figure 4 and Figure 6 show that there were two disruptive scenes (scene 2 and 4) were no preference to disruptive coloration on the corresponding time of detection was observed. It is difficult to know for sure why the targets in these two scenes behaved very different compared with the remaining 3 disruptive scenes (scene 1, 3 and, 5). An inspection of the two scenes, given in the inset images in Figure 4 and Figure 6 might give us a clue, although it is to be underlined that this is the author's speculations and attempt to give an explanation to these two scenes. As it is seen that the two targets' overall matching over the local background in scene 2 and 4 was very poor (this is also seen by the persistently low detection times), it is possible that the targets were revealed through other, and more disclosing, visual mechanisms as a camouflaged target will always be hampered by its weakest parameter, measuring signature effectiveness.

The results reported here show an anomaly effect of the human vision system with a potential evolutionary explanation [7]. Interestingly, it seems that the disruptive effect is not necessarily incorporated in mathematical models of human vision [22] as it either i) not well known or ii) not easy to model mathematically as such high contrast effects along the body outline may also be revealing [23] and obviously more work is needed in order to map the human eyes' responses to disruptive coloration incorporated in targets of some kind.

5. CONCLUSION

In this study the effect of a disruptive patch along a human-shaped target's head outline has been investigated and we have seen that this is likely to increase the time of detection by human observers significantly compared to an identical target with a near-similar camouflage pattern without the disruptive patch. This seemed to hold as long as the disruptive target was matching the background well, but vanished whenever the target's background matching was poor. The results may be of interest when the human vision is to be modelled mathematically.

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