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Adaptive Camouflage for Moving Objects

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Abstract. *Targets that are well camouflaged under static conditions are often easily detected as soon as they start moving. We investigated and evaluated ways to design camouflage that dynamically adapts to the background and conceals the target while taking the variation in potential viewing directions into account. In a human observer experiment, recorded imagery was used to simulate moving (either walking or running) and static soldiers, equipped with different types of camouflage patterns and viewed from different directions. Participants were instructed to detect the soldier and to make a rapid response as soon as they have identified the soldier. Mean target detection rate was compared between soldiers in standard (Netherlands) Woodland uniform, in static camouflage (adapted to the local background) and in dynamically adapting camouflage. We investigated the effects of background type and variability on detection performance by varying the soldiers' environment (such as bushland and urban). In general, detection was easier for dynamic soldiers compared to static soldiers, confirming that motion breaks camouflage. Interestingly, we show that motion onset and not motion itself is an important feature for capturing attention. Furthermore, camouflage performance of the static adaptive pattern was generally much better than for the standard Woodland pattern. Also, camouflage performance was found to be dependent on the background and the local structures around the soldier. Interestingly, our dynamic camouflage design outperformed a method which simply displays the 'exact' background on the camouflage suit (as if it was transparent), since it is better capable of taking the variability in viewing directions into account. By combining new adaptive camouflage technologies with dynamic adaptive camouflage designs such as the one presented here, it may become feasible to prevent detection of moving targets in the (near) future.* © *2021 Society for Imaging Science and Technology.*
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1. INTRODUCTION

In nature, both predators and prey typically use camouflage to reduce their visual signature against background scenes, to avoid detection and recognition [14, 38, 39]. The more a camouflaged target resembles its local background, the less likely it is to be detected.

Several different biological camouflage principles can be distinguished, such as background pattern matching, countershading, disruptive colouration, flicker-fusion camouflage and motion dazzle [48]. Background pattern matching (or "crypsis" [38]) involves matching a target's colouration, lightness, and patterning to a random sampling of its immediate background [14, 48]. Countershading works by counteracting the shadow gradients that result from directional lighting. Disruptive colouration (or "dazzle camouflage") involves the use of false edges and boundaries to mask a target's true outlines, for instance by introducing high contrast details near the edge of a target [22, 23, 44, 48]. Flicker-fusion camouflage [52] refers to the visual effect that the different colours in a pattern merge into a uniform colour that blends in with the environment during movement [47], while they reappear at high contrast when the target becomes static again. Motion dazzle is the effect that high-contrast patterns such as stripes and edges disrupt the perception of the motion direction and speed of a target [20, 26, 49]. Biological systems like cephalopods (i.e., octopus) often deploy hybrid camouflage patterns, for instance combining crypsis and dazzle elements, probably as protection against both near (dazzle: to hinder capture) and far (crypsis: to avoid detection) predators [21].

The military has adopted several camouflage principles to counteract the target acquisition process by opponents, thereby enhancing the survivability of their high-value assets such as soldiers and platforms. An example of background pattern matching is the adornment of targets (e.g., vehicles or persons) with foliage of a background scene (e.g., a Ghillie suit), thereby providing the target with similar colouration and patterning as the surrounding vegetation. An example of countershading are Yehudi lights [11]: lamps of automatically-controlled brightness placed on the front and leading edges of an aircraft to raise its luminance to the average sky brightness, thereby reducing the plane's contrast against the sky. Examples of disruptive colouration are the complex dazzle patterns painted on ships consisting of geometric shapes in contrasting colours, interrupting and intersecting each other [5, 13]. Unlike other forms of camouflage, the intention of dazzle is not to conceal but to prevent target identification [22, 23, 26].

Regardless of the type of camouflage that is deployed, the detectability of a target increases significantly as soon as it moves [19]. The detection of a moving target involves the discrimination of coherently moving features from randomly moving ones and the perceptual binding of these features into a meaningful object (Gestalt). The common fate of a target's moving features (i.e., its local coherent and directed motion) creates a pop-out of the target shape from its local background [10, 19] (figure-ground segregation: the target's edges become clearly visible when it moves across its

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background) and facilitates target identification [37]. This is especially relevant for the concealment of moving soldiers [6, 9], since the human visual system is highly sensitive for the detection of motion that results from actions of biological organisms [29, 40] (biological motion). Previous studies have shown that camouflaged moving soldiers become highly salient, even at very low speeds [6, 9]. Camouflage patterns that are near-perfect for static targets, mostly reduce their saliency at the lowest speeds and have little or no effect at higher velocities [9]. Thus, while static camouflage patterns can serve to compromise the identification of moving targets [19], they are unsuitable for target signature reduction in dynamic scenarios. Low local contrast patterns with a spatial frequency that matches the background seem to be an exception to this rule [10]. An additional problem is the fact that camouflage effectiveness may depend on viewing direction. Covering a target with a camouflage pattern that is similar to the covered part of the background seen from a given viewing direction may be no longer optimal when the target is seen from a different direction. In that case, a pattern that captures the general background characteristics (e.g., a fractal pattern [27]) may be a better choice. In general, overall camouflage performance will increase when a pattern's design accounts for a variation in viewing angles [41].

The effectiveness of military camouflage measures also depends on the mission context. Currently, military personnel and vehicles are adorned with camouflage patterns that have been designed to reduce their detectability in static scenarios and specific backgrounds like woodland, desert, arctic or urban environments [25]. However, since movement of soldiers and vehicles across different types of terrain is an essential part of most military scenarios, camouflage measures should be effective across multiple backgrounds and target velocities. As shown by nature, adaptive camouflage may be an effective strategy to reduce the detectability of moving targets. Interestingly, few animal species have developed the ability to dynamically modify their appearance to match the specific characteristics of their immediate surroundings, or to perform background matching and context-dependent body patterning while moving [30, 31]. For instance, using specialized tissues, cephalopods can dynamically and rapidly camouflage themselves against a variety of natural backgrounds, sometimes even in an anticipatory fashion (adapting to the upcoming background) during movement [31].

Recent advances in technology have spurred the interest in the development of adaptive military camouflage systems that autonomously adapt to the environment [15, 16, 28, 61]. For instance, the ACAMSII (Adaptive Camouflage for the Soldier II) [2] project funded by the European Defence Agency (PADR-FPSS-01-2017 ACAMSII; see http://www.acamsii.eu) aims to integrate several active and passive adaptation mechanisms into a textile based camouflage system to reduce the soldier's signature in several wavelength bands, such as visual, near infrared, short wave infrared, thermal infrared and radar [2].

In this study we investigated and evaluated new ways to design camouflage that dynamically adapts to the background and conceals the target, taking into consideration the variations in potential viewing directions. We evaluated the new designs in a human observer experiment with imagery that simulated moving (either walking or running) and static soldiers, viewed from different directions against different backgrounds (like bushland, and urban).

1.1 *Experiment*

On every trial, a movie clip was presented showing a soldier walking or running across a bush or urban scene and participants were instructed to press the space bar as rapidly as possible when they detected the soldier. If participants responded, then a random noise mask replaced the movie so that participants were no longer able to search for the soldier. When the mask was shown, participants were instructed to indicate the target location by using the mouse to verify whether the soldier had been detected correctly (see Figure 1a). If participants failed to detect the soldier (i.e., when no response was provided during the course of the movie), then the movie was followed by a blank screen for 500 ms (see Fig. 1b). This blank screen was shown instead of the mask, to indicate that no response was recorded (i.e., feedback).

The soldiers' camouflage suit was either (i) the Netherlands Woodland camouflage pattern (the standard condition), (ii) camouflage that adapted to the environmental properties for the initial position only (the adaptive static condition), or (iii) camouflage that adapted dynamically to its immediate environmental properties (the adaptive dynamic condition). Furthermore, we measured performance using two different backgrounds (bush, and urban) to examine the camouflage effectiveness in several environments. The soldier was either not moving (static), or walking or running over a distance of approximately 5 m. We manipulated the motion-speed as it is known that this affects camouflage performance [9, 10]. A static condition was included to investigate whether the camouflage works properly when there is no motion at all, and to examine to what extent motion breaks camouflage. The distance between the camera and the (simulated) soldier was randomly chosen and the size of the soldier scaled linearly with distance in the scene. Note that the soldier was only shown at naturalistic locations (e.g., not in the air, or in a treetop). Furthermore, for the adaptive camouflage conditions, we manipulated the range over which samples were taken from the background, from the optimal situation up to a broader range. By default, it is impossible to detect the soldier when the camouflage is identical to its background, as if the soldier is "transparent". However, it remains unclear whether this "ideal" camouflage works properly if the viewing position deviates from the viewing position the camouflage was designed for. Therefore, we adapt the camouflage for the participants point of view (viewing angle is optimal) and in another condition we adapt the camouflage for a different point of view (viewing

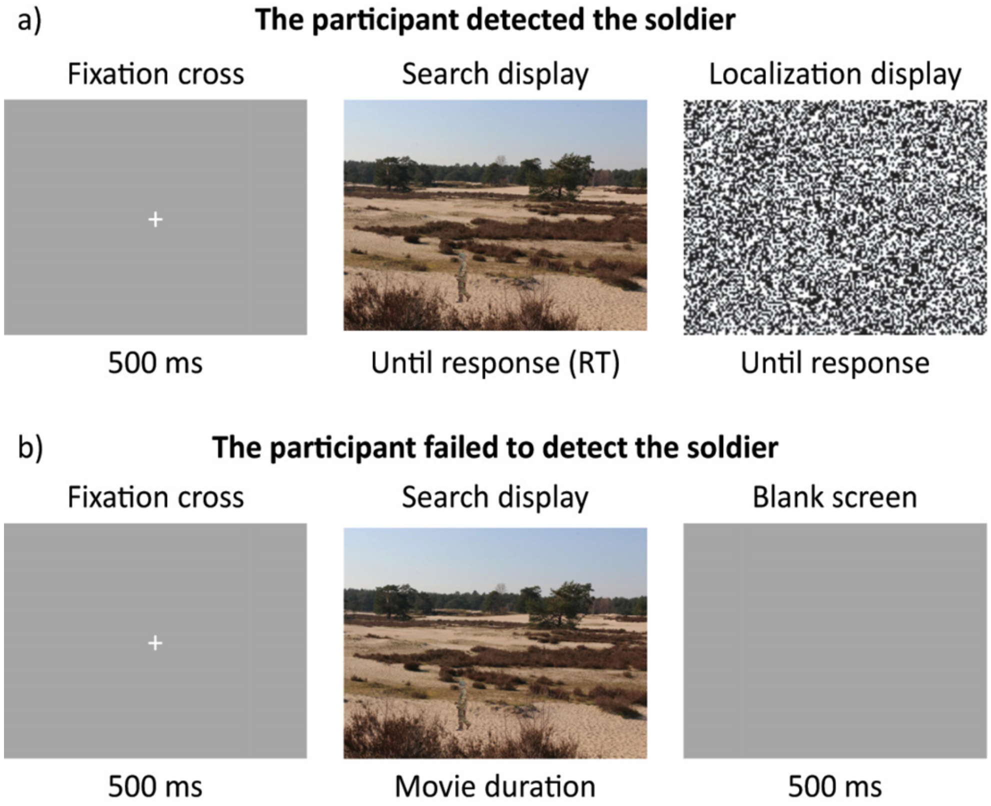


Figure 1. Schematic overview of the two different trial types. Participants saw a fixation cross for a duration of 500 ms. Subsequently, a movie was shown, and participants were instructed to press the space bar as rapidly as possible when they detected the soldier. If participants detected the soldier (panel a), then a mask replaced the movie, and participants were instructed to indicate the target location by using the mouse. If participants failed to detect the soldier (i.e., no response was provided), then the movie was followed by a blank screen for 500 ms (panel b).

point is different) to examine the effect of viewing angle on camouflage performance.

2. METHOD

2.1 *Participants*

Thirteen participants (3 females; 10 males, mean age was 30.5 years, ranging from 19 to 64 years) participated in the experiment. Ten participants were naïve as to the purpose of the experiment. The other three participants were the authors. Participants signed an informed consent form prior to the experiment. The experimental protocol was reviewed and approved by the TNO Internal Review Board (TNO, the Netherlands: reference 2019-024) and was in agreement with the Helsinki Declaration of 1975, as revised in 2013 (World Medical Association, [4]).

2.2 *Stimulus and Apparatus*

The experiment was programmed and run using PsychoPy 3.0 software [43]. Participants sat a distance of approximately 105 cm from the 32” LCD monitor (Display++; 1920 × 1080 pixels, 70.9 × 39.9 cm^2; 120 Hz refresh-rate) in a dimly lit room, resulting in a horizontal field-of-view (HFOV) of 37.3°. A standard QWERTY keyboard and a mouse were used for recording the responses. Movies (1920 × 1080 pixels) were recorded from a male actor (height of 180 cm, 53 years) wearing a standard Netherlands camouflage suit (type woodland) using a Canon 80D camera. The recordings were taken in Soesterberg, the Netherlands on March 16th 2020. The actor moved with either a constant walking (3.6 km/h = 1.0 m/s) or running (6.8 km/h = 1.9 m/s) speed over a fixed distance of approximately 5 m in the scene. We decided to keep this distance fixed so to eliminate (a) eccentricity differences between the walking and running conditions and (b) local differences between the target and the background, which are known to affect search performance [17]. During the recordings, the actor always moved to the right. Motion to the left was established by mirroring the movie over the vertical axis. The soldier was either projected against a bush or urban background. The bush background was taken on March 26th 2020 (Soesterduinen, Netherlands), while the urban background was recorded on April 14th 2020 (Amsterdam, Netherlands). The focal length of the camera was 25 mm for the bush background (HFOV = 43.8°) and 28 mm for the urban background (HFOV = 48.5°). Hence, the bush background was displayed with a magnification factor of 0.85 and the urban background was displayed with a magnification factor of 0.77. At the viewing distance of 105 cm, a 5 m displacement of a soldier seen at a distance of 100 m in the scene resulted in a displacement over 125 pixels (146.0 arcmin) for the bush

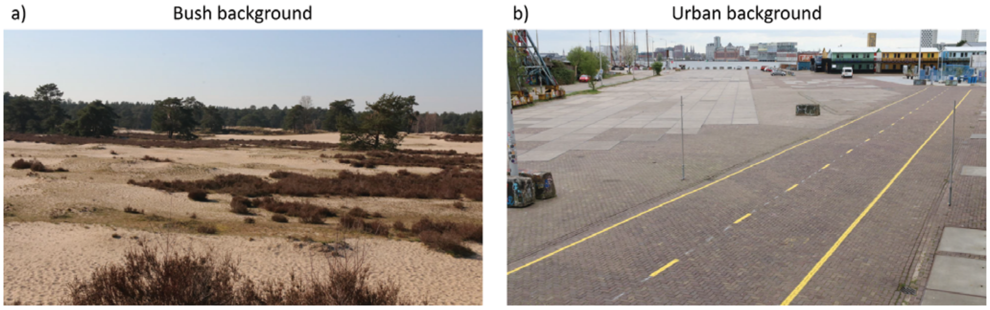


Figure 2. The two backgrounds used in the present study.

scene and 113 pixels (132.2 arcmin) for the urban scene. Figure 2 illustrates the two different backgrounds used.

From each actor movie frame, we extracted the actor and scaled his size according to the distance using a linear scaling function, as if the soldier moved in the real 3D scene. The distance of the soldier varied between 23.5 m and 251.4 m for the bush background, and between 21.2 m and 176.0 m for the urban background. This resulted in angular speeds ranging between 0.2° and 2.0° for the walking condition and between 0.4° and 3.9° for the running condition in the bush background, and between 0.3° and 2.0° for the walking condition and between 0.5° and 3.9° for the running condition in the urban background. Subsequently, we adjusted the camouflage to its background, if required. We applied three different camouflage conditions: (i) the adaptive dynamic condition, (ii) the adaptive static condition and (iii) the standard camouflage condition. In the *adaptive dynamic condition*, for each frame, the colour of each pixel of the suit was determined by the colour of its immediate surrounding pixels. An illustration of our adaptive camouflage algorithm is depicted in Figure 3(a) and 3(b).

For each pixel of the camouflage suit (at location x, y) we adapted its colour properties to one of the pixels in the background on the horizontal plane, using a Gaussian distribution. Note that we explicitly decided to take pixels from the horizontal plane, to avoid that the soldier breaks horizontal structures in the background (such as horizons). The range from where pixels were drawn from the background was predefined by the standard deviation of the Gaussian ($\text{SD} = 0$, or $\text{SD} > 0$) and the likelihood to select a specific pixel within this range was determined by the Gaussian distribution around location x, such that pixels closest to the actual background had a greater chance to be selected than pixels far away. This procedure was repeated for each pixel in the camouflage suit and (independently) for each frame, such that the pattern adapts to the environment in a dynamic fashion. Note that when the SD was zero (and no offset was used), the camouflage suit was identical to its background (as the Gaussian distribution forms a peak around location x). In the $\text{SD} > 0$ condition, the actual SD was 0.36 m (i.e., expressed in pixels scaling with the size of the target). Fig. 3(d) and 3(e) illustrate examples where the SD is zero, or larger than zero, respectively. Furthermore, we also examined the effect of viewing position, by either adapting the camouflage from the participants' perspective (the optimal situation), or by adapting the camouflage from a different viewpoint (see Fig. 3(a) and 3(b) for an illustration). In the latter condition, the camouflage suit adapted to a different location, such that the camouflage was not optimized from the participants' point of view. In this different viewing angle condition, the mean of the Gaussian moved accordingly, such that pixels were drawn from a different part of the environment. More specifically, the mean moved 0.72 m to either the left or right. Fig. 3(f) and 3(g) illustrate two examples where the camouflage suit was adapted, but not from the perspective of the participant. In the *adaptive static condition*, we took the still image from the first frame of the dynamic adaptive camouflage condition (so the first frame in both adaptive conditions is the same) and moved this pattern with the same speed and in the same direction along with the soldier, as if the soldier was wearing this adaptive pattern. In the *standard camouflage condition*, we captured the actor from each movie frame and kept the original Netherlands Woodland camouflage as is (see Fig. 3(c) and Fig. 1 for examples).

The soldier was either moving (dynamic), or stationary (static). In the latter condition, we randomly selected a frame from the movie, and showed that to the participants. For the dynamic condition, the frame rate was 50 ms per frame, except for the first and the last frame. The first frame was shown for 500 ms, to avoid an unrealistic situation where the motion of the soldier starts with the movie onset. The last frame remained on the screen for 1000 ms, so that participants had ample time to report their response. The movie duration for the walking and running conditions were 4950 ms and 2600 ms, respectively. The movie duration in the static walking and running conditions was similar to that in the corresponding dynamic conditions.

2.3 *Procedure*

A schematic overview of the two trial types is depicted in Fig. 1. A trial started with the presentation of a white fixation cross at the center of a grey screen for a duration of 500 ms. Subsequently, the movie was presented, and participants were asked to press the space bar as soon as they detected the soldier. When participants pressed the space bar, the movie was replaced by a random dot mask, so that they were

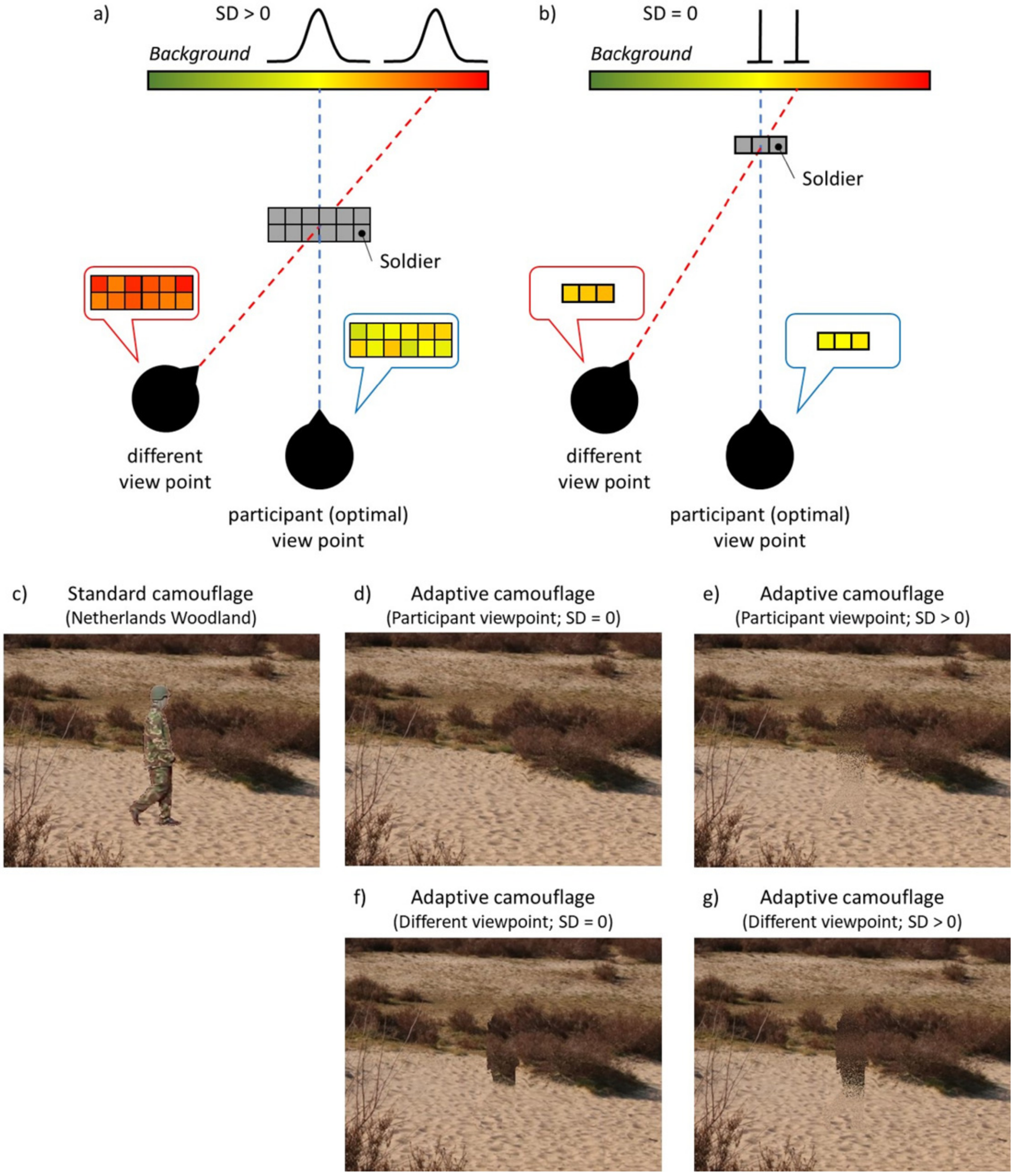


Figure 3. Adaptive camouflage algorithm. (a) Illustration of the algorithm for a target nearby when the SD was > 0, and the viewing angle was either from the participant's point of view or from a different point of view. (b) Same as panel A, but the target is now far away, and the SD = 0. (c) Random movie frame of the target wearing the standard Netherlands woodland uniform. (d–g) Same movie frame as in panel c, but the camouflage pattern of the target was adapted to its background.

no longer able to search for the soldier. Participants were instructed to use the mouse pointer and to press the left mouse button to indicate the location of the soldier to verify whether they had indeed detected the soldier (see Fig. 1(a) for an example trial). In the case no response was provided, the last frame of the movie was replaced by a blank screen for 500 ms (i.e., feedback).

2.4 *Design*

The dependent variable was the detection rate (i.e., the proportion of detections out of 30 trials). On each trial, the motion direction (left versus right) was randomly determined. The independent variables were motion dynamics (static versus dynamic), soldier movement (walking versus running), background (bush versus urban), and camouflage type (standard, adaptive static, and adaptive dynamic). In the case of adaptive camouflage (static or dynamic), we also manipulated the SD of the Gaussian (SD = 0 versus SD > 0) and the viewing angle (optimal versus different). In total, there were 72 different combinations (conditions). Each condition was repeated 30 times, representing 30 different locations of the soldier for each background scene. The locations were randomly determined for each participant. The location of the soldier on the horizontal plane was

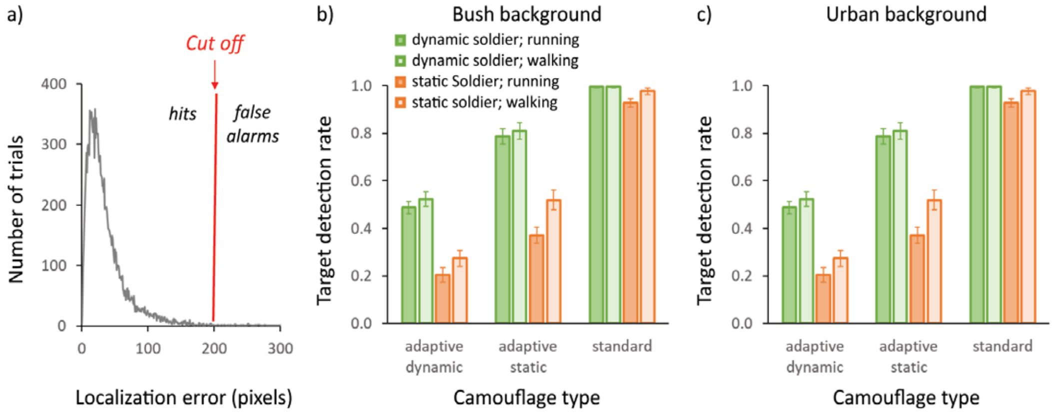


Figure 4. (a) Distribution of the responses as a function of the localization error. Participants reported the target location after each trial to confirm that they saw the soldier. The localization error reflects the distance between the participants' response and the soldier's location (determined by the center of mass). Note that we did not plot the whole distribution of the localization error, as we predominantly focus on the peak of the distribution. (b,c) Behavioral results. Here, the target detection rate is plotted as a function of the camouflage type for the bush (b) and urban background (c). Note that the soldier was either moving (green bars) or static (orange bars), and that the soldier was either running (dark bars) or walking (light bars). In the case of a static soldier, one frame of either a running or walking soldier was shown. Error bars represent the standard error of the mean (SEM).

randomly determined. In contrast, his location on the vertical plane was randomly determined following a linear probability. That is, locations further away had a greater chance to be selected than locations nearby. This was done because we expect that soldiers nearby are rather easy to detect, so most interesting information is expected for soldiers far away. Furthermore, we aim to plot heat maps corresponding to the locations where soldiers were detected. Therefore, more samples are needed for soldiers far away, as the size of the soldier scaled with distance. Participants received instructions on the screen prior to the experiment. Participants completed one practice block to get familiar with the task, followed by 10 experimental blocks of 72 trials each (i.e., one session). In total participants performed three sessions (of $\sim$ 50 minutes each), leading to 2160 trials in total. Participants were instructed to respond as fast and accurately as possible, and were allowed to take a break between blocks.

3. RESULTS

3.1 *Target Detection Rate*

We first examined the target detection rate for each condition. Thereto, we excluded those trials in which participants made a response (suggesting that they saw the soldier) but failed to indicate the location of the soldier (i.e., a false alarm). Figure 4(a) illustrates the distribution of the responses as a function of the localization error. The localization error reflects the difference between the participants' location response and the actual location of the soldier. More specifically, if the soldier was detected at frame f, then we calculated the actual location of the soldier by determining his center of mass for that specific frame. We applied a cut off-of of 200 pixels, considering a localization error greater than 200 pixels as a false alarm, and a localization error smaller than or equal to 200 pixels as a hit. A cut-off of 200 pixels resulted in an exclusion of 1.5% of the trials. Practice trials were also excluded from further analyses.

The results of the experiment are shown in Fig. 4(b) and 4(c). Here, the (average) target detection rates are plotted as a function of the camouflage type for both the bush and the urban background condition, respectively. Note that the soldier was either moving (green bars) or static (orange bars), and that he was either running (dark bars) or walking (light bars). We conducted an ANOVA on the group mean target detection rate with motion dynamics (static versus dynamic), soldier movement (walking versus running), background (bush versus urban), and camouflage type (standard, adaptive static, and adaptive dynamic) as within-subject variables. Alpha was set to 0.05 and where applicable, p-values were Huynh-Feldt corrections were done to eliminate sphericity violations.

The four-way interaction failed to reach significance, $F(2, 24) = 3.131$, $p = 0.063$. The ANOVA yielded a significant background × motion dynamics × camouflage type interaction, $F(2, 24) = 26.986$, $p < 0.001$. This interaction was no longer significant when we excluded the standard woodland camouflage condition, $F(1, 12) = 3.545$, $p = 0.084$, indicating that the previously mentioned three-way interaction was predominantly driven by the ceiling performance in the standard woodland condition. The background × motion dynamics interaction was significant, $F(1, 12) = 33.860$, $p < 0.001$. This interaction was further examined using two-tailed t-tests for each motion dynamics condition. A dynamic target was easier to spot in a bush environment (0.79) than in an urban environment (0.77), $t(12) = 2.382$, $p = 0.035$, whereas a static target was easier to spot in an urban environment (0.55) than in a bush environment (0.49), $t(12) = 4.731$, $p < 0.001$. The background × camouflage type interaction was significant, $F(2, 24) = 5.572$, $p = 0.010$, as the camouflage efficiency depended on the background in general.

The main effect of camouflage type was significant, $F(2, 24) = 574.684$, $p < 0.001$. As expected, overall, target detection was significantly lower when the soldier wore an adaptive dynamic camouflage suit (0.37) than when he wore an adaptive static camouflage suit (0.60), $t(12) = 29.570$, $p < 0.001$ (two-tailed t-tests). Furthermore, it was significantly easier to detect the target when he wore the standard camouflage suit (0.97) than when he wore an adaptive static or dynamic camouflage suit, $t(12) = 16.034$, $p = 0.001$ and $t(12) = 31.541$, $p < 0.001$, respectively.

The main effect of motion dynamics was significant, $F(1, 12) = 814.719$, $p < 0.001$, as well as a significant motion dynamics × camouflage type interaction, $F(2, 24) = 484.834$, $p < 0.001$. For each camouflage condition, the target was easier to detect when the soldier was dynamic than when he was static (all $t(12)$ values ≥ 3.865, p values ≤ 0.001). However, this effect was less pronounced when the camouflage type was standard than when the camouflage was adaptive (either dynamic or static). The motion dynamics × camouflage type interaction also interacted with the soldier movement (walking or running), $F(2, 24) = 24.355$, $p < 0.001$. This was not explored further as it was evident that it is easier to find a moving soldier than a static soldier, indicating that motion breaks camouflage.

The main effect of soldier movement was significant, $F(1, 12) = 90.631$, $p < 0.001$, and the soldier movement × motion dynamics interaction was significant as well, $F(1, 12) = 288.173$, $p < 0.001$. The effect of soldier movement was further examined using two-tailed t-test for each motion dynamic condition. When the soldier was static, the t-test yielded a significant effect of soldier movement, $t(12) = 14.126$, $p < 0.001$, as the target detection rate was higher when the soldier was walking (0.56) than when the soldier was running (0.47). So, even though a still image (i.e., a single frame for a longer period) was shown to the participants (i.e., the static condition) from either a running or walking soldier, this still leads to a significant performance difference. This difference most likely reflects a presentation duration effect: the walking soldier was visible for a longer duration (4950 ms) than in the running condition (2600 ms). Interestingly, no such performance difference was observed when the soldier was dynamic, $t(4) = 0.939$, $p = 0.366$. So, even though the presentation duration of the walking soldier was longer than for the running soldier, this did not result into a performance difference in the dynamic condition (performance walking and running was 0.78 and 0.78, respectively). Of course, the longer presentation duration did presumably also result in an improved performance in the walking condition compared to the running condition (like in the static condition), however, this difference was most likely compensated by the fact that a walking soldier was simply better camouflaged than a running soldier (i.e., an effect of motion-speed [9, 10]). Indeed, Duncan and Humphreys [18] found compelling evidence that if the target-distractor difference (in our case the motion-speed of the soldier in static environment) increases, it becomes easier to detect a target in a visual search paradigm [12]. The soldier movement × motion dynamics interaction also interacted with the background, $F(1, 12) = 10.904$, $p = 0.006$. This interaction most likely signifies that overall, camouflage efficiency was better in the bush environment than in an urban environment. The soldier movement × camouflage type interaction was significant, $F(2, 24) = 13.170$, $p < 0.001$, but not further examined.

All other interactions and main effects failed to reach significance (all p-values ≥ 0.088).

3.2 *Effect of Visual Angle for Both Adaptive Camouflage Conditions*

For both the adaptive camouflage conditions (the adaptive static and the adaptive dynamic condition) we manipulated the visual angle to investigate whether the camouflage patterns work properly if the viewing position deviates from the viewing position the camouflage was designed for. The viewing angle was either optimal (i.e., the camouflage suit was adapted for the participant's point of view) or different (i.e., the camouflage suit was adapted for another point of view). Furthermore, for the adaptive static and the adaptive dynamic camouflage conditions, we also manipulated the range from where samples were taken from the background from a narrow range (SD = 0) to a broader range (SD > 0). Provided that the viewing angle depends on where the soldier was presented (as we scaled the soldier's size, viewing angle and SD) we took into account the distance to the soldier. The distance was divided into four equal bins (1–4, where the first bin represents nearby and the last bin represents further away). Figure 5 illustrates the target detection rate as a function of distance, viewing angle (optimal versus different), SD (0 versus > 0), and soldier dynamics (static versus dynamic) for both the adaptive dynamic and the adaptive static camouflage conditions.

We conducted an ANOVA on the mean target detection rate with distance, viewing angle (optimal versus different), SD (0 versus > 0), soldier dynamics (static versus dynamic) and camouflage type (adaptive static versus adaptive dynamic) as within-subject variables.

Like in our previous analyses, we observed a significant main effect of motion dynamics, $F(1, 12) = 928.884$, $p < 0.001$. The two-way interaction between camouflage type and motion dynamics was also significant, $F(1, 4) = 46.116$, $p < 0.001$.

The five-way interaction failed to reach significance, $F(2, 36) = 1.633$, $p = 0.205$. Importantly, the ANOVA yielded a significant camouflage type × viewing angle × SD × motion dynamics interaction, $F(1, 12) = 124.803$, $p < 0.001$. This four-way interaction reflects the different pattern observed in Fig. 5(a) (see histogram) compared to the patterns observed in Fig. 5(b,c), which look overall rather similar. This observation was further investigated using two-tailed t-tests. We first examined whether the SD had an effect on target detection for both the static and the dynamic target, provided that the viewing angle was optimal and that the camouflage pattern adapted dynamically (see the

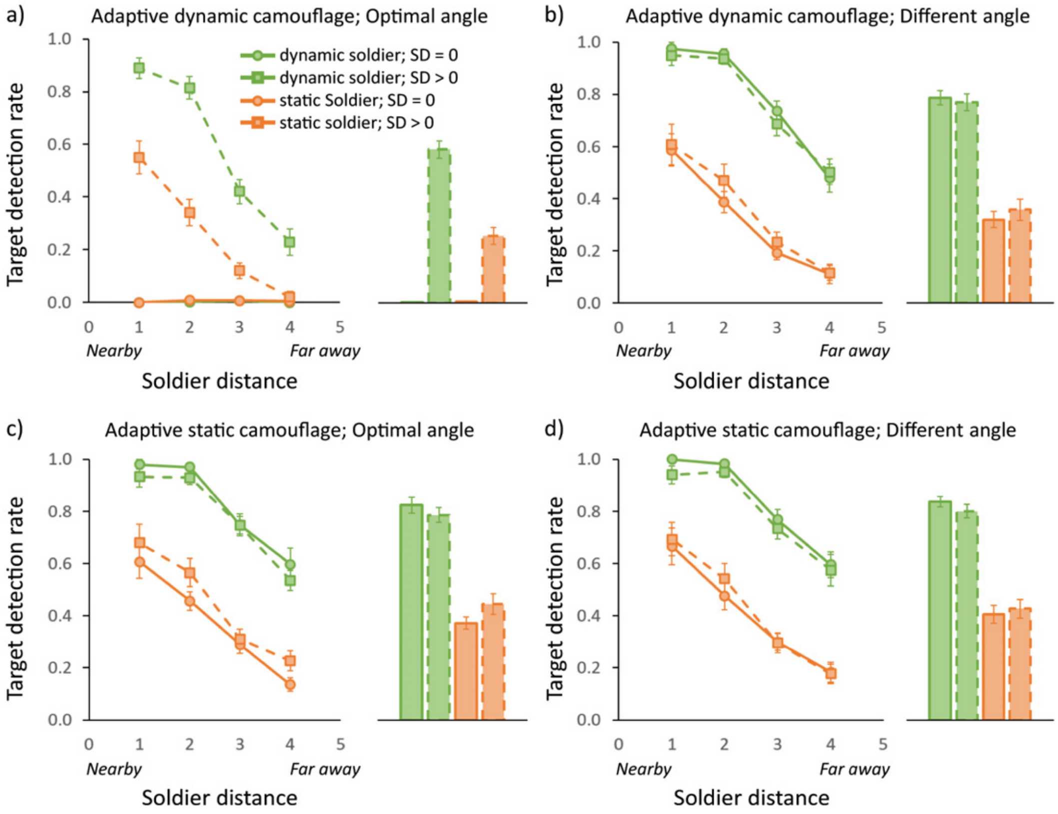


Figure 5. Target detection rate as a function of distance, viewing angle (optimal versus different), SD (optimal versus broad), soldier dynamics (static versus dynamic) for both the adaptive dynamic and the adaptive static camouflage conditions. Note that the distance was divided in four equal bins ranging from nearby (1)–far away (4). The histogram represents the mean target detection across all distances. The error bars represent the standard error of the mean (SEM).

histogram in Fig. 5a). When the target was dynamic, the SD had a major impact on the target detection, $t(12) = 17.174$, $p < 0.001$, as the target detection rate was much higher when the SD was larger than zero (0.59) than when the SD was zero (0.00). When the target was static, the SD had a major impact on the target detection, $t(4) = 8.054$, $p < 0.001$, as the target detection was much higher when the SD was larger than zero (0.26) than when the SD was zero (0.01). Thus, if the SD is zero and the viewing angle is optimal, then it becomes impossible to detect the target when its camouflage pattern adapts dynamically to its environment, regardless on whether the soldier is static or dynamic. This makes sense as in this particular condition the suit is identical to its background (i.e., the perfect camouflage). Moreover taking samples from a broader range in the background resulted in a major increase in target detection.

Next we examined whether the SD had an effect on target detection for both the static and the dynamic target provided that the viewing angle was *not* optimal and the camouflage pattern was *not* adaptive dynamic (i.e., excluding the data in Figure 6a). Thereto, we collapsed the data in Fig. 5(b,c,d), which showed quite similar patterns. When the target was dynamic, target detection was higher when the SD was zero (0.61) than when the SD was larger than zero (0.59), $t(12) = 3.208$, $p = 0.008$. In contrast, an opposite SD effect was observed when the soldier was static (target detection was 0.27 when the SD was zero, and 0.31 when the SD was larger than zero), $t(12) = 2.935$, $p = 0.012$. These results are interesting and good news. It is clear that under less ideal circumstances (viewing angle is not optimal *and* the camouflage suit is not adaptive dynamic), the variable SD leads to a significantly better camouflage type (compared to the SD equal to zero condition), but only when the target is dynamic. In fact, target detection became worse for static targets when the SD was variable compared to when the SD was zero. In other words, when motion breaks camouflage, we can improve the camouflage pattern by adapting the camouflage pattern to a broader range from its background.

There was a significant main effect of distance, $F(3, 36) = 107.933$, $p < 0.001$, as the target detection rate decreased with increasing distance. This drop in performance was stronger when the soldier was dynamic than when the soldier was static, as confirmed by a significant distance × motion dynamics interaction, $F(3, 36) = 4.021$, $p = 0.014$. The distance also interacted with viewing angle, $F(3, 36) = 14.576$, $p < 0.001$, as the effect of viewing angle (i.e., better performance when the viewing angle was optimal than when it was variable) was stronger when the soldier was nearby (distance bins 1 and 2) than when the soldier was further away (distance bins 3 and 4). This makes perfect sense as the viewing angle scaled linearly with the soldiers' distance (like in natural scenes).

Furthermore, there was a main effect of camouflage type, $F(1, 12) = 484.059$, $p < 0.001$, as the detection rate was higher for the adaptive static condition (0.61) than for the adaptive dynamic condition (0.39). However, the effect of camouflage type depended on the viewing angle, as the couflage type × viewing angle interaction was significant, $F(1, 12) = 260.426$, $p < 0.001$. The two-way interaction was further examined for each viewing angle condition using two-tailed t-tests. When the viewing angle was optimal, the detection rate was significantly higher for the adaptive static condition (0.61) than for the adaptive dynamic condition (0.21), $t(12) = 22.708$, $p < 0.001$. When the viewing angle was deviant from the optimal viewing angle, the overall detection rate was significantly higher for the adaptive static condition (0.62) than for the adaptive dynamic condition (0.56), $t(12) = 5.307$, $p < 0.001$. These findings are important as they indicate that camouflaging a soldier in a dynamic fashion decreases the chances of being detected regardless of the viewing angle. Furthermore, it is important to note that the three-way interaction among camouflage type, viewing angle and distance was also significant, $F(3, 36) = 10.883$, $p < 0.001$. This interaction illustrates that the effect of camouflage type and viewing angle depended on the distance of the soldier in the scene. Indeed, when the viewing angle was deviant (right panels Fig. 5) and the soldier was dynamic (green lines), the effect of camouflage type was rather limited for the first two distance bins as the overall detection rate was at ceiling performance. In other words, a dynamic soldier was rather easy to find when he was nearby, but once he was allocated further away, the dynamic camouflage pattern performed significantly better than the static camouflage pattern.

An overview of the remaining statistical results are depicted in Table I.

Table I. Significant within subjects effects. All other effects failed to reach significance (all p values ≥ 0.112).

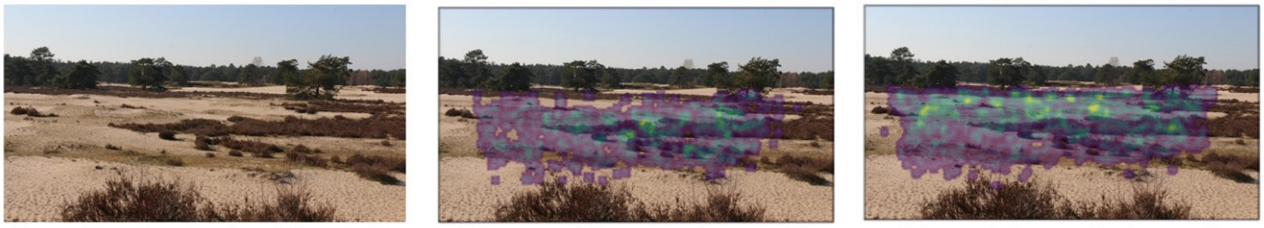
Viewing angle	$F(1, 12) = 538.475$	$p < 0.001$
SD	$F(1, 12) = 55.537$	$p < 0.001$
Camouflage × SD	$F(1, 12) = 137.680$	$p < 0.001$
Camouflage × distance	$F(3, 36) = 3.917$	$p = 0.016$
Viewing angle × SD	$F(1, 12) = 179.213$	$p < 0.001$
Viewing angle × Motion	$F(1, 12) = 137.710$	$p < 0.001$
SD × Motion	$F(1, 12) = 6.390$	$p = 0.027$
SD × distance	$F(3, 36) = 22.816$	$p < 0.001$
Camouflage × Viewing angle × SD	$F(1, 12) = 161.179$	$p < 0.001$
Camouflage × Viewing angle × Motion	$F(1, 12) = 154.169$	$p < 0.001$
Camouflage × SD × Motion	$F(1, 12) = 129.647$	$p < 0.001$
Camouflage × SD × distance	$F(3, 36) = 30.420$	$p < 0.001$[a]
Camouflage × Motion × distance	$F(3, 36) = 3.573$	$p = 0.023$
Viewing angle × SD × Motion	$F(1, 12) = 60.260$	$p < 0.001$
Viewing angle × SD × distance	$F(3, 36) = 50.044$	$p < 0.001$[a]
Camouflage × Viewing angle × SD × distance	$F(3, 36) = 34.565$	$p < 0.001$
Viewing angle × SD × Motion × distance	$F(3, 36) = 5.908$	$p = 0.007$[a]

[a] Mauchly's test of sphericity indicates that the assumption of sphericity is violated ($p < 0.05$).

3.3 *Spatial Analyses*

Subsequently, we plotted a spatial map to indicate the locations where the moving soldiers were detected (as indicated by the mouse after participants pressed the space bar). Such a spatial map may yield important information about the camouflage efficiency. Fig. 6 illustrates where the moving soldiers (either running or walking) were detected for the adaptive dynamic camouflage condition (except for the optimal condition: i.e., the suit was identical to the background) and the standard Netherlands woodland condtion for both the urban (panel a–e) and the bush environment (panel f–j).

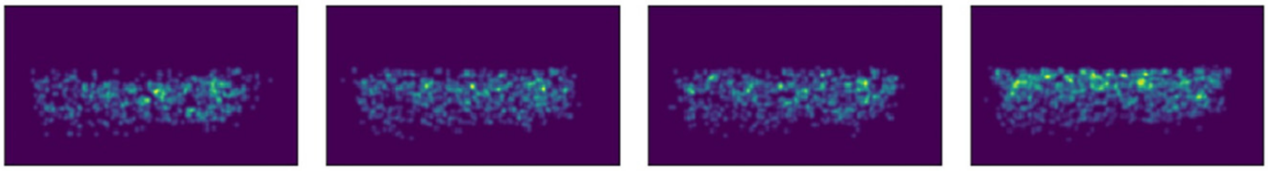
Note that although the target locations were randomly determined for each participant, the locations across the different conditions for each background were fixed for each participant. Therefore, any differences between the different conditions cannot be attributed to the randomization of the target locations. Visual inspection of Fig. 6 reveals a couple of interesting things. Perhaps the most striking result is the difference between the standard camouflage condition and the adaptive dynamic camouflage conditions for the urban background (Fig. 6j versus Fig. 6i). When the soldier was wearing a standard Netherlands woodland camouflage suit, the responses were rather distributed over all the locations. This is clearly visible when the hits were superimposed on the urban background image (Fig. 6h). In contrast, when the soldier was wearing an adaptive dynamic camouflage suit, the responses were not randomly distributed over the image, but instead more allocated toward locations forming structures (Fig. 6g). For instance, in the adaptive dynamic camouflage conditions, the yellow line in the urban background becomes clearly visible in the heatmap. This suggest that when the moving target was wearing an adaptive camouflage suit, the target was very well camouflaged when no clear structures were present at the local background, and pops-out from its environment when the moving target breaks a structure (such as the yellow lines, or borders between different materials/colours like the sandy/bush border in the bush environment). Interestingly, horizontal structures (such as the border between the concrete plates and the bricks in the urban environment, and the sand/bush border in the bush background) were not allocated as target locations, indicating that the moving target did not pop-out from its background when it moved in front of a horizontal structure. This makes sense, as for the adaptive camouflage conditions, each pixel x on the camouflage suit was randomly drawn from a nearby pixel on the left or right from that specific pixel x. As a result, horizontal structures (such as the concrete plates in Fig. 6g) remained intact on the camouflage suit so that the moving soldier stayed well camouflaged.



a) Bush background

b) Bush + hits (SD > 0; optimal angle)

c) Bush + hits (standard camouflage)

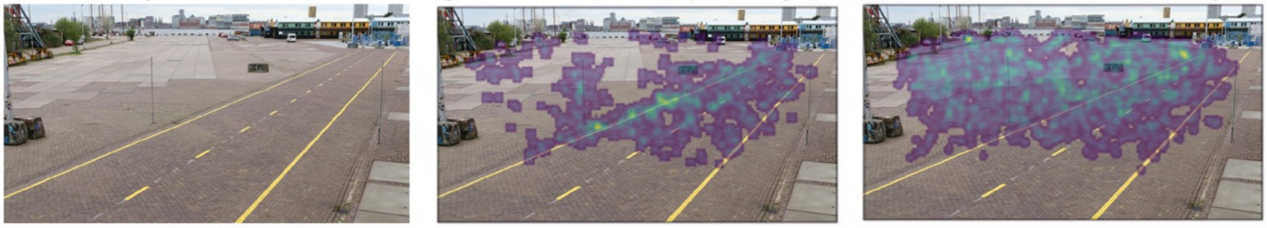


d) Hits (SD > 0; optimal angle)

Hits (SD > 0; different angle)

Hits (SD = 0; different angle)

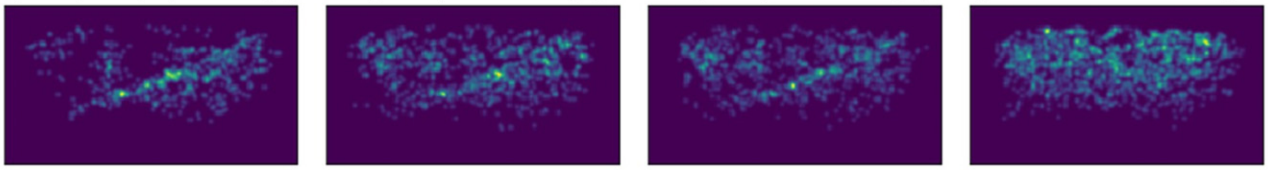
e) Hits standard camouflage



f) Urban background

g) Urban + hits (SD > 0; optimal angle)

h) Urban + hits (standard camouflage)



i) Hits (SD > 0; optimal angle)

Hits (SD > 0; different angle)

Hits (SD = 0; different angle)

j) Hits standard camouflage

Figure 6. Spatial maps signifying the locations where the running and walking soldiers were detected for both the bush (panels a–e) and urban background (panels f–j). The soldier was either wearing an adaptive dynamic camouflage suit (panels d and i) or a standard Netherlands woodland camouflage suit (panels e and j). (b) Indicates where in the bush environment the soldiers were detected when wearing an adaptive dynamic camouflage suit generated form the point of the observer ($SD > 0$; d left panel). (c) Indicates where in the bush environment the soldiers were detected when wearing standard camouflage suit (e). (g) Indicates where in the urban environment the soldiers were detected when wearing an adaptive dynamic camouflage suit generated from the point of the observer ($SD > 0$; i left panel). (h) Indicates where in the bush environment the soldiers were detected when wearing standard camouflage suit (j).

3.4 *When did the Participants Detect the Moving Targets?*

Finally, we examined at what moment the participants detected a moving target, as this may provide important information about the underlying search process [42, 53, 54, 58]. Figure 7 illustrates when (i.e., which movie frame) the participants detected the running or walking soldier for each camouflage condition. Here, the mean number of responses is plotted as a function of the movie duration for running (continuous lines) and walking targets (dotted lines) for each camouflage condition. Note that the first frame of each movie started with a 500 ms still image of the soldier and that the last frame of each movie was again a still image of the soldier displayed for 1000 ms so that participants had ample time to make a response. To avoid a large response peak for either the first or the last frame of the movie, we decided to divide the mean number of responses for the first frame by 10 and the last frame by 20 equal data points separated by 50 ms (i.e., the mean number of responses over the 10 and 20 samples) for illustrative purpose in Fig. 7 (see the shaded areas).

For the running condition, we conducted an ANOVA on the mean number of responses with camouflage (adaptive dynamic, adaptive static and standard Netherlands woodland) and movie duration (23 frames) as within subject variables. The ANOVA yielded a significant camouflage × movie duration interaction, $F(44, 528) = 31.744$, $p < 0.001$. This interaction was further examined by comparing each camouflage condition for each frame using two-tailed t-tests. Note that for multiple comparisons, p-values were FDR corrected [7]. The mean number of responses (i.e., the detection rate) for the standard Netherlands woodland condition was significantly higher than the adaptive dynamic condition and the adaptive static condition between 0 and 650 ms (frame 1–4), and 0 and 700 ms (frame 1–5), respectively. In contrast, the mean number of responses was significantly higher for both adaptive camouflage conditions compared to the standard Netherlands woodland condition between 850 and 2600 ms (i.e., the last 16 frames). These differences were clearly due to the peak of the distributions.

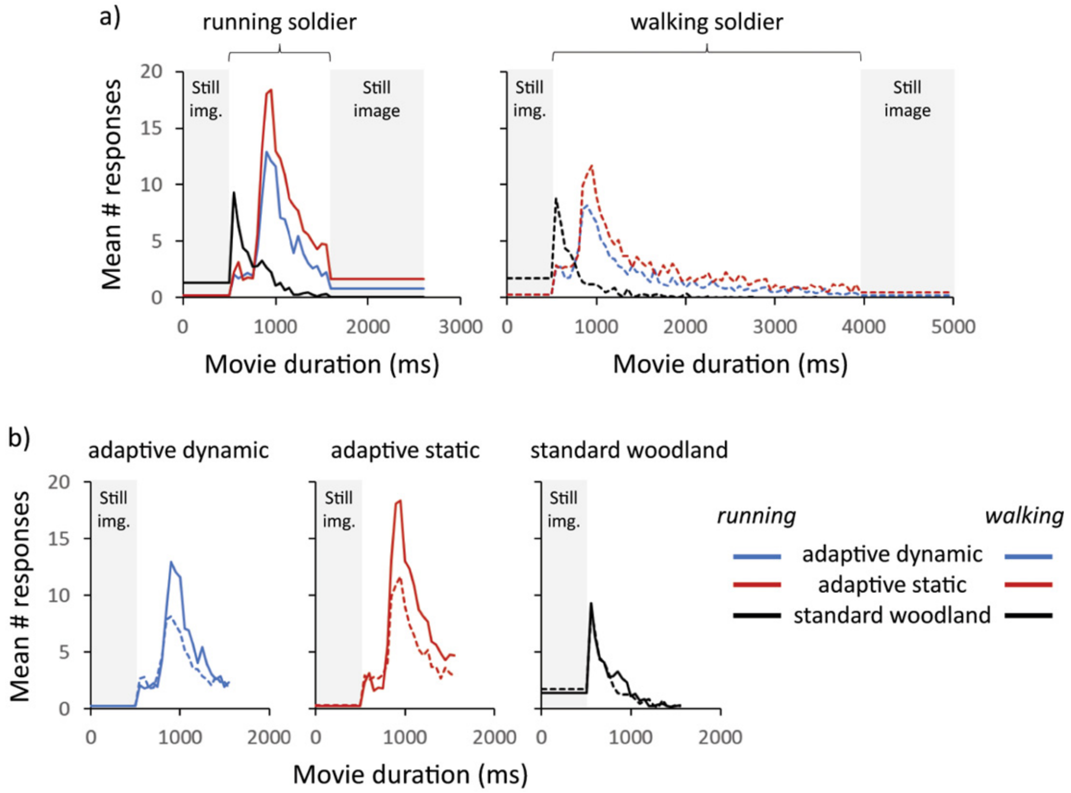


Figure 7. (a) Mean number of responses plotted as a function of the movie duration for running or walking targets for each camouflage condition. The left panel provides the response distribution for the running soldier, whereas the right panel provides the distribution for the walking soldier. Note that the first frame of each movie started with a 500 ms still image of the soldier and that the last frame of each movie was shown for 1000 ms so that participants had ample time to make a response. (b) The effect of motion-speed for each camouflage condition.

For the standard woodland condition, the peak was at 550 ms, and this peak was clearly not due to the motion onset of the moving soldier as the motion was initiated 50 ms before the peak (i.e., 500 ms after the onset of the movie). We therefore propose that the standard Netherlands woodland camouflage suit pops-out from its environment as soon as the trial starts, and that this has little to do with the motion itself. It is more likely that the soldier did pop-out on the vast majority of trials due to a contrast, shape or colour difference compared to its background [50, 51, 60], explaining why the peak was so early, and why the target was detected on many trials (mean number of responses was 13.6) during the very first frame of the movie. With regard to the adaptive camouflage conditions, although the target was detected during the first frame on some trials (mean number of responses was 2.0), a clear peak was observed for both conditions around 900 ms and 950 ms for the adaptive dynamic and the adaptive static condition, respectively. This suggests that the initiation of the motion captured attention such that participants were able to detect the target rather rapidly after the motion onset (i.e., responding within 500 ms from the motion onset). However, the motion onset did not capture attention on all trials as the mean number of responses did not drop to zero (like in the standard woodland condition). Finally, the peak was higher for the adaptive static condition than the adaptive dynamic condition, and consistent with our previous analyses was the mean number of responses significantly higher for the adaptive static condition than for the adaptive dynamic condition for the last 16 frames (except 2 frames).

For the walking condition (see the left panel in Fig. 7a), we observed a pattern very similar to the running condition. We conducted an ANOVA on the mean number of responses with camouflage (adaptive dynamic, adaptive static and standard Netherlands woodland) and movie duration (90 frames) as within subject variables. The ANOVA yielded a significant interrelation, $F(138, 1656) = 16.566$, $p < 0.001$, which was further examined by comparing each camouflage condition for each frame using two-tailed t-tests (FDR corrected). The mean number of responses (i.e., the detection rate) for the standard Netherlands woodland condition was significantly higher than the adaptive dynamic condition and the adaptive static condition between 0 and 650 ms (frame 1–4), and 0 and 600 ms (frame 1–3), respectively. In contrast, the mean number of responses was significantly higher for the adaptive dynamic and adaptive static camouflage condition compared to the standard Netherlands woodland condition between 800 and 4950 ms (i.e., the last 64 frames, except 13 random frames), and between 850 and 4950 ms (i.e., the last 64 frames, except 2 random frames). For the standard woodland condition, the peak was at 550 ms, and this peak was clearly not due to the motion onset of the moving soldier as the motion was initiated 50 ms before the peak (i.e., 500 ms after the onset of the movie). For all three camouflage conditions, the peak of the distributions were identical to that of the running condition. Although participants had more time to detect the target in the walking condition compared to the running condition, the mean number of responses for the adaptive camouflage conditions never dropped to zero, suggesting that even though the target continuously moved this did not capture attention on a vast majority of trials (like in the standard Woodland condition). Finally, the mean number of responses was significantly higher for the adaptive static condition than for the adaptive dynamic condition, but predominantly during the the peak (in total 12 different frames were significant).

Although we had examined the effect of motion-speed earlier, it is important to mention that in these analyses the results were confounded by the duration of the movies (but not the traversed distance). Therefore, we decided to re-analyze the effect of motion-speed by predominantly focusing on the first 22 dynamic frames (i.e., excluding the first still image), which were identical for both the walking and the running condition (except for the travelled distance). Fig. 7(b) illustrates the mean number of responses for the first 22 frames of walking or running target for each camouflage condition. We conducted three separate ANOVA's on the mean number of responses with movie duration (frame 2–23: 500–1550 ms) and motion-speed (walking or running) as within-subject variables for each camouflage condition. For the adaptive dynamic condition, the ANOVA yielded a significant motion-speed effect, $F(1, 12) = 144.072$, $p < 0.001$, as the mean number of responses was significantly larger when the soldier was running (4.80) than when the soldier was walking (3.66). However, the two-way interaction was significant, $F(21, 252) = 4.650$, $p < 0.001$, indicating that the effect of motion speed depended on the movie duration (i.e., frames). The effect of motion-speed was further examined for each frame using two-tailed t-tests. The t-tests (FDR corrected) yielded a significant motion-speed effect during the peak (900–1100 ms) and another single frame (frame 17), suggesting that the motion onset captured more attention for the running soldier than for the walking soldier, with little of an effect after this peak. For the adaptive static condition, the ANOVA yielded a significant motion-speed effect, $F(1, 12) = 736.525$, $p < 0.001$, as the mean number of responses was significantly larger when the soldier was running (7.14) than when the soldier was walking (4.93). However, the two-way interaction was significant, $F(21, 252) = 5.986$, $p < 0.001$, indicating that the effect of motion speed depended on the movie duration (i.e., frames). The effect of motion-speed was further examined for each frame using two-tailed t-tests. The t-tests (FDR corrected) yielded a significant motion-speed effect during the peak (900–1400 ms) and another single frame (frame 20), suggesting that the motion-onset captured more attention for the running soldier than for the walking soldier, with little of an effect after this peak. For the standard Netherlands woodland condition, the ANOVA yielded a significant motion-speed effect, $F(1, 12) = 6.665$, $p = 0.024$, as the mean number of responses was significantly larger when the soldier was running (2.07) than when the soldier was walking (1.85). However, the two-way interaction was significant, $F(21, 252) = 2.291$, $p = 0.001$, indicating that the effect of motion speed depended on the movie duration (i.e., frames). The effect of motion-speed was further examined for each frame using two-tailed t-tests. The t-tests (FDR corrected) yielded a significant motion-speed effect for frame 9 and 16. Whereas for frame 9 the mean number of responses was significantly higher for the running condition compared to the walking condition, the opposite was observed for frame 16. Given that we did not find some systematic motion-speed differences over a couple of successive frames (like for the other two conditions), we therefore assume that these (opposing) effects have little to do with the motion-speed.

4. CONCLUSION & DISCUSSION

In the present study, we examined whether we can efficiently camouflage a moving target by adapting the camouflage pattern to its immediate surroundings. In general, we show that motion breaks camouflage–a dynamic soldier was much easier to find than a static soldier. However, this does not imply that a soldier is always detected when he moves [19]. Indeed, we show that factors like motion-speed, viewing angle and camouflage technique also play a significant role in the visibility of the target object. More specifically, and consistent with the literature, a walking soldier was more difficult to find than a running soldier, indicating that the detection rate increased with increasing motion-speed [9, 10]. Interestingly, the camouflage technique had a major impact on the detection rate as dynamically adapting the camouflage to its environment was more efficient than the adaptative static camouflage technique and the standard Dutch woodland camouflage suit. That the dynamic adaptive camouflage pattern resulted in the best performance is not surprising, as it is known from the visual search literature that a target is more difficult to find when it is very similar to its surrounding than when it is dissimilar to its surrounding [12, 18, 32].

The distributions of the responses revealed important information regarding the underlying search process for each camouflage condition. The standard Netherlands woodland camouflage did pop-out on the vast majority of trials, as the distribution showed a large peak of the responses, and the number of responses dropped to zero after this peak. This was also supported by the detection rate which was rather close to ceiling performance. This pop-out effect can not be attributed to the the motion, as (i) the peak of the distribution was observed 50 ms after the onset of the target motion, and (ii) the soldier was detected on a vast majority of trials before the motion onset. That the presence of the soldier captured attention was not very surprising as the Netherlands woodland camouflage suit was designed for a woodland environment, and not for a sandy/bush or urban environment. The observed pop-out effect was presumably caused by a contrast, colour, shape and/or orientation difference compared to its background, which are all known features to capture attention [60]. For both adaptive camouflage conditions we observed a very similar peak, as in the standard camouflage condition. However, the peak of the distributions was at approximately 950 ms after the movie onset, and very little responses were made during the first movie frame (i.e., the still image). Therefore, we propose that the peak reflects a capture effect due to motion onset. Indeed, the motion was ∼450 ms initiated before the peak of the distribution, and it is very likely that the motion onset captured attention. However, the motion onset did not capture attention on all trials. Interestingly, and in in contrast to the standard camouflage condition, the number of responses never dropped to zero. This even though the soldiers were continuously moving (except during the last frame). Taken together these results indicate that the motion onset, and not the motion itself captures attention. This does not mean that motion doesn't do anything, as it is very likely that the motion makes an object more salient than a static object. This also explains why the detection rate was higher for moving soldiers than for static soldiers. In fact, we also found an effect of motion-speed, but interestingly enough, this was predominantly caused by a larger peak for the running condition compared to the walking condition, indicating that the initiation of a running soldier captured more attention than the initiation of a walking soldier. Whereas other studies [9, 10] observed an effect of motion-speed, the present study favors the notion that this is predominantly driven by the motion onset and not by the motion it self.

That a motion onset is capable to capture someone's attention is known from the visual search literature [1, 46]. However, such a motion transient does not capture attention under all circumstances [58]. Van der Burg and colleagues [58] showed that a unique motion transient does not necessarily pop-out when it is surrounded by other moving objects (as if the the motion transient was camouflaged by other motion transients; see also [53, 55] for a similar effect when using abrupt onsets). Interestingly, Van der Burg and colleagues found compelling evidence that a motion transient did pop-out, but only when this transient resulted in a (temporarily) unique motion direction compared to the motion direction of the other moving objects (e.g., when all the other objects move in the opposite direction). What is most likely important for visual search and for camouflage efficiency, is that an object (like a static or dynamic soldier) stands out from its surrounding when at least a single feature is unique compared to its environment (and/or surrounding distractor elements) [17, 32, 33].

What is the best camouflage pattern then? Obviously, one that is always identical to its background (such that the target effectively becomes transparent) regardless of whether the target is moving or not. However, this is only possible in an experimental setup, but not realistic to apply in a real world context where it is impossible to know the "exact" location (x, y and z) of the eyes of the enemy (observer) in advance. It is clear from the results that if the perfect camouflage (one that adapts dynamically to its environment) is perceived from a different viewing angle then the soldier is no longer protected by its "optimal" camouflage pattern. It is therefore better to come up with a kind of camouflage pattern that works under multiple viewing angles. In that case, the camouflage pattern will also protect soldiers if they are viewed from multiple directions. A method to improve the camouflage for moving objects is to not take the exact background, but instead take samples from a broader range of the background. Indeed, under none-ideal, more realistic circumstances (i.e., the camouflage was not identical to its background), the participants showed that the target detection rate dropped when the soldiers' camouflage pattern was taken from a broader range in its background (SD was larger than zero) than when the camouflage pattern was an exact copy of its background (SD = 0).

Although we found that the broad SD condition under none-ideal circumstances did lead to just a small improvement (i.e., the soldier was less often detected on 0–10% of the trials, depending on the distance), the fact that we did find evidence for an improvement with a broader SD can be taken as a proof of principle. What is interesting though, is that this SD effect is consistent with a recent study by Smart and colleagues [45]. In their study, they investigated how human participants were able to localise a moving target in peripheral vision. The target was either a small black square, a uniform grey square (with a luminance equal to the mean background luminance), or a square matching the background. The background was generated using a 1/f function. Interestingly, the target was more difficult to localise when it was unpatterned uniform grey than when it matched the background. Perhaps unsurprisingly, the target was easiest to spot when it was black. That the target was better camouflaged by a uniform grey background than a matched background is consistent with our finding that a moving soldier is more difficult to detect when the SD is broad than when it is zero (i.e., when the camouflage suit exactly matches the background). Indeed, taking samples from a broader range generates a more uniform camouflage suit, which mean luminance approaches the local mean luminance of the targets' background. More research is required to improve our understanding about what the optimal parameters are. For instance, it would be informative to conduct a follow-up experiment, in which both the viewing angle and the SD parameters are systematically manipulated. This may not only improve the adaptive camouflage, but may also inform the soldier in the field about whether he/she is protected by its camouflage under certain conditions. Indeed, if one knows the approximate viewing angle and distance to the enemy, then one can be informed about the camouflage protection, and may decide to stay at a certain location, or alternatively decide to start moving.

The spatial analysis reveals important information about where the targets were most frequently detected. This analysis leads to a couple of interesting observations. For the standard woodland camouflage condition, the detections were distributed over the whole image. This makes sense, as the camouflage did not adapt to its local background, and did pop-out on the vast majority of trials. In the adaptive dynamic condition, the soldiers were detected at locations when the soldier broke a structure in the environment (such as the yellow line in the urban environment). This suggest that the camouflage works well, but fails in situations where the background consists of clear structures or objects. However, this is not the case for horizontal structures. This makes perfect sense, as in the adaptive dynamic camouflage condition, the pixels on the camouflage suit were sampled from its local environment on the left or right. As a result, horizontal structures (like a bush border or a horizon) will be projected on the camouflage suit as well, explaining why the soldier is rather well camouflaged when it crosses a horizontal structure.

In the present study we investigated the effects of camouflage on detection performance. An intriguing question is whether camouflage also affects the ability to identify the soldier. Indeed, recently Hall and colleagues [19] showed that although their camouflaged moving objects were unable to decrease detection, they were significantly more difficult to identify than uncamouflaged objects. These findings are interesting and consistent with the visual crowding literature. This phenomenon refers to the inability to identify (*not* detect) a target in peripheral vision due to nearby clutter [36]. Typically, crowding is much stronger when the target is surrounded by similar objects than when it is surrounded by dissimilar objects [3, 8, 34], and also observed in highly cluttered scenes [56, 57], like natural environments [59]. Importantly, the inability to identify an object depends also on the target eccentricity, that is the angular distance between the fixation point and the target location, although there is some evidence that crowding does not depend on the target eccentricity in densely cluttered environments [57]. With regard to the present study, one might argue that even though participants were able to detect the moving soldier occasionally, it does not necessarily imply that they were able to identify the soldier (due to the camouflage). Unfortunately, unlike the Hall et al. [19] study, we were not able to investigate whether the identification of the soldier was affected by the camouflage, as the participants only performed a detection task. Furthermore, we were also not able to specify the maximum target eccentricity to detect the soldier, as participants were allowed to move their eyes during the course of a trial. As a result, on some trials the soldier was presumably detected by coincidence. For future research, it would be informative to measure eye-movements and to combine the detection task with an identification task, to examine whether camouflage affects the ability to detect and to identify the moving soldier, and to determine the minimum target eccentricity required to perform these tasks with a given level of accuracy (see e.g. [24, 35]).

The present study introduces a promising methodology to create a camouflage pattern that rapidly adapts to its environmental properties. Of course, more research is required to optimize the camouflage effectiveness, but the fact that we found interesting results is promising. The findings of the present study have theoretical implications for the visual search, and the visual crowding literature, but also implications for more applied projects, like ACAMSII [2], in order to improve camouflage for moving objects.

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