

# Detecting Threat-Related Intentional Actions of Others: Effects of Image Quality, Response Mode, and Target Cuing on Vigilance

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Three experiments examined the vigilance performance of participants watching videos depicting intentional actions of an individual's hand reaching for and grasping an object—involving transporting or using either a gun or a hairdryer—in order to detect infrequent threat-related actions. Participants indicated detection of target actions either manually or by withholding response. They also rated their subjective mental workload before and after each vigilance task. Irrespective of response mode, the detection rate of intentional threats declined over time on task and subjective workload increased, but only under visually degraded viewing conditions. This vigilance decrement was attenuated by temporal cues that were 75% valid in predicting a subsequent target action and eliminated with 100% valid cues. The findings indicate that detection of biological motion targets, and threat-related intentional actions in particular, although not attention sensitive under normal viewing conditions, is subject to vigilance decrement under degraded viewing conditions. The results are compatible with the view that the decrement in detecting threat-related intentional actions reflects increasing failure of attention allocation processes over time.

**Keywords:** vigilance, biological motion, attention, intent, action recognition

Rapidly detecting and identifying the actions and movements of other people is a critical need in many civilian and military surveillance environments. For example, sensors on semiautonomous uninhabited vehicles (UVs) and other platforms are increasingly being used to provide video or infrared images to remotely located operators (Cooke, Pringle, Pedersen, & Connor, 2006; Parasuraman, Cosenzo, & de Visser, 2009). More traditionally, closed-circuit TV (CCTV) monitors are often used in surveillance operations in such settings as prisons, airports, train terminals, highways, and busy city streets. Surveillance images typically show people or vehicles in motion and engaged in various activities. Such information can be used to identify individuals who pose potential threats or to determine the potential for danger in crowd-control situations.

Attention may influence the detection, identification, and response to motion-based targets in such situations. For example, visual search for a specific moving target among distractors is speeded up by valid location cues that direct attention appropri-

ately and is slowed down by invalid cues (Remington, Folk, & McLean, 2001). Functional MRI (fMRI) studies have also shown that the cortical middle temporal area which responds preferentially to movement, shows enhanced activation when attention is directed either voluntarily or reflexively to motion stimuli (Corbetta & Schulman, 2002; O'Craven, Rosen, Kwong, Treisman, & Savoy, 1999). However, the role of attention in the processing of movements of other living organisms (people or animals)—so-called *biological motion* (Johansson, 1973)—has been less well studied. Perhaps because of its ecological significance and important role in survival—detecting the movements of predators or prey can help an animal in the fight or flight response—biological motion has often been conceived of as a relatively “primitive” or automatic function that requires little or no help from attention. Seemingly consistent with this view is evidence that newborn (2-day-old) infants show a preference for looking at point-light displays of biological motion (Simion, Regolino, & Bulf, 2008), and that older adults, who typically exhibit an age-related reduction in the efficiency of processing moving stimuli (Gilmore, Wenk, Naylor, & Stuve, 1992; Jiang, Greenwood, & Parasuraman, 1999) and who also display attentional changes (Rogers, 2000), nevertheless are as efficient at processing biological motion stimuli as the young (Billino, Bremmer, & Gegenfurtner, 2008; J. F. Norman, Payton, Long, & Hawkes, 2004). In contrast, Thornton, Rensink, and Shiffrar (2002) showed that discrimination of point-light displays of human walkers was reduced when participants had to simultaneously perform a highly demanding secondary task, suggesting that under some conditions attention does influence the processing of biological motion.

In addition to selective or divided attention, the influence of another variety of attention—*sustained attention* or *vigilance*—on

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the processing of biological motion is not well understood. Arguably, this aspect of attention is more relevant in many everyday settings because actions or other human movements that constitute a threat to an observer are likely to occur relatively infrequently in proportion to benign or normal movements. Moreover, as in the case of remote observers monitoring CCTV screens (Donald, 2008) or video feeds from UVs during surveillance operations (Cooke et al., 2006), observation over long periods of time may be required. These features—a low probability of a critical event and a requirement for sustained observation—are defining characteristics of vigilance tasks.

Human vigilance for static targets has been extensively studied, but there has been comparatively little work on motion-based targets (Davies & Tune, 1970; Koelega, Brinkman, Zwep, & Verbaten, 1990; Parasuraman, 1979, 1986; Warm, 1984), with the exception of a few studies of air traffic controllers monitoring aircraft movements on radar displays (Metzger & Parasuraman, 2001; Thackray, Bailey, & Touchstone, 1979). Examining sustained attention in relation to the perception of biological motion is important because of its relevance for threat identification in surveillance situations, which typically involve infrequently occurring actions or movements over long periods of observation. Tickner, Poulton, Copeman, and Simmonds (1972) conducted some early relevant work on naïve and expert observers monitoring CCTV screens showing movements of people. They had observers watch 16 or 24 CCTV screens that showed mainly still scenes from a prison with occasional “suspicious” movements of inmates, which were the targets that had to be reported. Over a 1-hr watch period, 12 such suspicious incidents occurred. Detection performance was poorer when 24 rather than 16 screens had to be monitored. In subsequent studies, Tickner and Poulton (1973, 1975) used similar TV scenes but with a larger number of nontarget movements, both inside and outside the prison. A number of findings were reported, such as better detection of suspicious incidents inside rather than outside the prison and by younger (<30 years) compared with older (>45 years) prison guards. However, none of the studies found evidence of performance decline over time—that is, vigilance decrement. This could reflect many factors, including the possibility suggested by Tickner and Poulton (1975) that learning what to watch for may have masked any effects due to reduced vigilance.

Although the studies by Tickner, Poulton, and colleagues yielded several interesting findings on sustained monitoring of people and actions, they leave unanswered the basic question of whether such monitoring is subject to the normal effects of the requirement for sustained attention—vigilance over time on task—that is typically seen with static or nonbiological motion targets. One conclusion on the basis of their studies might be that detecting movements of people, as well as other forms of biological motion, is an automatic process robust to attentional changes, including vigilance effects (cf. Fisk & Schneider, 1981). An alternative is that perception of biological motion *is* attention sensitive, but only under certain viewing conditions. One such viewing factor could be image quality. In the Tickner and Poulton (1973, 1975) studies, participants viewed target and nontarget movements on good-quality CCTV screens, and the target “suspicious incidents” that had to be reported were clearly visible. However, in many real surveillance settings, image quality may be poor because of various factors, for example, low transmission bandwidth, vibration,

and sensor noise, as in the case of video images provided by UVs to remote observers. Nuechterlein, Parasuraman, and Jiang (1983) first showed that high levels of image degradation—blurring with low-pass filtering and addition of background visual noise—led to a rapid decline in detection sensitivity over time compared with low or no degradation in a simple digit-discrimination vigilance task, a result that has been subsequently replicated (Temple et al., 2000). A study using a secondary probe–reaction time (RT) method found that the vigilance decrement under these conditions was associated with increased probe RT—suggesting a decrease over time in the ability of participants to allocate attentional resources to target detection (Parasuraman, 1985). Subsequent studies using different methods yielded additional evidence for this view (Smit, Eling, & Coenen, 2004; Warm, Parasuraman, & Matthews, 2008). Measurement of cerebral blood flow velocity using transcranial doppler sonography has also provided converging neural evidence for depleted allocation of attentional resources to target detection as a basis for the vigilance decrement under conditions of low target salience (Helton et al., 2007; Hitchcock et al., 2003; Warm & Parasuraman, 2007). Overall, therefore, these findings suggest that vigilance for biological motion-based targets may similarly decline over time only under conditions of low target salience, as in the case of image degradation.

Biological motion-based threats could involve movements made by another person, actions performed on an object, or some combination. An example would be viewing a person reaching for an object such as a gun or other weapon. Such an action could represent a threat, particularly in comparison to viewing the same person reaching for another object generally not classified as a weapon, such as a hairdryer. More important, however, an appropriate response on the part of the viewer—for example, whether to react to a threat or not—depends on understanding the *intent* of the other person in executing the action with the object and not solely the movement or the identity of the object. Determining threat while viewing another person reaching for a weapon depends on what that person plans to do with that weapon: Seeing someone grasp a weapon in order to use it requires a different response to seeing someone grasp a weapon in order to move it or transport it from one location to another. Even utilization actions can have different implications for threat assessment depending on who or what they are directed toward, for example, watching a person who grasps a weapon and points it away from versus toward oneself.

In the present series of experiments, we examined the performance of participants required to detect infrequent threat-based intentional actions among more frequent nonthreat actions over a sustained period of observation. We filmed and processed a number of videos of an individual’s hand reaching for and grasping a weapon (a black gun) or a similarly sized nonweapon (a black hairdryer). The actor, whose face and body were not shown, grasped the gun or hairdryer in a manner compatible with using it (utilization intent) or in such a way that the object could not be used but only moved (transport intent). Only some of these intentional actions represented threats. We hypothesized that detection of intentional threats (targets) would be efficient under normal viewing but would decline over time under conditions of image degradation.

In addition to varying image degradation, we also manipulated the response mode to signal identification of threats. Participants

were required to either respond manually with a key press to the infrequent targets (“go”) and withhold response to the more frequent nontargets (“normal” response mode) or to respond to the nontargets and withhold response (“no go”) to the targets (“inhibition” response mode). There were two motivating reasons for this manipulation, one ecological and the other theoretical. First, many settings in which threats may be present require that the situation be handled by the observer *withholding* action, as when the action object is only potentially threatening, such as a weapon, and executing a response can be potentially lethal, for example, firing at a person who intends to grasp the weapon in order to transport it to another, perhaps safer location. In such cases, an observer might falsely respond as a result of misconstruing the intent of the actor. Accordingly, it is of interest to understand whether the effects of sustained attention on detection rate and the frequency of intention-based false positive responses differ depending on whether a person indicates detection by responding or by withholding a response to an infrequently occurring threat.

A second reason for manipulating response mode (go vs. no go to targets) is that it plays a central role in a current theoretical debate concerning the mechanisms of sustained attention. The attention allocation view of vigilance decrement proposed by many authors (Parasuraman, 1985; Smit et al., 2004; Warm et al., 2008) has typically been supported from evidence in vigilance tasks using a normal go response for targets. In contrast, Robertson, Manly, Andrade, Baddeley, and Yiend (1997) argued for a “mindlessness” theory on the basis of their use of the sustained attention to response task (SART). In this vigilance task, participants have to respond to frequent nontargets and withhold response (i.e., no go) to infrequent targets. According to the mindlessness perspective, an observer’s supervisory attentional system (D. A. Norman & Shallice, 1976) loses its effectiveness because of the infrequent occurrence of targets in a vigilance task, as a result of which he or she ceases to focus and approaches the task in a mindless, routinized manner. Various sources of evidence—correlations of vigilance performance with self-reports of absent-mindedness (Broadbent, Cooper, Fitzgerald, & Parkes, 1982; Robertson et al., 1997), online reports of “task-unrelated thoughts” during task performance (Smallwood et al., 2004), and fMRI activation patterns associated with the SART (O’Connor, Manly, Robertson, Hevner, & Levine, 2003) and with “mind wandering” (Mason et al., 2007)—have been used to support the mindlessness theory. At the same time, several studies comparing the no-go SART with traditional go vigilance tasks have provided evidence supporting the attentional resource theory (Grier et al., 2003; Helton et al., 2003; Helton & Warm, 2008). The two theories make differing predictions for performance changes over time in detecting low-salience intentional threats. According to the mindlessness theory, increasing image degradation, by making the target detection task more demanding and difficult, should decrease mind wandering (Smallwood & Schooler, 2006) or task-unrelated thoughts (Giambra, 1995) and therefore should reduce the vigilance decrement over time, whereas the resource theory predicts the opposite.

In summary, the present investigation examined sustained attention performance in detecting biological motion-based threats under low and high levels of image degradation. In addition, participants either responded to targets and withheld response to nontargets (normal response mode) or responded to nontargets and

not to targets (inhibition response mode). Under the attentional resource theory of vigilance, one would predict that the efficiency of detecting infrequent intentional actions using a weapon would show a greater decline with time on task for degraded than for undegraded images; the mindlessness theory predicts the opposite. To further evaluate the two theories, we used the NASA–Task Load Index (TLX) measure of subjective mental workload (Hart & Staveland, 1988). The NASA-TLX was administered before and after participants completed the vigilance task under each response mode. The mindlessness theory predicts that participants would not rate the overall mental demand of the vigilance tasks as high, particularly in the inhibition response mode condition, which is thought to induce a routine, mindless approach to task performance. In contrast, the resource theory predicts that subjective mental workload should be high and should increase from the beginning to the end of the vigil. Finally, given that biological motion plays an important role in inferring the intent of others (Blake & Shiffrar, 2007), and given that we examined detection of targets defined as intentional threats, we hypothesized that false detections (or false alarms) would also primarily be intention-based errors. We, therefore, predicted that when false alarms occurred, they would mainly involve participants’ confusing the goal of an action, that is, transporting rather than using a gun. In contrast, we expected fewer false alarms to be object-based errors, that is, to confusing a hairdryer for a gun.

We conducted three experiments to test these hypotheses. In Experiment 1, we examined sustained attention to biological motion in a situation that was close to normal viewing conditions, that is, detecting infrequent action-based intentional threats under low image degradation. In Experiment 2, we examined performance of the same task under conditions of high image degradation. Experiment 3 also examined sustained attention to intentional actions under degraded viewing conditions, but used a temporal target cuing technique to examine whether any vigilance decrement would be attenuated or eliminated. We predicted that if the vigilance decrement in detecting intentional threats under degraded viewing conditions represented an increasing rate of failures in attention allocation, then a temporal cue prior to target presentation should reduce the decrement, depending on the validity of the cue.

## Experiment 1

### Method

**Participants.** Twelve young adults aged between 20 and 24 years of age ( $M = 21$  years), six women and six men, participated and received \$15/hr for their participation.

**Stimuli.** We filmed and processed short-duration videos of an actor’s left or right hand shown reaching for and grasping an object that could be either a black gun or a similarly sized black hairdryer. The actor grasped the gun or hairdryer in a manner compatible with using either object (utilization intent) or in such a way that it could not be used but only moved (transport intent). In addition, we varied the object’s position in the visual field (left or right), the direction it pointed to (left or right), and the actor’s grasp position (over or under the object), to create a total of 32 such videos.

The videos were recorded with nondirectional lighting against a green background to enable later editing of the stimuli with video software. The video camera was positioned on a tripod and angled

downward to capture the arm and hand reaching for the target from a third-person perspective (approximately 45 degrees from the horizontal plane of the desktop). The gun and the hairdryer were placed on the green background at equal distance on either side of the center of the video frame. Each reach to grasp was completed in approximately 3 s, and clips were subsequently edited to 1-s segments using video-editing software Adobe Premiere Pro 2.0 (Adobe Systems, San Jose, CA). Finally, a red central fixation cross was added at the center of the frame. Although the videos were shot in color, in the present studies they were shown in monochrome.

The 32 videos we filmed represented all possible binary combinations of the following five factors ( $2^5 = 32$ ):

1. Object type—the object of the actor's action was either a black gun or a black hairdryer; these were of similar size, luminance, and contrast, with each having an end (tip) that oriented the object in one direction or other.
2. Object location—The gun or the hairdryer was located in either the viewer's left or right visual field.
3. Object facing direction—The tip of the object could point to either the left or the right.
4. Grasp type—The video displayed the actor (whose face or body was never visible) reaching for the object (gun or hairdryer) with either an overhand or an underhand grasp, that is, with the hand over the handle shaft or under it.
5. Grasping hand—The actor performed an action on the object (gun or hairdryer) using either the left or right hand.

Intentional actions were defined by the combination of the last three of these factors: object facing direction (left or right), grasp type (over or under), and grasp hand (left or right). For example, for the right hand, an object facing left and grasped with an overhand grip resulted in the object's being positioned facing away from the actor with the trigger next to the actor's index finger, consistent with a *utilization* intent. In contrast, grasping the object facing the same direction with the right hand using an underhand grip resulted in the object's facing toward the actor with the finger on the opposite side of the handle to the trigger, consistent with a *transport* intent. The 32 videos differed only in the three factors determining intent (object facing direction, grasp type, and grasp hand) and the two factors of object type and object location. All other aspects, such as the speed and smoothness of the hand movement, were held constant across the 32 videos. This was done during the filming process by asking the actor to keep his or her movements as similar as possible for all 32 filming shoots (repeat shoots were necessary to ensure that this was the case).

Targets were defined as a specific intentional action involving *using the gun with it pointing in a leftward* (but not rightward) direction, regardless of gun position (left or right visual field) and the combination of grasp type (over or under) and grasp hand (left or right). The choice of the gun's facing direction (left) was arbitrary, but participants were instructed that the leftward direction was where the (unseen) object of the threatening action was located, hence only a gun utilization action in this

direction represented a threat or target. These combinations resulted in four target types: a right-handed, overhand grip of the gun on the left (Figure 1A); a right-handed, overhand grip of the gun on the right (Figure 1B); a left-handed, underhand grip of the gun on the left (Figure 1C); and a left-handed, underhand grip of the gun on the right (Figure 1D). Figures 1A–1D show still frames from these four target videos. For example, Figure 1A shows a still frame of the actor reaching for the gun with a right-handed, overhand grasp in a manner compatible with using it (utilization grasp), with the weapon on the left side and also facing left. These four videos were chosen as targets from the set of 32 videos so that the ratio of targets to nontargets was relatively low, a necessary feature of a vigilance task. The remaining 28 other object–action combinations represented nontargets. Three examples are shown in Figures 1E–1G. Figure 1E shows a nontarget event in which the actor reached for a gun with an overhand grasp, but in this case to transport it. Figure 1F shows another type of nontarget event, involving an action aimed at using the hairdryer. Finally, Figure 1G shows a nontarget event in which the hairdryer was transported.

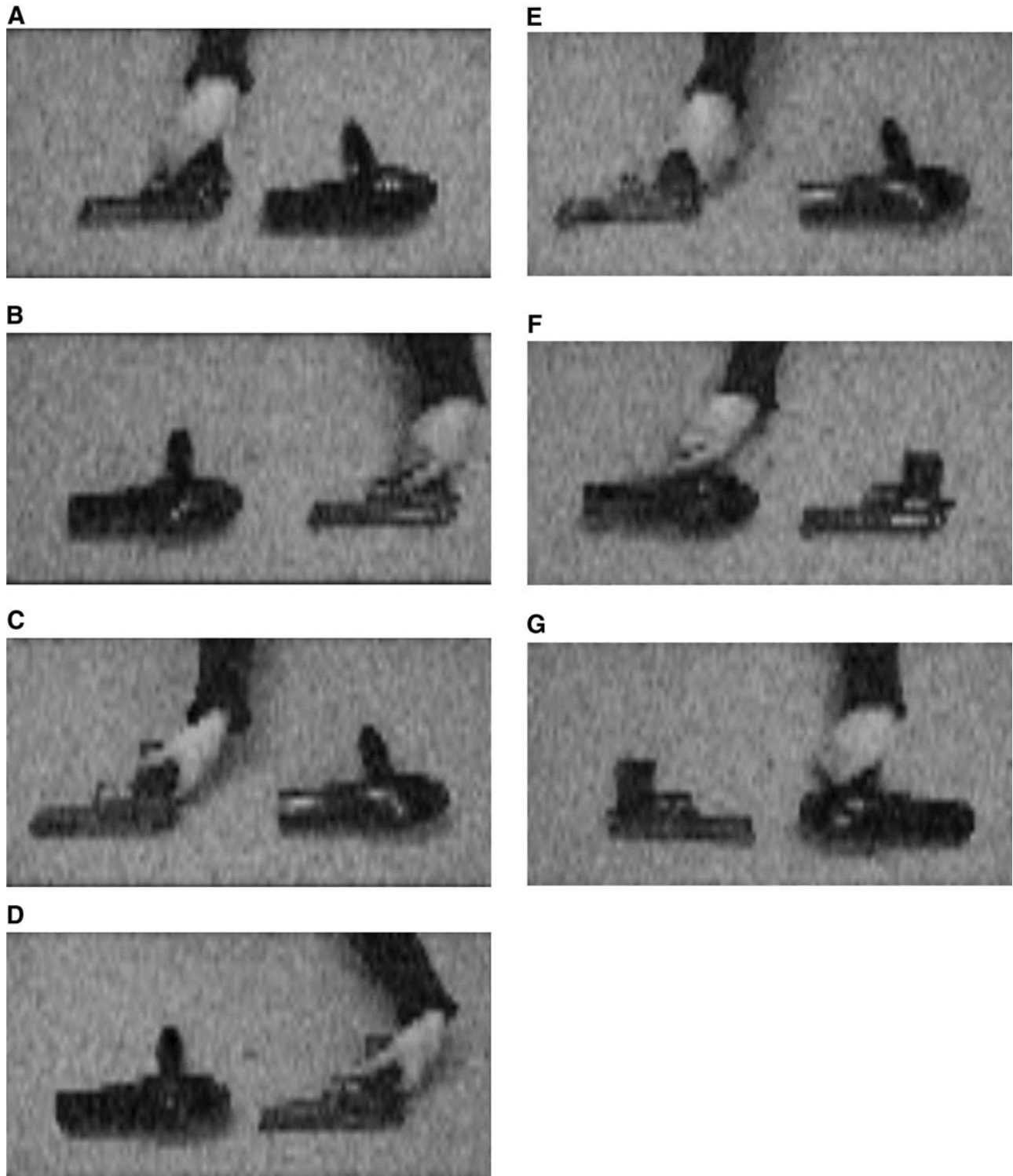
To summarize, of the 32 action videos, four were defined as targets and 28 as nontargets. Of the 28 nontarget types, 16 involved actions with the hairdryer, and 12 with the gun, eight in which the gun was transported and four in which it was used but pointing in a rightward direction. The overall probability of a given video representing an intentional threat target (using a gun pointing left) was therefore  $4/32 = .125$ .

Presentation software, Version 12.2 (Neurobehavioral Systems, Inc., Albany, CA), was used for timed presentation of all video stimuli in the vigilance task and for data collection. Each videotaped action sequence (i.e., a stimulus) was developed by trimming the original 3-s videos to show 30 frames lasting about 1 s, followed by a 1-s intertrial interval during which participants could respond. The vigilance task lasted approximately 22 min and consisted of 20 blocks of 32 stimuli each, for a total of 640 stimulus presentations (80 targets and 560 nontargets). Targets and nontargets were presented in a random sequence with the restriction that four targets and 28 nontargets were presented within every successive sequence of 32 stimuli, and a target never followed another target. Each participant completed the vigilance task twice using either the normal or the inhibition response mode in a counterbalanced order. In the normal response mode condition, participants were instructed to respond to targets only by pressing the keyboard *space bar* and to withhold response to nontargets. In the inhibition response mode condition, participants were instructed to respond only to nontargets by pressing the *space bar* and to withhold responses to targets. Instructions to participants emphasized accuracy rather than speed of response.

**Materials.** A digital version of the NASA-TLX (Hart & Staveland, 1988) was used to assess subjective perceptions of workload. This electronic version recorded workload in two parts. The first part showed the six dimensions of the TLX scale (Mental Demand, Temporal Demand, Physical Demand, Effort, Own Performance, Frustration). The second part allowed users to weight the different dimensions by showing all dimension pairings. We used these to determine the overall weighted subjective workload scores.

**Procedure.** Participants were welcomed into the experimental suite where they filled out an informed consent form. Phones,





*Figure 1.* Examples of still frames from the action videos. Panels A–D show the four target stimuli. Targets were defined as an action involving using (not transporting) the gun with it pointing in a leftward direction. (A) Right-handed, overhand grip of the gun on the left. (B) Right-handed, overhand grip of the gun on the right. (C) Left-handed, underhand grip of the gun on the left. (D) Left-handed, underhand grip of the gun on the right. Panels E–G show still frames from three examples (of 28) of nontarget actions. (E) Nontarget event involving reaching for the gun to transport it. (F) Nontarget event involving use of the hairdryer. (G) Nontarget event involving transport of the hairdryer.

watches, and other devices that indicated the time were collected and placed out of sight of the participant to avoid the *end-spurt effect*, which refers to a transient increase in performance toward the end of a vigilance task when participants know the end is approaching (Bergum & Lehr, 1963). Then, participants were screened for normal or corrected-to-normal (20/20) vision. Participants were seated approximately 20 in. from the computer monitor. Participants were first trained on the task by being shown examples of all 32 video clips, followed by repeated presentations of the target stimuli. Feedback was provided so that participants could distinguish between targets and nontargets. Participants were then exposed to two practice sessions lasting approximately 3 min. Response feedback was provided for each stimulus presentation. After each practice session, participants filled out the NASA-TLX. Immediately after the second practice task, participants started the first vigil, which lasted approximately 22 min. Either the normal or the inhibition response mode had to be used in performing the task, in a counterbalanced order. Participants then filled out the NASA-TLX again. Participants were then given a 10-min break. They could visit the bathroom and were given the option to play an online memory game. The experimenter then briefly instructed participants on the second response type, counterbalanced depending on the response type that was presented in the first vigil. Prior to starting the second vigil, participants were again exposed to two practice sessions for approximately 3 min. They also filled out the NASA-TLX after each practice session. After participants completed the second vigil, they again filled out the NASA-TLX. Participants were then debriefed, paid, and thanked for their participation.

## Results

In all three experiments reported here, analyses of variance (ANOVAs) were carried out on the performance measures of hit rate, false alarm rate, and weighted subjective mental workload scores. Directional  $p$  values are reported for all effects, with degrees of freedom corrected if necessary using Greenhouse–Geisser estimates of sphericity, and effect sizes for significant effects are reported with partial eta squared ( $\eta_p^2$ ).

For the purposes of analysis of vigilance decrement, the 22-min period of observation was divided into eight consecutive blocks lasting 2.75 min each. The mean percentages of correct detection of targets (hit rate) and false alarm rates were computed for each of the eight time blocks of the vigilance session for both the normal and the inhibition response modes. Initial analyses showed that there were no significant effects involving order (normal–inhibition or inhibition–normal) for either the hit rate or the false alarm rate; hence, the data were collapsed across this factor and submitted to a two-way repeated measures ANOVA with response mode (normal, inhibition) and block (1–8) as within-subject variables.

**Hits.** Figure 2 shows the mean hit rates across time on task and for the two response mode conditions. As indicated, detection performance was relatively high in both conditions. There was a significant main effect for response mode,  $F(1, 11) = 5.34$ ,  $p < .05$ ,  $\eta_p^2 = .327$ , with the hit rate higher in the normal response condition ( $M = 94.2\%$ ,  $SEM = 2.0$ ) than in the inhibition condition ( $M = 90.9\%$ ,  $SEM = 1.0$ ). There was no significant effect associated with block,  $F(7, 77) = 1.10$ ,  $p < .4$ . As Figure 2

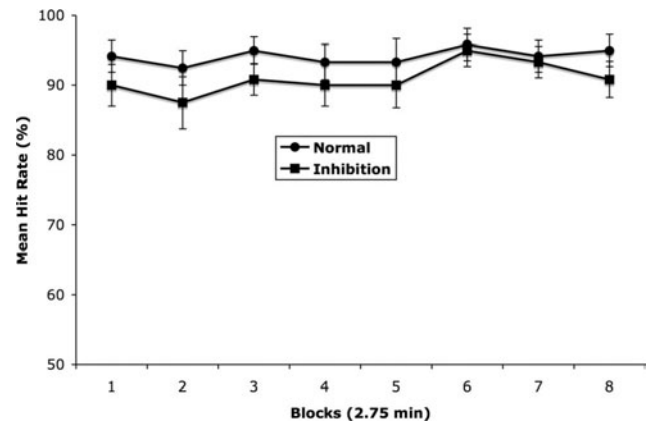


Figure 2. The mean rate of correct detection of threat-related target actions (hits) as a function of successive 2.75-min blocks for the normal and inhibition response modes (Experiment 1).

indicates, performance was relatively stable over time, with no indication of a vigilance decrement over time on task.

**False alarms.** The proportion of false alarms elicited was relatively small (see Figure 3). Mauchly's test indicated that the assumption of sphericity was violated for block ( $\chi^2 = 43.60$ ,  $p < .04$ ); therefore, degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ( $\epsilon_{\text{Block}} = 0.59$ ;  $\epsilon_{\text{Block} \times \text{Response Type}} = 0.56$ ). As Figure 3 shows, false alarm rates were fairly low under both response mode conditions but were higher for the inhibition response mode. There was a main effect for response mode,  $F(1.0, 11.0) = 29.78$ ,  $p < .001$ ,  $\eta_p^2 = .730$ ; the false alarm rate was higher in the inhibition response condition ( $M = 2.7\%$ ,  $SEM = 0.3$ ) than in the normal response condition ( $M = 0.8\%$ ,  $SEM = 0.3$ ). The main effect of block,  $F(4.09, 45.02) = 1.85$ ,  $p < .2$ , and the interaction between response type and block were not significant,  $F(3.92, 43.07) = 2.35$ ,  $p < .1$ .

**Subjective workload.** Figure 4 shows the overall weighted NASA-TLX subjective workload scores. These were subjected to an ANOVA with response mode (normal, inhibition) and phase (practice, start of vigil, end of vigil) as the within-subject variables. (*Practice* refers to the workload ratings given immediately after the first practice task, *start of vigil* refers to ratings given after the second practice task and just before the start of the vigilance task, and *end of vigil* refers to the ratings given immediately after the vigilance task.) There was a main effect for phase,  $F(2, 22) = 79.47$ ,  $p < .001$ ,  $\eta_p^2 = .878$ . Simple contrasts showed that subjective workload after the practice session and the start of the vigil were not significantly different,  $F(1, 11) = 1.31$ ,  $p < .3$ . Subjective workload at the end of the vigil was significantly higher ( $M = 29.61$ ,  $SEM = 2.04$ ) compared with the practice block ( $M = 15.17$ ,  $SEM = 0.95$ ),  $F(1, 11) = 78.55$ ,  $p < .001$ ,  $\eta_p^2 = .877$ , and to the start of the vigil ( $M = 14.19$ ,  $SEM = 0.99$ ),  $F(1, 11) = 105.55$ ,  $p < .001$ ,  $\eta_p^2 = .906$ . There was no significant effect for response mode,  $F(1, 11) = 1.14$ ,  $p < .4$ .

## Discussion

Experiment 1 examined performance during sustained detection of threat-related intentional actions at a low level of image degra-

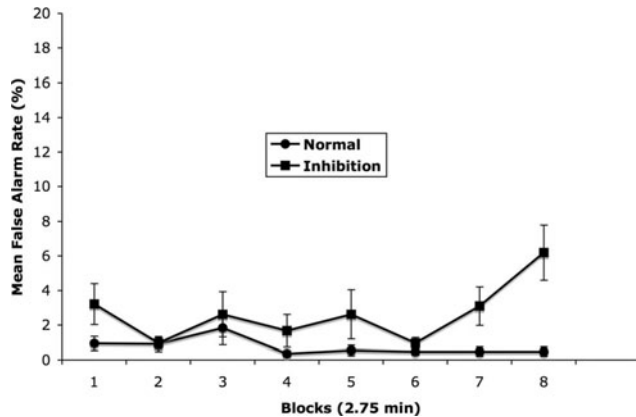


Figure 3. Mean false alarm rate as a function of successive 2.75-min blocks for the normal and inhibition response modes (Experiment 1).

dation corresponding to fairly normal viewing conditions. The results showed that detection rate of critical targets—reaching for a gun with the intention of using it—was relatively high, regardless of whether observers were required to indicate their detection by executing a response (normal response mode) or by withholding a response (inhibition response mode).

These findings suggest that detection of critical targets among biological motion stimuli is relatively immune to attentional deterioration under normal viewing. However, this does not necessarily mean that biological motion is always insensitive to attention. As suggested by Thornton et al. (2002), although it makes sense for biological motion—given its evolutionary significance for survival in the natural ecology—not to require high levels of the observer's attention, it may nevertheless be affected negatively by a large withdrawal of attention; in other words, biological motion is not a completely automatic process (see also Nakayama & Joseph, 1998, for a similar suggestion). Thornton et al. reached this conclusion by pairing a biological motion task with a demanding secondary visual task that competed for the observer's attention. In the present study, "withdrawal" of attention was examined by requiring subjects to perform a vigilance task for a prolonged period of time. Given that no evidence of vigilance decrement was observed, one conclusion is that the "attentional" manipulation of time on task was not sufficiently potent to influence performance. Previous studies have shown that increasing visual degradation leads to a decrease in detection rate over time, and that this vigilance decrement is associated with a depletion in attentional resources applied to target detection (Nuechterlein et al., 1983; Parasuraman, 1985; Temple et al., 2000; Warm et al., 2008). Accordingly, we conducted a second experiment repeating Experiment 1 but under conditions of higher image degradation. We predicted a vigilance decrement in hit rate over time under these conditions. We also predicted that observers would make a greater proportion of false alarms to nontarget actions consistent with a different intent (e.g., transport rather utilization) than for nontargets involving a different object (e.g., hairdryer rather than gun).

The hit rate in Experiment 1 was slightly higher when observers made a motor response to indicate a target detection than when they had to withhold a response, consistent with previous studies comparing a traditional go vigilance task with a no-go task like the

SART (Grier et al., 2003; Helton et al., 2003). This finding must be regarded with some caution given the near-ceiling levels of performance (>90%). More important, the false alarm rate, although relatively low, was higher in the inhibition condition than in the normal condition, again in agreement with previous research (Grier et al., 2003). That observers make relatively more false alarms when required to inhibit a prepotent target response has been attributed to the development of "mindlessness" due to the routine nature of a vigilance task in which targets occur infrequently (Robertson et al., 1997). The mindlessness and attention allocation theories were not distinguishable by the results of Experiment 1. We anticipated a stronger test in Experiment 2.

## Experiment 2

### Method

**Participants.** Thirty-four young adults aged between 20 and 31 years of age ( $M = 23$  years), 16 women and 18 men, participated and received \$15/hr for their participation. None had participated in the previous experiment.

**Stimuli.** The same videotaped stimuli that were presented in Experiment 1 were used except that they were each subjected to image degradation. All videos were visually degraded for image quality in the movie editor Adobe Premiere 2.0 to increase the difficulty of discriminating between target and nontarget actions. Noise and distortion were added using the noise HLS auto filter and the camera blur filter. (These digital methods for visual degradation are similar to the analog filtering method used by Nuechterlein et al., 1983.) Pilot tests showed that after training, participants were able to detect targets with at least 70% accuracy following training and during a practice session, as described below.

Prior to determining the appropriate visual degradation levels used in this experiment, performance was tested at a range of degradation levels using a psychophysical staircase procedure in a group of 10 young participants drawn from the same college population as the main experiment. The goal was to choose a degradation level that was associated with a moderate level of

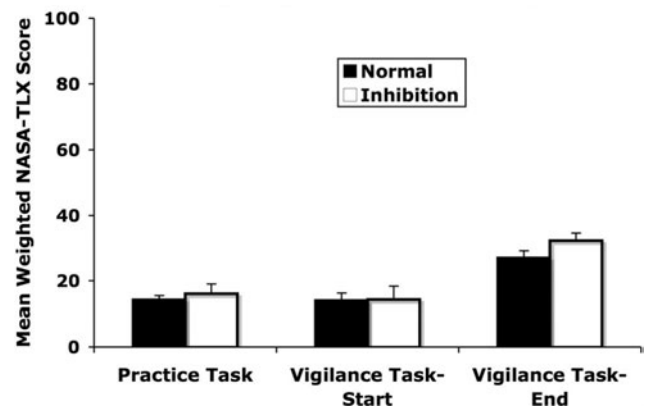


Figure 4. Mean weighted NASA-TLX subjective workload scores at the end of the first practice session and before and after each vigilance session for normal and inhibition response modes (Experiment 1).

detection performance, namely, a 70% hit rate. We first degraded eight selected videos, four targets and four nontargets, at eight levels of degradation from low to high, that combined different values of the noise HLS auto (from 30% to 100% in 10% increments) and camera blur (from 85% to 96% in 1–2% increments) filters. The eight levels appeared progressively more degraded, with Level 1 appearing almost as in normal viewing and Level 8 appearing highly degraded. Participants were shown an equal number of targets and nontargets, beginning with the lowest degradation level, and asked to respond to targets and withhold response to nontargets. When they correctly detected a target (hit) or correctly withheld response to a nontarget (correct rejection), the subsequent action video was shown at the next higher level of degradation; if participants missed a target or made a false alarm, the level of degradation was decreased by one step; and so on. Participants completed the staircase procedure when they had reached 70% overall accuracy and had been presented with at least 64 videos. The resulting degradation level was used as the high-degradation value for all participants for the main vigilance sessions in Experiment 2.

**Procedure.** The procedure was identical to that of Experiment 1. Following training, participants were given two practice blocks followed by two vigilance sessions interspersed with a 10-min break. Participants responded using the normal or inhibition response mode in the two vigilance sessions, in counterbalanced order. Each participant completed the NASA-TLX after the first practice block and before and after each vigilance session.

## Results

There were no significant effects associated with the order of response mode for either hits or false alarms and so the data were collapsed over this factor.

**Hits.** The hit rate data were submitted to a two-way repeated measures ANOVA with response mode (normal, inhibition) and block (1–8) as the within-subject variables. Figure 5 shows the mean hit rates over the eight successive blocks of the vigilance session for each response mode condition. Mauchly's test indicated that the assumption of sphericity was violated for block

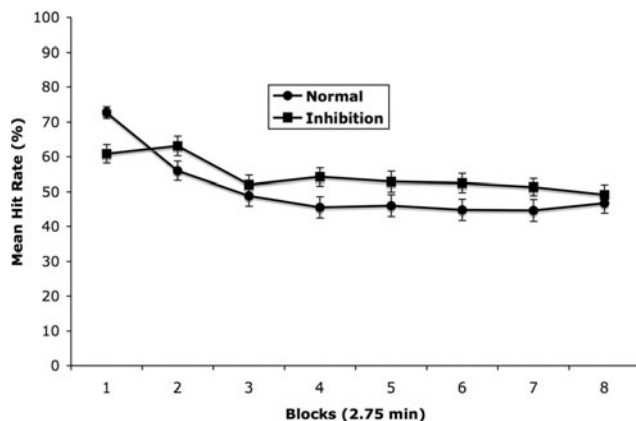


Figure 5. Mean hit rate as a function of successive 2.75-min blocks for the normal and inhibition response modes (Experiment 2).

( $\chi^2 = 48.65$ ,  $p < .008$ ); therefore, the degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ( $\epsilon = 0.61$ ). There was a main effect for block,  $F(4.29, 137.21) = 9.80$ ,  $p < .001$ ,  $\eta_p^2 = .23$ . There was also a significant interaction between response mode and block,  $F(7, 224) = 2.48$ ,  $p < .03$ ,  $\eta_p^2 = .07$ . The main effect of response mode was not significant,  $F(1, 32) = 0.688$ ,  $p < .5$ .

As Figure 5 shows, there was a decline in the detection rate of action-based intentional threats over time on task—the vigilance decrement. Simple contrasts showed that hit rate in the last time block ( $M = 48.0\%$ ,  $SEM = 3.0$ ) was significantly diminished compared with that in the first time block ( $M = 66.8\%$ ,  $SEM = 2.1$ ),  $F(1, 32) = 19.29$ ,  $p < .001$ ,  $\eta_p^2 = .38$ . Blocks 2 through 7 showed a similar decrease in hit rate compared with the first block. As Figure 5 indicates, although there was a vigilance decrement in both the normal and the inhibition response mode conditions, the extent of the decrement appeared greater under the normal condition. Tests of simple effects for the normal condition showed effects in the same conditions and in the same directions as compared with the results for overall effects of block. For the inhibition condition, however, tests of simple effects showed no difference between the first and second blocks. Hit rate in the third block was lower ( $M = 63.1\%$ ,  $SEM = 2.8$ ) compared with that in the second block ( $M = 52.0\%$ ,  $SEM = 2.8$ ),  $F(1, 32) = 10.87$ ,  $p < .003$ ,  $\eta_p^2 = .254$ .

Taken together, these analyses point to a significant vigilance decrement as demonstrated by a rapid decrease in hit rate across the first three blocks for the normal response mode and a significant but somewhat reduced decrement for the inhibition response mode.

**False alarms.** False alarm rates were submitted to an ANOVA with response mode (normal, inhibition) and block (1–8) as within-subject variables. Mauchly's test indicated that the assumption of sphericity was violated for block, ( $\chi^2 = 70.33$ ,  $p < .001$ ) and the Response Mode  $\times$  Block interaction ( $\chi^2 = 72.26$ ,  $p < .001$ ); therefore, degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ( $\epsilon_{Block} = 0.60$ ;  $\epsilon_{Block \times Response\ Mode} = 0.57$ ). There was a main effect for response mode,  $F(1.0, 32) = 6.84$ ,  $p < .02$ ,  $\eta_p^2 = .176$ . There was also a significant interaction between response mode and block,  $F(3.96, 126.69) = 3.68$ ,  $p < .008$ ,  $\eta_p^2 = .103$ . The main effect of block was not significant,  $F(4.17, 133.54) = 2.02$ ,  $p < .1$ , indicating that the false alarm rate did not change with time on task.<sup>1</sup>

As Figure 6 shows, the false alarm rate was higher when participants had to withhold responses to targets in the inhibition condition ( $M = 19.0\%$ ,  $SEM = 1.9$ ) compared with the normal response mode of responding to targets ( $M = 14.0\%$ ,  $SEM = 1.2$ ). Figure 6 also shows that whereas the false alarm rate appeared relatively stable across time blocks in the normal response mode

<sup>1</sup> The hit and false alarm rates were used to calculate the nonparametric indexes  $A'$  (sensitivity) and  $B'_d$  (bias or criterion) but are not reported here for the following reason. When there is a decrement in hit rate over time, and the false alarm rate is low and relatively stable over time, as in this experiment, hit rate and  $A'$  are highly correlated, and both decline over time. We did find a significant decrement over time in  $A'$ , a result that provided the same information as did the hit rate.



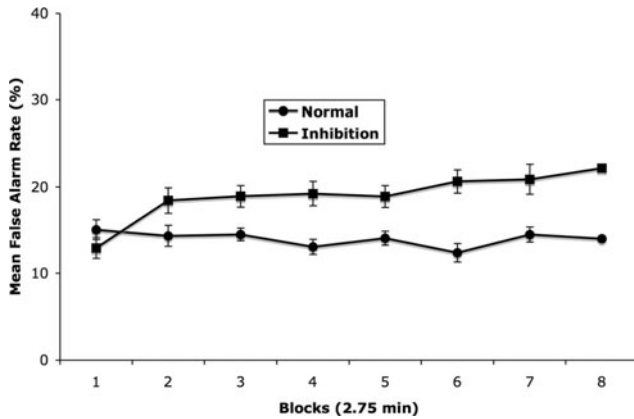


Figure 6. Mean false alarm rate as a function of successive 2.75-min blocks for the normal and inhibition response modes (Experiment 2).

condition, it increased over time in the inhibition condition. Simple effects revealed no significant differences between blocks in the normal condition. For the inhibition condition, there was a significant main effect for block,  $F(4.0, 129.21) = 5.0, p < .002, \eta_p^2 = .135$ . Repeated contrasts showed that the false alarm rate in the second block was higher ( $M = 18.4\%$ ,  $SEM = 1.2$ ) compared with that rate in the first block ( $M = 12.9\%$ ,  $SEM = 1.3$ ),  $F(1, 32) = 10.99, p < .003, \eta_p^2 = .256$ . Paired comparisons for response mode from Block 4 through Block 8 showed that false alarm rates were significantly higher for the inhibition condition compared with the normal condition.

There were several different types of action-object combinations (28 in all) that were not defined as critical targets. False alarms to such nontargets could potentially differ as a function

of nontarget type. Examination of the distribution of false alarms across the 28 action types revealed that the distribution of false alarms was not uniform. We predicted that observers would make more false alarms to nontarget actions involving a different goal or *intent* (e.g., transport rather than utilization) than for nontargets involving a different object (e.g., hairdryer rather than gun). As described previously, intent was defined by a combination of three factors in the video clips: the grasp type (over or under), the facing direction of the object (left or right), and the grasp hand (left or right). The resulting derived values of intent ("T" for transport and "U" for utilization) are shown as the bottom-row labels of the *x*-axis in Figure 7. The results supported our prediction. As Figure 7 shows, many more false alarms were made for the four nontarget types that differed from targets only according to intent as opposed to object type, that is, transporting rather than utilizing a gun facing left (either with the left or right hand using with an overhand or underhand grasp, and in the left or right position). For both response modes, the mean false alarm rates in these four conditions were more than 3 standard deviations greater than the mean of the remaining conditions.

To examine whether there were differences in false alarms between these four action types, we conducted a repeated measures ANOVA with response mode (normal, inhibition), object location (left, right), and grasping hand (left, right) as within-subjects variables. Results revealed significant main effects of object location,  $F(1, 33) = 7.61, p < .009, \eta_p^2 = .188$ , and grasping hand,  $F(1, 33) = 14.50, p < .001, \eta_p^2 = .305$ , as well as an interaction between object location and grasping hand,  $F(1, 33) = 26.84, p < .001, \eta_p^2 = .449$ . These results indicated that for both the normal and inhibition response modes, false alarms were significantly

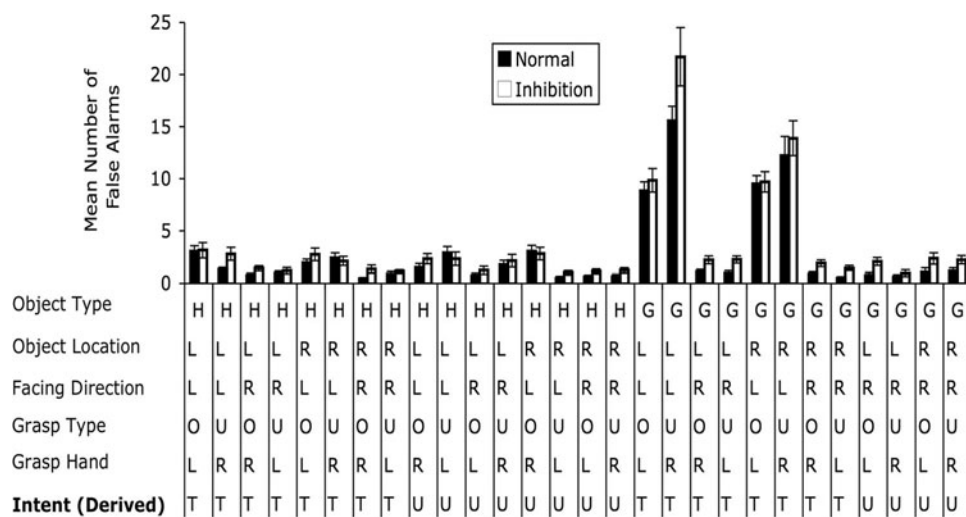


Figure 7. Distribution of the mean number of false alarms across the 28 nontarget types. Nontargets represented a combination of five factors. Label codes for the *x*-axis factors are, from top to bottom row, as follows. Object type: Gun (G) or hairdryer (H); Object location: left (L) or right (R) visual field; Object facing direction: left (L) or right (R); Grasp type: overhand (O) or underhand (U); Grasp hand: left (L) or right (R). As discussed in the text, an intentional action was defined by the combination of the last three of these factors: object facing direction, grasp type, and grasp hand. The resulting derived values of intent are shown as the bottom row (T = transport; U = utilization).

higher when the object was to the left of fixation and was grasped with the right hand.

**Subjective workload.** There were no order effects of response mode on the overall weighted NASA-TLX workload scores. These scores were submitted to a two-way repeated measures ANOVA with response mode (normal, inhibition) and phase (practice, start of vigil, end of vigil) as within-subject variables. There was a main effect for response mode,  $F(1, 32) = 10.57, p < .004, \eta_p^2 = .248$ . There was also a significant main effect for phase,  $F(2, 64) = 44.99, p < .001, \eta_p^2 = .584$ . The Response Type  $\times$  Phase interaction was not significant.

As Figure 8 shows, and as a simple contrast test confirmed, subjective workload was significantly higher in the inhibition response mode condition ( $M = 57.72, SEM = 1.91$ ) than in the normal response mode condition ( $M = 51.61, SEM = 2.82$ ),  $F(1, 32) = 10.57, p < .004, \eta_p^2 = .248$ . Furthermore, irrespective of response mode, participants reported greater experienced workload at the end of the vigil compared with the beginning and at the start of the vigil compared with the practice block. This was confirmed by simple contrast tests: The end of vigil value ( $M = 74.38, SEM = 2.39$ ) was greater than that at the start of the vigil ( $M = 49.20, SEM = 3.72$ ),  $F(1, 32) = 87.72, p < .001, \eta_p^2 = .733$ , and that at the start of vigil ( $M = 49.20, SEM = 3.72$ ) was greater than for the practice block ( $M = 40.4, SEM = 3.00$ ),  $F(1, 32) = 7.17, p < .02, \eta_p^2 = .183$ .

## Discussion

Clear evidence of a vigilance decrement was observed in Experiment 2. Participants were initially quite good at detecting threat-related intentional actions, but their hit rate declined progressively with time on task, with a subsequent slower decline toward the end of the 22-min vigilance session. The vigilance decrement in hit rate was observed both when participants indicated detection with a go motor response (normal response mode) and when they did so with a no-go withholding response (inhibition response mode), although the extent of the decrement was somewhat less in the latter case. Given that the false alarm rate was stable over time on task with normal

responding and increased slightly over time with the inhibition response mode, these findings associate the hit rate decline with a sensitivity decrement over time on task in both conditions (Parasuraman, 1979).

These findings stand in contrast to Experiment 1, where there was no vigilance decrement over time on task for either the normal or the inhibition response mode. Thus, vigilance decrement did not occur for biological motion targets under conditions of low image degradation but did under high image degradation. These findings suggest that biological motion can be attentive sensitive under demanding conditions, consistent with the conclusions of Thornton et al. (2002).

Taken together, the results of Experiments 1 and 2 are not compatible with the mindlessness theory (Robertson et al., 1997), which would predict that detection performance should decline less, not more, when a vigilance task is made more demanding by increasing image degradation and thereby reducing target salience (see also Smallwood & Schooler, 2006). Rather, the results are consistent with a role for attentional processes in the detection of infrequent biological motion targets (Parasuraman, 1985; Temple et al., 2000; Warm et al., 2008), which predicts an increase in the vigilance decrement as target salience is reduced and the task is made more demanding.

The subjective workload ratings confirmed that participants found the vigilance task mentally demanding, both under the normal and inhibition response modes. The general finding that the overall weighted NASA-TLX scores after performing the vigilance task were in the upper range of the scale (i.e., 70–100) is consistent with the pioneering findings of Warm, Dember, and Hancock (1996), who first demonstrated that the mental demand of vigilance tasks was higher than that of other tasks that ostensibly appear more demanding, such as card sorting and problem solving. That the workload ratings increased from the beginning to the end of the vigil is consistent with the view that vigilance tasks, although typically perceived as boring assignments, are nevertheless challenging and require hard mental work (Warm et al., 2008). That workload was rated as higher in the inhibition response mode condition compared to the normal response mode is inconsistent with the mindlessness view that vigilance performance is characterized by a mindless approach to the task in which central attentional resources are devoted to other activities such as task-unrelated thoughts (Smallwood et al., 2004) or to “mind wandering” (Mason et al., 2007). Rather, the mindlessness view would predict that observers should rate the vigilance task as not very demanding, and moreover that such ratings should be lower at the end of the task than at the beginning. This pattern of results was not observed.

Participants had a relatively high rate of false alarms under visually degraded viewing conditions. The distribution of false alarms across the 28 nontarget stimuli was not random, but, as predicted, disproportionately involved intention-based errors. These were cases in which participants tended to confuse the goal of the action, that is, transporting rather than using the gun. There were four such transport actions pointing in the same direction as a target (gun) action, and they all elicited significantly more false alarms than other nontargets. In contrast, object-based errors, or

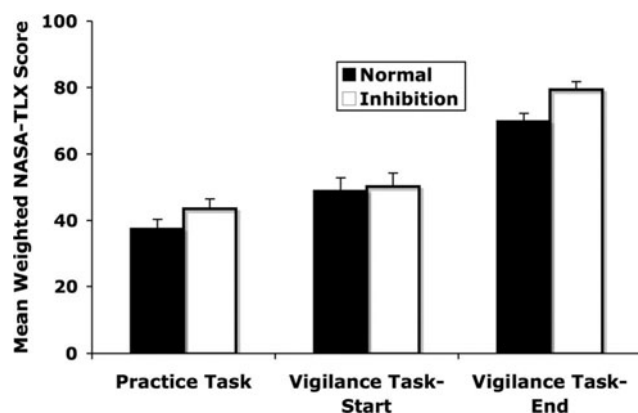


Figure 8. Mean weighted NASA-TLX subjective workload scores at the end of the practice task and before and after each vigilance session for normal and inhibition response modes (Experiment 2).

false alarms to actions involving the hairdryer, were much less frequent.<sup>2</sup>

The results suggest that the detection of threat-related intentional actions of others becomes increasingly difficult with time on task under conditions of visual degradation because of a failure of attention allocation prior to the presentation of an infrequent target. If so, then supporting attention through the use of temporal cuing should attenuate or even eliminate this performance decrement. Spatial cues preceding a target are well known to enhance detection efficiency when the location of a target is uncertain (Hawkins et al., 1990; Posner, 1980). Similarly, temporal cues given prior to the presentation of a target whose occurrence in time is uncertain also boost performance (Coull & Nobre, 1998), and this effect is also seen in prolonged vigilance tasks with infrequent, temporally unpredictable targets (Davies & Tune, 1970). Hitchcock, Warm, Matthews, Moroney, and See (1999) presented auditory verbal cues of varying reliability five trials (~10 s) prior to the occurrence of a critical target in a 40-min vigilance task involving discrimination of conflicting aircraft trajectories in a simulated air traffic control display. The cue was 100%, 80%, or 40% valid in indicating to the participant that a target was imminent. Hitchcock et al. found that compared with a control group who heard only a noninformative auditory stimulus, the vigilance decrement was completely eliminated in the 100% cued group; the decrement was still present in the other two groups, but was reduced in the 40% group and further reduced in the 80% group. It is interesting that Hitchcock et al. also varied the visual salience of the targets by adjusting the relative contrast of targets and nontargets and found that the beneficial effect of temporal cuing was restricted to the low salience targets. Hitchcock et al. interpreted their results within an attentional model by proposing that cuing reduced the need for observers to allocate attention to the visual display at all times as required in the control group, thereby allowing them to husband their attentional resources over the prolonged duration of this task. In a subsequent study, they provided supporting evidence for this view by repeating the experiment while participants' cerebral blood flow was monitored with transcranial doppler sonography (Hitchcock et al., 2003). Cerebral hemovelocity declined precipitously over time on task in the control group but progressively less so in the 40% and 80% cued groups, while remaining stable in the 100% group, paralleling the detection rate findings.

Given these previous findings, we used temporal cuing to further test the attention allocation view of vigilance decrement for degraded biological motion targets. There is also an ecological reason for examining the effects of variable-reliability cuing. Such cues could be derived from automated systems that are currently being developed to detect and identify various forms of biological motion (e.g., Fablet & Black, 2002; Wang, Tan, Hu, & Ning, 2003). However, such systems are not 100% reliable. It is therefore of interest to examine the effects of imperfect automation-based cuing on human performance in detecting biological motion targets. We used the temporal cuing procedure of Hitchcock et al. (2003) to examine whether the attention-related decline in detection of intentional actions under visually degraded conditions can be attenuated with auditory verbal cues. We compared a control condition without cuing with 100% valid and 75% valid cuing conditions. We predicted that the vigilance decrement noted in Experiment 2 would occur in the control condition but would be reduced with 75% cuing and eliminated with 100% cuing.

## Experiment 3

### Method

**Participants.** Thirty-six young adults between 18 and 25 years of age ( $M = 21$  years), 18 women and 18 men, participated and received \$15/hr for their participation. None had participated in the previous experiments. Participants were assigned randomly to one of three cuing groups, each with 12 participants, with the restriction that each group contained an equal number of men and women.

**Stimuli.** The same stimuli that were presented in Experiment 2 were used, with the addition of auditory cues that preceded critical targets. Cues consisted of the word "target" (delivered in a male voice binaurally at 60 dBA) that came on a few seconds before a critical intentional threat occurred. The cue was presented at least one and up to four nontargets before the critical target. In the 100% valid condition, the cue always preceded a target; in the 75% valid condition, the cue was presented on three of every four consecutive targets. In the control condition, the word "logged" was presented with the same voice and at the same intensity and random times during the vigilance task. A total of 80 auditory stimuli were presented in all conditions to match for total auditory stimulation. In the 100% reliable condition, all 80 stimuli consisted of the word "target." In the control condition, all 80 stimuli consisted of the word "logged." In the 75% reliable condition, 60 auditory stimuli were the word "target" and 20 were the word "logged." Thus, the total number of auditory stimuli and the overall intensity of secondary auditory stimulation was the same across all three conditions.

### Results

**Hits.** The hit rate data were submitted to a  $3 \times 8$  mixed effects repeated measures ANOVA with cue validity (100%, 75%, and no cue) as the between-subjects variable and block (1–8) as the within-subject variable. As Figure 9 shows, a vigilance decrement occurred for the control condition, but was reduced for the two cuing conditions. ANOVA gave a main effect for block,  $F(7, 231) = 7.02, p < .001, \eta_p^2 = .175$ , a main effect for cue validity,  $F(2, 33) = 157.56, p < .001, \eta_p^2 = .905$ , and a Block  $\times$  Cue Validity interaction,  $F(14, 231) = 2.26, p < .01, \eta_p^2 = .12$ . Contrasts showed that there were no significant differences between the conditions in the first time block,  $F(2, 33) = 0.646, p < .54$ . Subsequently, in the 100% cuing condition, the hit rate remained stable throughout the eight blocks, with no significant differences between blocks,  $F(7, 77) = 0.387, p < .92$ . However,

<sup>2</sup> Unexpectedly, there were also differences *within* these four nontarget types associated with a higher false alarm rate. Participants were most likely to make false alarms for stimuli in which the object, facing left, was left of the fixation point and the actor made a transport grasp with the right hand. Several factors could explain this result, including the possibility that a transport grasp made to the leftward facing gun with the right hand required an easier, less awkward movement than a utilization grasp: The former involved rotating the hand in a counterclockwise manner (when viewed from an allocentric viewpoint), whereas the latter involved a biomechanically awkward clockwise rotation. Seeing the more biomechanically natural grasp from the right hand directed toward a threatening object facing in the target direction appears to have triggered more false alarms.

in the 75% and the no-cue conditions, the hit rate decreased from Blocks 1 to 2 and then stabilized after Block 3. After Block 3, the highest hit rate was observed in the 100% valid condition ( $M = 87.7\%$ ,  $SEM = 1.2$ ), followed by the 75% valid condition ( $M = 62.3\%$ ,  $SEM = 4.9$ ), and then the no-cue condition ( $M = 46.8\%$ ,  $SEM = 4.1$ ).

**False alarms.** Figure 10 shows the false alarm data. Whereas the false alarm rate was relatively high for the control condition, it was reduced in the two cuing conditions. Mauchly's test indicated that the assumption of sphericity was violated for block ( $\chi^2 = 107.46$ ,  $p < .001$ ); therefore, degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ( $\epsilon_{\text{Block}} = 0.56$ ). ANOVA gave a main effect for block,  $F(3.8, 125.92) = 3.87$ ,  $p < .007$ ,  $\eta_p^2 = .105$ , and a main effect for cue validity,  $F(2, 33) = 35.97$ ,  $p < .001$ ,  $\eta_p^2 = .686$ . The interaction was not significant. The false alarm rate was smallest ( $M = 1.7\%$ ,  $SEM = 1.5$ ) in the 100% valid condition, followed by the 75% valid condition ( $M = 6.1\%$ ,  $SEM = 1.0$ ), and highest in the no-cue condition ( $M = 15.6\%$ ,  $SEM = 2.4$ ). Furthermore, simple contrasts showed that overall false alarms decreased in the last block ( $M = 5.8\%$ ,  $SEM = 1.4$ ) compared with the first block ( $M = 10.0\%$ ,  $SEM = 1.9$ ),  $F(1, 33) = 9.20$ ,  $p < .006$ ,  $\eta_p^2 = .218$ .<sup>3</sup>

As in Experiment 2, we examined whether there were differences in false alarms between the four nontarget conditions that differed from the targets only in terms of the intent of the actor. A repeated measures ANOVA was conducted with object location (left, right) and grasping hand (left, right) as within-subjects variables and cue validity as a between-subjects variable. Results revealed significant main effects of object location,  $F(1, 33) = 65.78$ ,  $p < .001$ ,  $\eta_p^2 = .666$ , and grasping hand,  $F(1, 33) = 20.59$ ,  $p < .001$ ,  $\eta_p^2 = .384$ , and cue validity,  $F(2, 33) = 36.97$ ,  $p < .001$ ,  $\eta_p^2 = .692$ . In addition, there were significant interactions between object location and grasping hand,  $F(1, 33) = 24.94$ ,  $p < .001$ ,  $\eta_p^2 = .430$ , object location and cue validity,  $F(2, 33) = 14.94$ ,  $p < .001$ ,  $\eta_p^2 = .475$ , grasping hand and cue validity,  $F(2, 33) = 8.08$ ,  $p < .001$ ,  $\eta_p^2 = .329$ , and an Object Location  $\times$  Grasping Hand  $\times$  Cue Validity interaction,  $F(2, 33) = 11.18$ ,  $p < .001$ ,  $\eta_p^2 = .404$ . A post hoc Bonferroni test showed that the false alarm rate in the four conditions was lower in the 100% condition relative to the 75% condition ( $p < .02$ ) and the no-cue condition ( $p < .001$ ) and lower

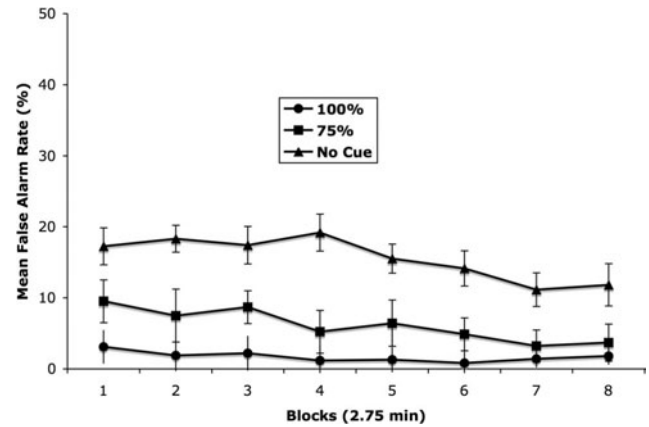


Figure 10. Mean false alarm rate as a function of successive 2.75-min blocks for the 100% valid, 75% valid, and no-cue conditions.

in the 75% condition relative to the no-cue condition ( $p < .001$ ). Further contrasts revealed that, in the no-cue condition, there was a main effect of object location,  $F(1, 11) = 51.35$ ,  $p < .001$ ,  $\eta_p^2 = .824$ , and grasping hand,  $F(1, 11) = 14.00$ ,  $p < .003$ ,  $\eta_p^2 = .560$ , and an Object Location  $\times$  Grasping Hand interaction,  $F(1, 11) = 17.99$ ,  $p < .001$ ,  $\eta_p^2 = .618$ . In the 75% condition, there was also a main effect of object location,  $F(1, 11) = 16.83$ ,  $p < .002$ ,  $\eta_p^2 = .605$ , and an Object Location  $\times$  Grasping Hand interaction,  $F(1, 11) = 6.05$ ,  $p < .03$ ,  $\eta_p^2 = .372$ . There were no significant differences in the distribution of false alarms between the four conditions in the 100% condition (see Figure 11).

**Subjective workload.** Mauchly's test indicated that the assumption of sphericity was violated for block ( $\chi^2 = 6.84$ ,  $p < .034$ ); therefore, degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ( $\epsilon_{\text{Block}} = 0.84$ ). ANOVA gave a main effect for phase,  $F(1.68, 55.35) = 88.64$ ,  $p < .001$ ,  $\eta_p^2 = .729$ , and an interaction between phase and cue validity,  $F(4, 66) = 19.00$ ,  $p < .001$ ,  $\eta_p^2 = .535$ . Bonferroni post hoc comparisons showed that the subjective workload in the practice session and the start of the vigil were not different,  $F(1, 33) = 0.414$ ,  $p < .53$  (see Figure 12). Subjective workload at the end of the vigil was significantly higher in the no-cue condition ( $M = 71.8$ ,  $SEM = 4.33$ ) compared with the practice session ( $M = 23.5$ ,  $SEM = 2.45$ ) and the start of the vigil ( $M = 24.69$ ,  $SEM = 3.11$ ). There were no significant differences between the 100% and 75% cue validity conditions in the end of vigil phase.

**Discussion.** The performance of the control group indicated a significant drop in the detection rate of threat-related intentional actions over time on task under degraded viewing conditions, a result that replicated the findings of Experiment 2. However, as predicted, temporal precuing of targets reduced the extent of the vigilance decrement. Compared with the control group, the 75% and 100% valid cuing groups exhibited a reduced decline in

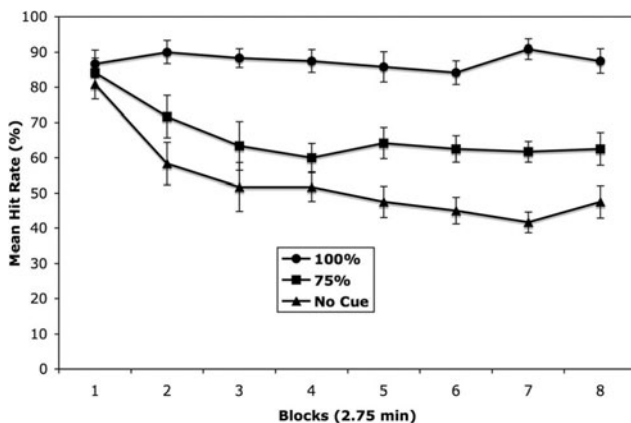


Figure 9. Mean hit rate as a function of successive 2.75-min blocks for the 100% valid, 75% valid, and no-cue conditions.

<sup>3</sup> As in Experiment 2, measures of sensitivity and bias were computed from the hit and false alarm rates but are not reported here because  $A'$  declined over time and interacted with cue validity in the same way as did the hit rate. Furthermore, the effects of cue validity could not be mediated via changes in bias because the hit rate increased with cue validity, whereas the false alarm rate decreased, indicating a primary effect on sensitivity.



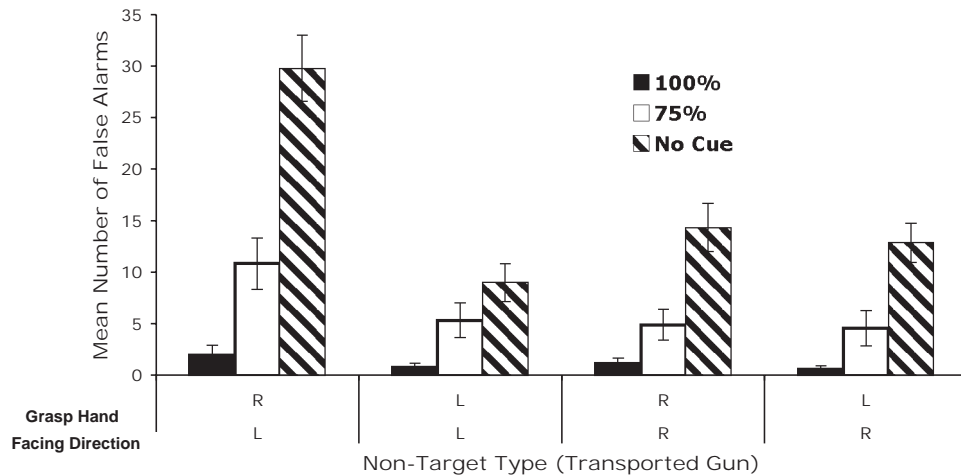


Figure 11. Mean false alarm rates for nontargets consisting of the gun being transported, as a function of grasp hand and object location, for the 100% valid, 75% valid, and no-cue conditions.

detection rate, and in the case of 100% valid cuing, the vigilance decrement was completely eliminated. These findings are consistent with the view that the detection of threat-related intentional actions of others becomes increasingly difficult with time on task under conditions of visual degradation because of a failure of attention allocation prior to the presentation of an infrequent target. Attention allocation can be supported by temporal cues, which attenuate the performance decrement.

The cuing manipulation did not simply enhance detection performance by inducing observers to use a more liberal decision criterion. If that were the case, the false alarm rate would have increased (Parasuraman & Davies, 1976). Rather, the false alarm rate was reduced in the 75% valid condition compared with the control condition and further reduced in the 100% condition. These findings indicate that cuing enhanced the participants' sensitivity in detecting intentional threat-related targets, consistent with an improvement in attention allocation. The distribution of false alarms across stimulus type was consistent with the results observed in Experiment 2, although these effects decreased as a

function of cue validity, consistent with an increase in support for attention allocation. The cuing effect also cannot be attributed to increased arousal. Secondary auditory stimulation can enhance vigilance performance by increasing the observer's level of phasic or tonic arousal (Davies & Parasuraman, 1982). However, the intensity and total number of auditory stimuli were the same in the valid cue and control conditions, yet performance was superior in the former, thus ruling out the arousal explanation.

Subjective ratings of the workload associated with performing the vigilance task supported this interpretation. NASA-TLX ratings were high in the control no-cue condition, as reported in many previous vigilance studies (Warm et al., 1996). Subjective workload was reduced with 75% valid cuing and reduced further with 100% valid cuing, consistent with the previous findings of Hitchcock et al. (1999, 2003).

The control group findings for false alarm rate replicated the results of Experiment 2. Participants made disproportionately more false alarms to the four nontarget types involving a transport action on the gun, consistent with the view that such responses represent intention-based rather than object-based errors. Intention-based errors were reduced, although not completely eliminated, with temporal cuing.

## General Discussion

Three experiments were conducted to examine whether detection of biological motion targets, and intentional actions in particular, is attention sensitive under sustained observation. The results showed that under normal viewing conditions, participants are remarkably good at detecting the threat-related intentional actions of others, even when four different types of target intentions have to be discriminated from up to 28 nontarget actions. However, when the dynamic actions of others are viewed under visually degraded conditions, detection of threat-related targets declines over time; this vigilance decrement is associated with higher experienced cognitive workload, and occurs whether observers indicate the detected threat with a manual action or by withholding response. False detections under such conditions primarily reflect

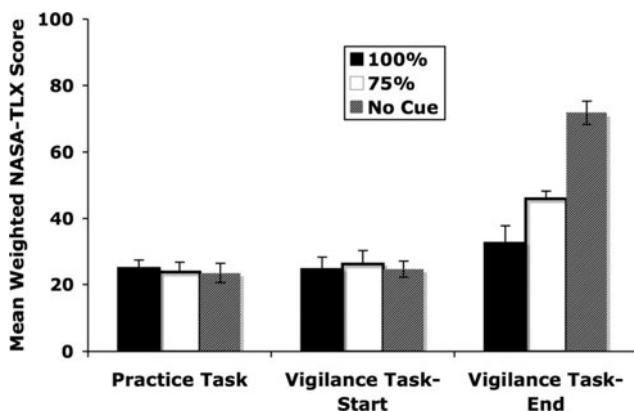


Figure 12. Mean weighted NASA-TLX subjective workload scores at the end of the practice task and before and after the vigilance session for the 100% valid, 75% valid, and no-cue conditions.

intention-based errors. Finally, temporal cuing of impending threatening actions attenuates or eliminates the vigilance decrement over time on task.

The finding that detection of intentional action-based threats under good viewing conditions is efficient and shows no decline with sustained observation is consistent with the view that biological motion is relatively insensitive to attention. This could be a function of its important role in survival at all ages, which could explain why detecting biological motion is robust in neonates who are yet to fully develop their attentional capabilities (Simion et al., 2008) and in those, like older adults, who experience diminished attentional capacity (J. F. Norman et al., 2004).

Although detection of biological motion-based targets may be immune to attentional decline under normal viewing conditions, a sufficiently robust attentional challenge may lead to a deterioration in performance. Image degradation and sustained observation were the methods of choice in the present study. Under such conditions, there was a significant reduction in the detection rate of threat-related intentional actions over time on task. Previous findings with simple static targets have similarly shown that a vigilance decrement occurs under high levels of image degradation and can be attributed to a decrease over time in the ability of participants to allocate attentional resources to target detection (Nuechterlein et al., 1983; Parasuraman, 1985; Smit et al., 2004; Warm et al., 2008). The present results indicating that temporal precuing of impending target actions reduced the vigilance decrement even when it was not completely reliable (75%), and eliminated it when perfect (100%), are consistent with this view. Temporal cuing, by reducing the need for observers to allocate attention to the visual display at all times, allowed for the management and conservation of attentional resources when challenged by the degraded viewing conditions and the need for sustained performance (Hitchcock et al., 1999, 2003). These results are consistent with the view that although biological motion may not normally require high levels of the observer's attention, it may nevertheless be attention sensitive under conditions that impose significant demands on attentional capacity (Thornton et al., 2002).

The manipulation of response mode carried out in Experiments 1 and 2—requiring participants to indicate detection of target actions either manually or by withholding response—was intended to compare the differing predictions of the mindlessness (Robertson et al., 1997; Smallwood & Schooler, 2006) and attention allocation theories (Parasuraman, 1985; Smit et al., 2004; Warm et al., 2008) regarding the effects of visual image degradation on the vigilance decrement. The SART vigilance task, in which observers withhold a motor response when indicating target presence, leads to an increase in the false alarm rate, a result that has been interpreted as support for the mindlessness theory (Robertson et al., 1997). A slightly higher false alarm rate in the inhibition response mode condition compared with normal responding was also found in Experiment 2 of the present study and in previous studies comparing the SART with a standard vigilance task (Grier et al., 2003; Helton et al., 2007). Rather than supporting the mindlessness theory, however, this finding could simply reflect an increasing reluctance of observers in the inhibition response mode condition to constantly execute a key press response to the more frequent nontargets. More specifically, the results for hit rate did not support the mindlessness theory. This theory predicts that increasing image degradation, by making target detection more

demanding, should decrease mind wandering (Smallwood & Schooler, 2006) or task-unrelated thoughts (Giambra, 1995) and therefore reduce the vigilance decrement over time. In fact, the opposite was found—image degradation increased the decrement—consistent with the predictions of the attention allocation theory, further support for which was provided by the finding in Experiment 3 that temporal cuing reduced the vigilance decrement.

If participants were not mindful of the actions shown on the videos they monitored over an extended period of time, then one would expect that false alarms to nontarget actions should not vary according to the type of action being portrayed. Therefore, false alarms should be randomly distributed across the 28 different nontarget actions. However, in both Experiments 2 and 3, false alarms were disproportionately distributed across nontarget types. More false alarms were made to the four nontarget actions involving transporting rather than using the gun than to other nontargets. This finding suggests that some active processing of nontarget actions occurred associated with intent inference, rather than mindlessness. Given that target detection required ascertaining an intentional action and not simply identifying an object, such false alarms to nontarget transport actions reflect processing associated with erroneous detection of intent.

The extant literature on vigilance performance is large (Davies & Parasuraman, 1982; Warm, 1984). However, there has been little or no work using biological motion displays. Although Ticker and colleagues (1972) did conduct experiments on monitoring for people and actions, they did not report vigilance decrement. The present study provides the first evidence for vigilance effects in detecting biological motion targets. With some exceptions (e.g., Parasuraman, 1986; Pigeau, Angus, O'Neill, & Mack, 1995), most vigilance studies have been conducted with simple and somewhat artificial laboratory tasks involving static lines, symbols, letters, and so forth. One contribution of the present study is the extension of the vigilance paradigm to more naturalistic displays involving the movements and actions of other people.

A potential limitation of this study is that the videos we developed depicted only the actor's hand actions with an object and not the actor's face or body. This represents more restrictive viewing conditions than found in many observational settings, in which facial and bodily cues can also be used by the observer to infer intent and detect a potential threat. Using color versions of the same video clips used in the present experiments, we have shown in a recent fMRI study that inferring intent recruits a network of brain regions including the posterior superior temporal sulcus (Ortigue, Thompson, Parasuraman, & Grafton, *in press*). This brain network also integrates emotional information from the face and body posture to allow people to infer the intent of others during object grasping (e.g., Carter & Pelphrey, 2008; Vander Wyk, Hudac, Carter, Sobel, & Pelphrey, 2009). However, our primary motivation for excluding the face or body in this study was so that we could more easily control the types of cues that viewers used to judge intent. We strictly defined intent as reflecting the combination of three factors: the grasp type (over or under), the facing position of the object (left or right), and grasp hand (left or right). Nevertheless, it is the case that it would be important in future studies to understand how cues from other types of biological motion, including face, eye, and body movements, interact with hand movements of the type examined in the present study to influence vigilance for threatening actions.

Detecting potentially threatening actions among the movements and activities of other people is of growing concern in an increasingly security-conscious society. Surveillance by military UVs also require remotely located operators to watch for unusual or suspicious actions of people. The present results suggest that detection of such events can be efficient under normal viewing. However, the attentional resource demands imposed by degraded viewing conditions (e.g., due to sensor noise, vibration, or low bandwidth communication channels) can lead to poorer performance, particularly, as may be often the case in surveillance operations, when the watch-keeping period extends for long periods of time.

The results of Experiment 3 suggest that temporal cuing of impending targets, even if only 75% valid, can reduce the extent of the performance decrement, and 100% valid cuing can eliminate it. Such cuing might be triggered by automated image analysis systems for detecting different aspects of biological motion. Several such systems have been proposed, for example, those based on modeling of two-dimensional optic flow patterns and development of three-dimensional articulated body models (Fablet & Black, 2002) or use of sequential shape analysis for gait recognition (Wang et al., 2003). Such systems are not likely to be 100% reliable; however, as our results show, even imperfect aiding can boost detection performance. Furthermore, the *joint* detection performance of imperfect human and automated partners can exceed that of each agent alone (de Visser & Parasuraman, 2007; Parasuraman, 1987; Sorkin & Woods, 1986;), although this would need to be empirically demonstrated. Finally, given that humans do not always use automated systems as designers intended (Parasuraman & Riley, 1997), issues such as trust and reliance (Lee & See, 2004) would need to be carefully evaluated before automated aids for biological motion detection are implemented.

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