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Objective: We investigated performance, workload, and stress in groups of paired observers who performed a vigilance task in a coactive (independent) manner. Background: Previous studies have demonstrated that groups of coactive observers detect more signals in a vigilance task than observers working alone. Therefore, the use of such groups might be effective in enhancing signal detection in operational situations. However, concern over appearing less competent than one's cohort might induce elevated levels of workload and stress in coactive group members and thereby undermine group performance benefits. Accordingly, we performed the initial experiment comparing workload and stress in observers who performed a vigilance task coactively with those of observers who performed the vigilance task alone. Method: Observers monitored a video display for collision flight paths in a simulated unmanned aerial vehicle control task. Self-reports of workload and stress were secured via the NASA-Task Load Index and the Dundee Stress State Questionnaire, respectively. Results: Groups of coactive observers detected significantly more signals than did single observers. Coacting observers did not differ significantly from those operating by themselves in terms of workload but did in regard to stress; posttask distress was significantly lower for coacting than for single observers. Conclusion: Performing a visual vigilance task in a coactive manner with another observer does not elevate workload above that of observers working alone and serves to attenuate the stress associated with vigilance task performance. Application: The use of coacting observers could be an effective vehicle for enhancing performance efficiency in operational vigilance.

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The Independence and Interdependence of Coacting Observers in Regard to Performance Efficiency, Workload, and Stress in a Vigilance Task

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Method: Observers monitored a video display for collision flight paths in a simulated unmanned aerial vehicle control task. Self-reports of workload and stress were secured via the NASA-Task Load Index and the Dundee Stress State Questionnaire, respectively.

Results: Groups of coactive observers detected significantly more signals than did single observers. Coacting observers did not differ significantly from those operating by themselves in terms of workload but did in regard to stress; posttask distress was significantly lower for coacting than for single observers.

Conclusion: Performing a visual vigilance task in a coactive manner with another observer does not elevate workload above that of observers working alone and serves to attenuate the stress associated with vigilance task performance.

Application: The use of coacting observers could be an effective vehicle for enhancing performance efficiency in operational vigilance.

Keywords: vigilance, coacting groups, multiobserver independence/dependence, evaluation apprehension, workload, stress

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INTRODUCTION

Vigilance or sustained attention tasks require observers to maintain their focus of attention and remain alert to stimuli for prolonged periods of time (Hancock, 2013; Langner & Eickhoff, 2013; Warm, Finomore, Vidulich, & Funke, 2015). These tasks are of interest to human factors specialists because they are a key element in many situations wherein observers are required to scan the environment for untoward events or monitor systems for indications of malfunction (Warm et al., 2015). Among these settings are military surveillance; cockpit and seaboard monitoring; air traffic and unmanned vehicle control; airport, border, and cyber security; industrial quality control; long-distance driving; and medical functions involving cytological screening and the inspection of anesthesia gauges during surgery (Drury, 2015; Hancock & Hart, 2002; Pop, Stearman, Kazi, & Durso, 2012; Sawyer et al., 2014; Vidulich, Wickens, Tsang, & Flach, 2010; Warm, Parasuraman, & Matthews, 2008). Laboratory studies of vigilance typically find that observers are not as efficient as might be desired; critical signals for detection are often missed, especially over time (Davies & Parasuraman, 1982; Hancock, 2013; Warm et al., 2015). In addition, on an operational level, studies have shown that accidents ranging from minor to major have resulted from detection failures on the part of nonvigilant observers (Hawley, 2006; Langner & Eickhoff, 2013; Molloy & Parasuraman, 1996). Consequently, there is a need to find ways to enhance signal detection in vigilance tasks. Solutions toward that end have included psychophysical techniques to amplify signal visibility, pharmacological aids for observers in the form of stimulant drugs, training regimens to foster operator familiarity with the vigilance task involved, and procedures to augment the selection of individuals who are best suited for the task to be performed (Craig, 1984; Fisk & Schneider, 1981; Lieberman, Coffey, & Kobrick, 1998; Reinerman-Jones, Matthews, Langheim, & Warm, 2011; Warm et al., 2015). Another potential solution to enhance signal detection is the use of groups of observers rather than single individuals under the assumption that "two heads are better than one" (Wiener, 1964). It is that solution that is of interest in the present study.

Williams (1947) first suggested the use of multiobserver groups, and experiments have shown that the group approach can indeed be effective. In one version of this method, the coaction approach (Harkins, 1987), pairs of observers individually monitor a common display for critical signals and the group as a unit receives credit if any member correctly detects a signal. It should be noted that the use of the term *group* in this sense is somewhat atypical in that it does not require collaboration between members in performing the task (DeLamater, 1974). As described by Wiener (1964), the coaction arrangement can be thought of as a "parallel switching circuit" in which the system will react if at least one member of the group responds. Several experiments have shown that this approach lets the group outperform single monitors in regard to signal detection (Harkins, 1987; Klinger, 1969; Morgan & Alluisi, 1965; Schafer, 1949; Waag & Halcomb, 1972; Wiener, 1964). Morgan and Alluisi (1965) and Wiener (1964) have accounted for the enhanced performance of the coacting group by an independent events model in which enhanced group performance is asserted to result from the application of the rules for combining simple probabilities with the assumption that the performances of the group's observers are independent. If this is the case, these authors point out that, using the mean detection rate of a control group of individual observers (p_m) as an estimate of the detection probability of a hypothetical single observer, the independent events model predicts that the detection probability of a two-observer coacting group should be the following:

$$1 - (1 - p_m)^2. \tag{1}$$

Employing Equation 1, the mean detection rate of the control observers exactly predicted the mean detection rate of the coacting groups in both Morgan and Alluisi's (1965) and Wiener's (1964) studies.

Although the independent events model accounts for the enhanced detection performance of the coacting vigilance group, this does not necessarily tell the complete story of coacting group dynamics in regard to vigilance tasks. There are other dimensions of observer experience in a vigilance task that could potentially paint a different picture. Those aspects are perceived mental workload and stress. There is substantial evidence showing that the need to sustain attention imposes a high mental workload on operators, who also find tasks requiring such attention highly stressful (Warm, Parasuraman et al., 2008; Warm et al., 2015). Studies of the cognitive demands of vigilance tasks have employed the NASA-Task Load Index (NASA-TLX; Hart & Staveland, 1988), which is considered one of the most effective measures of perceived mental workload currently available (Wickens, Hollands, Banbury, & Parasuraman, 2013). It provides a measure of global or overall workload on a scale of 0 to 100 and identifies the relative contributions of six sources of workload, three of which reflect the demand that a task places on operators—mental, physical, and temporal demand—and three of which characterize the interactions between observers and the task confronting them—performance, effort, and frustration. Several studies using the NASA-TLX have shown that global workload scores in vigilance tasks typically fall above the midpoint of the scale, indicating a high level of mental workload, and that mental demand and temporal demand are among the primary components of this workload (Finomore, Shaw, Warm, Matthews, & Boles, 2013; Warm, Dember, & Hancock, 1996; Warm et al., 2015; Warm, Matthews, & Finomore, 2008; Warm, Parasuraman et al., 2008).

The elevated workload of vigilance tasks is accompanied by amplified levels of stress as revealed through physiological and self-report measures (Warm et al., 2015). One self-report measure that has been used extensively in vigilance studies and is featured in this study is the Dundee Stress State Questionnaire (DSSQ; Matthews et al., 2002). As described by Funke (2007), the DSSQ is a 96-item, experimentally validated measure designed to assess transient states associated with task engagement, distress, and worry. Typical results, summarized in Matthews, Szalma, Panganiban, Neubauer, and Warm (2013) and Warm, Matthews et al. (2008), have indicated that participation in a vigilance task leads to a loss of task engagement and increased feelings of distress.

Social facilitation research has shown that an important element in coaction group functioning is "evaluation apprehension," wherein the possibility of having their responses identified and appraised leads group members to be concerned with appearing to be incompetent, particularly with regard to their cohorts (Bond & Titus, 1983; Harkins, 1987). Consequently, in the case of group vigilance, evaluation apprehension could lead group members to work harder than single observers and to experience greater task-induced workload and stress. Such an effect would be an important operational concern, as stress reduces an individual's productivity, safety, and health (Hancock & Warm, 1989; Huey & Wickens, 1993; Miller, Chen, & Zhou, 2007; Nickerson, 1992; Strauch, 2002) and might therefore countermand the signal detection benefits derived from group coaction. Accordingly, the goal for this study was to determine if the heightened level of signal detection expected in group vigilance is accompanied by elevated workload and stress reactions among group members.

METHOD

Participants

Fifty-one individuals, 31 men and 20 women, recruited from the Dayton, Ohio area served as observers for a single payment of $30. Overall, the observers ranged in age from 18 to 30 years, with a mean age of 22.10 years and a standard deviation of 3.04 years. As indicated by self-reports, all observers had normal or corrected-to-normal vision and normal hearing. The experiment was conducted under conditions approved by the Wright-Patterson Air Force Base Institutional Review Board.

Experimental Design

A 2 (Observer Condition: Single-Observer, Coacting Groups) × 4 (Periods of Watch) split-plot experimental design was employed. Seventeen observers (11 men and 6 women) were assigned at random to a single-observer condition, and 34 observers (20 men and 14 women) were paired to form 17 coacting groups. Group pairings were determined at random with the restriction that the members of all dyads were of the same sex and had no prior acquaintance with each other. To ensure that age differences were not a confounding factor in the design of this study, we compared the mean ages of the single-observer (M = 23.06 years, SD = 3.23) and the coacting group (M = 21.62 years, SD = 2.82) conditions and found that they were not significantly different from each other ($p > .05$). We also examined age differences within the dyads of the coacting group observer condition and found that they were minimal ($M_{difference}$ = 3.24 years, SD = 2.80 years). Observers in all conditions participated in a 40-min vigilance session divided into four continuous 10-min periods.

Vigilance Task

Observers were told that they would be assuming the role of either a single unmanned aerial vehicle (UAV) monitor (single-observer condition) or a member of a dyadic group of UAV monitors (coacting group condition). This was done to enhance the observers' interest and motivation in the vigilance task they were to perform. It was not meant to simulate an operational UAV control environment or to focus the experiment specifically on UAV control. In both the single-observer and coacting group conditions, observers were tasked with monitoring the flight pattern of a squadron of four UAVs projected in the center of a 43.18-cm visual display terminal (VDT) as shown in Figure 1. The display, adapted from Dillard et al. (2014), Funke et al. (2011), and Shaw et al. (2013), contained a single circular viewing field, 10.19 cm in diameter, presented on a gray background (transluminance = 42 cd/m^2). The viewing field consisted of three concentric circles. The diameters of the small and middle circles were 2.54 cm and 6.35 cm, respectively. The largest circle

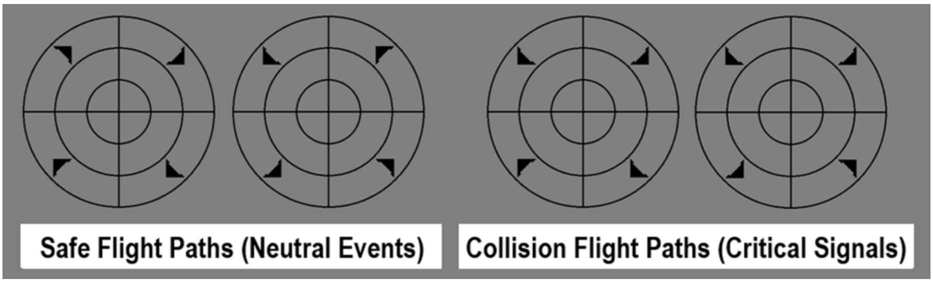

Figure 1. Examples of neutral events and critical signals in the display (adapted from Dillard et al., 2014; Funke et al., 2011; Shaw et al., 2013).

formed the exterior black border of the viewing field, which was divided into four equal 90° quadrants defined by black lines. In all cases, the lines defining the viewing field were .32 cm thick, their transluminance was 37 cd/m^2, and their contrast with the gray background based on the Michaelson Contrast ratio (Coren, Ward, & Enns, 1999) was 6.33%.

Normally, the quadrants of the viewing field were blank. When activated, each quadrant of the display contained a black triangular icon (base = 1.35 cm; altitude = .95 cm; transluminance = 37 cd/m^2; contrast with the gray background = 6.33%), which represented a UAV. The flight orientation of the squadron of UAVs, clockwise or counterclockwise (defined by the "noses" of the UAVs), was random throughout the vigil with the restriction that they occurred equally often across stimulus presentations. Critical signals for detection were cases in which one of the UAVs was flying in an inappropriate direction relative to the others so that a collision could occur. Neutral events (i.e., stimuli requiring no overt observer responses) and critical signals in the clockwise and counterclockwise flight paths are illustrated in Figure 1.

In both experimental conditions, the display was updated 30 times per minute (one stimulus event every 2,000 ms) with an exposure time of 1,000 ms. Sixteen critical signals occurred at random intervals during each 10-min period of watch (four in each display quadrant, two clockwise and two counterclockwise; overall signal probability = .053). Observers in both conditions were allowed 2,000 ms from the onset of a critical signal to respond by pressing the space bar on a computer keyboard. Failures to respond within that window were counted as errors of omission (misses); all other responses were considered errors of commission (false alarms).

A "parallel" decision rule was adopted to determine correct detections in the coacting group condition (Waag & Halcomb, 1972; Wiener, 1964). Under this rule, the group received credit for a correct detection if either member detected a critical signal and was penalized with a false alarm if either member made a commission error. This scoring approach could lead to inflated correct detection and false alarm rates if both observers in a pair responded to the same stimulus events. To counter such problems, the following recording rules were observed: If both observers made a correct detection within the appropriate time frame, only the fastest response was accepted as a correct detection and included in group scoring. Likewise, if both group members made an error of commission to the same noncritical signal event, the fastest response was counted as a group false alarm and the slower response was not included in group scoring. In cases in which both group members failed to respond to a critical signal, the group was charged with a miss.

Procedure

Upon reporting to the laboratory, observers surrendered their time pieces and cell phones and signed an informed consent form. They were unaware of the length of the vigil other than it would not exceed 1 hr.

In the single-observer condition, observers performed the vigilance task alone and consequently were solely responsible for identifying potential collisions between the UAVs. Observers in the coacting group condition were seated adjacent to each other in the same room, separated by an opaque divider. They were provided with identical display terminals and keyboards with which to complete the vigilance task. Coactors were aware of each other's presence in the room and were informed that although they would be jointly responsible for signal detection on the same task, they were not to communicate, collaborate, or strategize. Apart from the direction not to communicate with the other member of the group, coactors were given identical instructions to that of the single-observers. The arrangement of the testing room prohibited coactors from acquiring knowledge of the accuracy of their cohort's responses. In both experimental conditions, the vigilance task was administered in a quiet (ambient sound level = 40 dBA) 1.78 × 2.41 × 2.67 m windowless laboratory room. The VDT was mounted on a table 99.10 cm directly in front of the seated observer. Ambient illumination in the testing room was 5 cd/m^2. It was provided by a 50-watt incandescent bulb dimmed to half power and positioned above and behind the seated observer(s) to minimize glare.

To ensure comprehension of instructions and the ability to detect critical signals, each observer received an individual 10-min training vigil immediately prior to the initiation of the main vigil, which duplicated the signal presentation conditions of the main vigil. To facilitate the discrimination of critical signals during training, a computerized female voice provided feedback as to correct detections, misses, and false alarms. The use of a female voice in this regard is consistent with studies indicating that voiced warning signals are perceived to be more urgent when spoken in a female than a male voice (Barzegar & Wogalter, 1998; Hollander & Wogalter, 2000). Observers were required to detect 11 of the 16 presented critical signals and make no more than 10 false alarms during training in order to continue in the experiment. All observers met these requirements on the first attempt. Feedback was not provided during the main vigil. Upon its completion, observer workload was assessed using the NASA-TLX. The DSSQ was administered prior to the training phase and at the conclusion of the main vigil to gauge task-induced stress. Computerized versions of both instruments were employed.

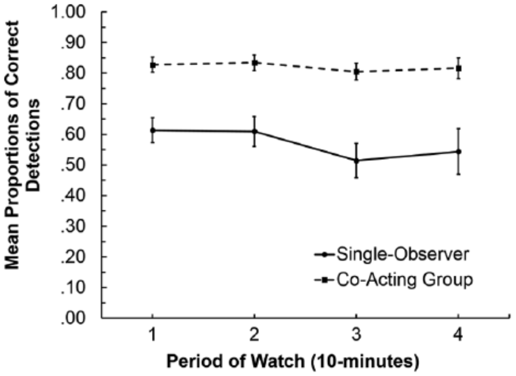

Figure 2. Mean proportions of correct detections in the single-observer and coacting group conditions by periods of watch. Error bars are standard errors.

RESULTS

Performance Efficiency

The focus of interest in regard to performance efficiency was on differences between single observers and coacting groups. Consequently, in regard to performance, the units of analysis were individual observers in the single-observer condition and observer groups in the coacting condition. In both cases, $N = 17$.

Correct detections. Mean proportions of correct detections in the single-observer and coacting group conditions are plotted as a function of periods of watch in Figure 2.

It is evident in the figure that detections were greater in the coacting group condition than in the single-observer condition and that the frequency of signal detections remained stable over time. These impressions were confirmed by a 2 (Conditions) × 4 (Periods of Watch) mixed-model analysis of variance (ANOVA) of the arcsines of the proportion of correct detection scores. The arcsine transform was employed to normalize the data (Kirk, 1995). The ANOVA revealed that the coacting group detected significantly more signals ($M = .82$, $SE = .023$) than did single observers ($M = .57$, $SE = .050$), $F(1, 32) = 17.51$, $p < .001$, $\eta_p^2 = .35$. The main effect for periods of watch was not statistically significant ($p = .15$), nor was the Conditions × Periods interaction ($p = .54$). In this and all subsequently reported ANOVAs, the Box correction (Maxwell

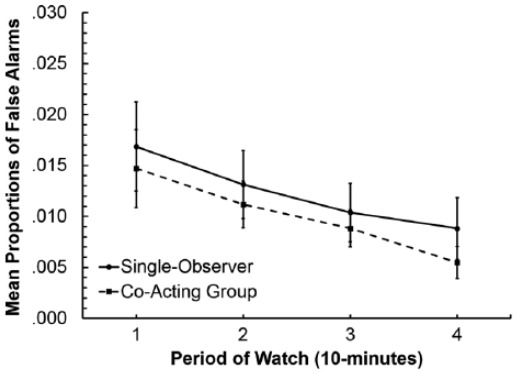

Figure 3. Mean proportions of false alarms in the single-observer and coacting group conditions by periods of watch. Error bars are standard errors.

& Delaney, 2004) was employed when appropriate to compensate for violations of the sphericity assumption.

Following the procedure outlined by Morgan and Alluisi (1965) and Wiener (1964), the mean detection rate of the group of individual observers ($p_m = .57$) was used as an estimate of the detection probability of a hypothetical single observer in Equation 1 to predict, on the basis of the independent events model, the mean detection probability of the coacting groups. Equation 1 forecasts that value to be .82, and that is the precise value obtained for those groups.

False alarms. Mean proportions of false alarms in the single-observer and the coacting group conditions are plotted as a function of periods of watch in Figure 3.

A 2 (Conditions) × 4 (Periods of Watch) mixed-model ANOVA of the arcsines of the proportions of false alarms revealed a statistically significant main effect of period of watch, $F(2.02, 70.48) = 7.52$, $p < .001$, $\eta_p^2 = .19$. Neither the main effect of conditions ($p = .83$) nor the Conditions × Periods interaction ($p = .78$) were statistically significant. Across the experimental conditions, the probability of a false alarm, which was low to begin with, declined with time-on-task (*M*s for Periods 1–4 = .016, .012, .010, and .007; *SE*s = .003, .002, .002, and .002, respectively).

Intragroup performance. A potentially important question that could be asked in regard to group performance in this experiment is whether the correct detection and false alarm rates in the dyads were driven to a greater degree by a single observer due to differences in speed of responding. To answer that question, we identified individuals in each dyad who on average had the fastest and slowest speed of response for correct detections and individuals in each dyad who had the fastest and slowest speed of response for false alarms. There were no significant differences between "fast" and "slow" observers in either the proportion of the groups' correct detections or the proportion of the groups' false alarms ($p > .05$ in each case), indicating that observers in the dyads performed similarly and no one individual in a given dyad was primarily responsible for correct detections or false alarms.

Workload and Stress

Unlike the case of performance efficiency, where the focus of interest was on groups of coacting observers, the focus of interest in regard to workload and stress was on the individual observers themselves. Therefore, the units of analysis in the statistical tests used in conjunction with the workload and stress measures were the individual observers in both the single-observer ($N = 17$) and coacting group ($N = 34$) conditions.

Mental workload. Workload scores on each of the six subscales of the NASA-TLX were determined using the unweighted scoring procedure recommended by Nygren (1991). Mean workload ratings in both conditions and for each subscale are presented in Table 1.

As can be seen in the table, the global workload rating for both experimental conditions ($M = 55.65$) fell above the midpoint of the scale (50), indicating that observers generally found the assignment to be demanding. A 2 (Conditions) × 6 (Subscales) mixed-model ANOVA was performed on the workload data. The presence of unequal *N*s was accounted for by the use of Type III sums of squares, which are invariant to cell frequencies and hence can be used with both balanced (equal *N*) and unbalanced (unequal *N*) designs (Field, 2005). The analysis revealed a significant main effect for subscale, $F(3.87, 190.41) = 46.20$, $p < .001$, $\eta_p^2 = .485$. Neither the main effect of experimental condition ($p = .28$)

TABLE 1: Mean NASA-TLX Subscale Scores (and Associated Standard Errors) for Each Task Condition

Observer Condition	Subscale						
	MD	PD	TD	P	E	F	Global
Single observer	67.06 (7.84)	17.65 (6.36)	81.88 (4.78)	56.18 (5.48)	72.94 (5.59)	50.88 (5.84)	57.76 (3.48)
Coacting group	72.74 (3.82)	18.00 (3.62)	71.35 (4.27)	48.76 (3.87)	67.29 (3.76)	43.09 (4.23)	53.54 (2.12)
Mean	69.90 (3.62)	17.82 (3.17)	76.62 (3.31)	52.47 (3.17)	70.12 (3.11)	46.99 (3.43)	55.65 (1.83)

Note. E = effort; F = frustration; MD = mental demand; P = performance; PD = physical demand; TD = temporal demand.

nor the Condition × Subscale interaction (p = .47) was statistically significant. Regarding the subscale main effect, a post hoc Tukey's honestly significant difference test (HSD; $\alpha = .05$, critical difference = 12.27) indicated that observers perceived mental demand, temporal demand, and effort to be the greatest contributors to their experience of workload. The scores for these subscales, which did not differ significantly from each other, were significantly greater than those for each of the remaining subscales.

Stress state. Scores for the factors of the DSSQ (task engagement, distress, and worry) were calculated in the manner proscribed by the developers of the scale (Matthews et al., 2002); that is, standardized values ($M = 0$, $SD = 1$) were calculated using normative data.

Task-induced stress was indexed for each observer in the single and coacting group conditions in the form of change scores (postvigil minus previgil) for each DSSQ scale. Mean change scores from pre- to postvigil for each DSSQ subscale are presented for the single-observer and coacting group conditions in Figure 4.

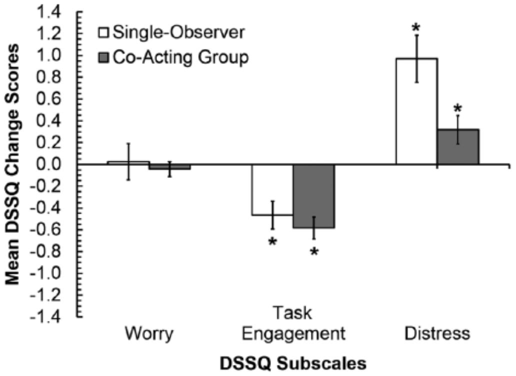

Figure 4. Mean DSSQ change scores in each task condition by subscale. Scores marked with asterisks indicate change scores that are significantly different from zero. Error bars are standard errors.

To establish that the stress state of observers changed significantly as a result of performing the vigilance task, separate t tests were computed within each DSSQ subscale comparing the mean change score for each of the two experimental conditions against a value of zero (zero indicating no change from pre- to postexperiment). Within each subscale, the two t tests were Bonferroni-corrected with alpha set at .05. No significant changes in regard to the Worry subscale were noted for the single-observer or the coacting group conditions (p = .88 and .54, respectively). On the other hand, significant declines in task engagement were obtained for both observer conditions, $t_{\text{single observer}}(16) = 3.61$, $p < .01$, $d = 1.80$, and $t_{\text{coacting group}}(33) = 5.78$, $p < .001$, $d = 2.01$, and there were significant increases in distress for both conditions, $t_{\text{single-observer}}(16) = 4.50$, $p < .001$, $d = 2.25$, and $t_{\text{coacting group}}(33) = 2.47$, $p = .02$, $d = .86$.

To further examine differences in stress response to the vigilance task, separate t tests were computed comparing change scores for task engagement and distress between observers in the single-observer and coacting group conditions (worry was omitted from these tests because change scores for this measure did not significantly differ from zero in either condition). The results of the analysis of task engagement indicated that observers in both conditions reported similar declines ($p = .49$). In regard to distress, however, the analysis revealed a statistically significant difference between observer conditions, $t(49) = 2.76, p < .01, d = .84$; observers working alone reported an increase in distress ($M = .95$) that was over three times greater than that experienced by coacting observers ($M = .30$). In terms of Cohen's (1988) criteria for interpreting effect size, the group effect represents a large effect.

DISCUSSION

Consistent with earlier investigations (Harkins, 1987; Klinger, 1969; Morgan & Alluisi, 1965; Schafer, 1949; Waag & Halcomb, 1972; Wiener, 1964), coacting groups detected significantly more critical signals on a vigilance task than individual observers working alone. In respect to that performance difference, the results of this study support Morgan and Alluisi's (1965) and Wiener's (1964) inference that signal detections of coacting observers are operationally independent, as the formula for calculating observer independence in group performance (i.e., Equation 1) exactly predicted the mean detection rate of coacting observers.

Although the coacting group approach clearly increases critical signal detection, this benefit needs to be considered with some caution. As noted by Wiener (1964), Equation 1 predicts that false alarm rates will be higher for coacting groups than for individual observers. This did not occur in the present study; the false alarm rates of the single-observer and coacting group conditions were comparably low and declined in a similar manner over time. The absence of higher false alarm rates in coacting groups was also reported by Klinger (1969) and Morgan and Alluisi (1965), but higher false alarm rates for coacting groups were observed in the studies by Waag and Halcomb (1972) and Wiener (1964). Evidently, although a higher commissive error rate in groups of coacting observers does not always occur, it is a possibility to be kept in mind in regard to the benefits of the coacting group approach for the augmentation of vigilance performance.

With regard to performance efficiency, the algorithm for the calculation of observer independence focused on the total number of signals detected in the course of a vigil. However, a major characteristic of vigilance tasks is that signal detection declines over time, a phenomenon known as the vigilance decrement (Davies & Parasuraman, 1982; Hancock, 2013; Warm et al., 2015). One might ask if the benefits of the coacting group approach extend not only to the total number of signals detected but to the vigilance decrement as well; that is, the decrement is attenuated in coacting groups in comparison to observers working alone. Of the earlier studies on coaction in vigilance, only Wiener (1964) examined that possibility, and he found that the decrement was indeed attenuated in a coacting group condition in comparison to one involving individual observers. As was the case in Wiener's (1964) study, the vigilance decrement was absent in the coacting groups of the present experiment. However, it was also absent in the single-observer condition, even though previous studies with the display employed herein did find a vigilance decrement among single observers over the same time span (Dillard et al., 2014; Funke et al., 2011; Shaw et al., 2013). In the earliest days of vigilance research, Jerison (1963) pointed out that several factors may determine the presence or absence of the decrement, a theme echoed by Davies and Parasuraman (1982) and more recently by Hancock (2013) and Thomson, Smilek, and Besner (2015). Accordingly, we are not sure why the decrement did not appear in the single-observer condition of our study, and further research is needed to answer that question and to determine if Wiener's (1964) finding that the decrement is minimized in coacting groups in comparison to individual observers can be replicated.

The central theme of the present study was that although coacting observers might be independent in terms of performance efficiency on a vigilance task, they might be interdependent with respect to the workload and stress associated with that task. This idea was based on the evaluation apprehension element in social facilitation research wherein group members are concerned with appearing less competent than their cohorts (Bond & Titus, 1983; Harkins, 1987). Consequently, it was conceivable that this uneasiness could lead coacting observers to work harder and thus to rate the vigilance task as having a higher level of workload and stress than those who performed the vigilance task by themselves, a result that would undermine the benefits of group vigilance in the operational world. This study did indeed show interdependence among coacting observers but not in the manner expected.

As in many previous studies (e.g., Finomore et al., 2013; Warm et al., 1996; Warm et al., 2015; Warm, Matthews et al., 2008; Warm, Parasuraman et al., 2008), observers who performed the vigilance task individually in this study reported high levels of workload. Their scores on the NASA-TLX fell above the midpoint of the scale, and mental demand and temporal demand were among the major components of the workload of the task. Workload ratings by coacting observers mirrored those of individual observers. Accordingly, although the present study provides the initial demonstration that vigilance tasks induce substantial workload in coacting observers, it also shows that contrary to expectations based on the notion of evaluation apprehension, their workload ratings do not differ significantly from those of observers working singly.

In regard to task-induced stress, all observers in this study showed a significant posttest loss in task engagement and a gain in distress on the DSSQ. These results are consistent with previous findings in vigilance research with this scale involving individual observers (Matthews et al., 2013; Warm, Matthews et al., 2008), and furthermore, they indicate that task-induced stress also occurs among observers working in coacting groups. Although the loss of task engagement over the course of the vigil did not differ significantly between the coacting and single observers, the task-induced increase in distress was significantly less among the former than the latter—an effect directly opposite to the expectation generated from the evaluation apprehension notion.

The coacting groups' experience of relatively low task-induced distress may be explained by two aspects of social relationships that contribute to psychological security. The first is the finding that companionship has a protective effect on individuals under stress (Buck & Parke, 1972; Rook, 1987, 2015; Schachter, 1959). Thus, joint presence might have served to moderate task-induced distress for coacting observers. A second possibility comes from Wilson, Salas, Priest, and Andrews' (2007) suggestion that opportunities for backup behavior might reduce stress among individual group members working on a difficult task. Coacting observers may have experienced less task-induced distress because they were aware of their joint responsibility for UAV monitoring—if one of them missed a signal, the other might detect it, avoiding a potential mishap.

In sum, the present study indicates that both independence and interdependence characterize group dynamics in carrying out a vigilance task under a coaction format. Specifically, the coacting groups detected more signals than individual observers, and as reflected in the algorithm proposed by Morgan and Alluisi (1965) and Wiener (1964), this finding was the result of combining the simple probabilities of the individual performances of the group members. Additionally, group membership led coacting observers to report lower levels of task-induced stress than observers who performed the vigilance task individually.

Accordingly, when system requirements, facilities, and system costs permit, the coacting groups approach remains a viable vehicle for enhancing signal detection in operational vigilance settings. Along that line, it is important to remember that this study and all of the earlier coacting observer vigilance studies were basic-science investigations that utilized naïve observers in laboratory vigilance tasks. In a recent review, Drury (2015) has pointed out that laboratory-based findings in vigilance do not always generalize to operational settings. Consequently, the next step in evaluating the utility of the coacting groups approach will be to apply it with sophisticated observers in a variety of specific operational settings such as those described in the introduction to this report.

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neuroscience, aging, automation, and epigenetics. Raja was also a foremost leader in the human factors community and a magnificent teacher and mentor to many students. He will be greatly missed.

KEY POINTS

- A group approach in which paired observers performed coactively facilitated signal detection in a vigilance task.
- Coacting group observers were independent in regard to performance efficiency but interdependent in regard to task-induced distress.
- Postvigil distress indexed by the DSSQ was significantly less in coacting group observers than in those who worked alone.
- As indexed by the NASA-TLX, coacting group observers and those working alone reported equally high levels of workload in the performance of the vigilance task.
- With regard to performance efficiency and stress, the results of this study support the possibility of using coacting groups to enhance signal detection in operational vigilance settings.

REFERENCES

Barzegar, R. S., & Wogalter, M. S. (1998). Intended carefulness for voiced warning signal words. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *42*, 1068–1072.

Bond, C. F., & Titus, L. J. (1983). Social facilitation: A meta-analysis of 241 studies. *Psychological Bulletin*, *94*, 265–292.

Buck, R. W., & Parke, R. D. (1972). Behavioral and physiological response to the presence of a friendly or neutral person in two types of stressful situations. *Journal of Personality and Social Psychology*, *24*, 143–153.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Coren, S., Ward, L. M., & Enns, J. T. (1999). *Sensation and perception* (5th ed.). Fort Worth, TX: Harcourt-Brace.

Craig, A. (1984). Human engineering: The control of vigilance. In J. S. Warm (Ed.), *Sustained attention in human performance* (pp. 247–291). Chichester, UK: Wiley.

Davies, D. R., & Parasuraman, R. (1982). *The psychology of vigilance*. London: Academic Press.

DeLamater, J. (1974). A definition of "group." *Small Group Behavior*, *5*, 30–44.

Dillard, M. B., Warm, J. S., Funke, G. J., Funke, M. E., Finomore, V. S., Jr., Matthews, G., … Parasuraman, R. (2014). The sustained attention to response task (SART) does not promote mindlessness during vigilance performance. *Human Factors*, *56*, 1364–1379.

Drury, C. G. (2015). Sustained attention in operational settings. In R. R. Hoffman, P. A. Hancock, M. W. Scerbo, R. Parasuraman, & J. L. Szalma (Eds.), *The Cambridge handbook of applied perception research* (Vol. 2, pp. 769–792). New York: Cambridge University Press.

Field, A. (2005). *Discovering statistics using SPSS* (2nd ed.). Thousand Oaks, CA: Sage.

Finomore, V. S., Jr., Shaw, T. H., Warm, J. S., Matthews, G., & Boles, D. B. (2013). Viewing the workload of vigilance through the lenses of the NASA-TLX and the MRQ. *Human Factors*, *55*, 1044–1063.

Fisk, A. D., & Schneider, W. (1981). Control and automatic processing during tasks requiring sustained attention: A new approach to vigilance. *Human Factors*, *23*, 737–750.

Funke, G. J. (2007). *The effects of automation and workload on driver performance, subjective workload, and mood*. Unpublished doctoral dissertation, University of Cincinnati, Cincinnati, OH.

Funke, M. E., Warm, J. S., Matthews, G., Finomore, V. S., Jr., Vidulich, M. A., Knott, B. A., … Parasuraman, R. (2011). Static and dynamic discriminations in vigilance: Effects on cerebral hemodynamics and workload. In T. Marek, W. Karwowski, & V. Rice (Eds.), *Advances in understanding human performance: Neuroergonomics, human factors design, and special populations* (pp. 80–90). Boca Raton, FL: CRC Press.

Hancock, P. A. (2013). In search of vigilance: The problem of iatrogenically created psychological phenomena. *American Psychologist*, *68*, 97–109.

Hancock, P. A., & Hart, G. (2002). Defeating terrorism: What can human factors/ergonomics offer? *Ergonomics and Design*, *10*, 6–16.

Hancock, P. A., & Warm, J. S. (1989). A dynamic model of stress and sustained attention. *Human Factors*, *31*, 519–537.

Harkins, S. G. (1987). Social loafing and social facilitation. *Journal of Experimental Social Psychology*, *23*, 1–18.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload* (pp. 239–250). Amsterdam: North Holland Press.

Hawley, J. K. (2006). Patriot fratricides: The human dimension lessons of Operation Iraqi Freedom. *Field Artillery*, *11*, 18–19.

Hollander, T. D., & Wogalter, M. S. (2000). Connoted hazard of voiced warning signal words: An examination of auditory components. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *44*, 702–705.

Huey, B. M., & Wickens, C. D. (1993). *Workload transition: Implications for individual and team performance*. Washington, DC: National Academy Press.

Jerison, H. J. (1963). On the decrement function in human vigilance. In D. N. Buckner & J. J. McGrath (Eds.), *Vigilance: A symposium* (pp. 199–216). New York: McGraw-Hill.

Kirk, R. E. (1995). *Experimental design: Procedures for the behavioral sciences* (3rd ed.). Pacific Grove, CA: Brooks/Cole Publishing Company.

Klinger, E. (1969). Feedback effects and social facilitation of vigilance performance: Mere coaction versus potential evaluation. *Psychonomic Science*, *14*, 161–162.

Langner, R., & Eickhoff, S. B. (2013). Sustaining attention to simple tasks: A meta-analytic review of the neural mechanisms of vigilant attention. *Psychological Bulletin*, *139*, 870–900.

Lieberman, H. R., Coffey, B., & Kobrick, J. (1998). A vigilance task sensitive to the effects of stimulants, hypnotics, and environmental stress: The scanning visual vigilance test. *Behavior, Research Methods, Instruments, & Computers*, *30*, 416–422.

Matthews, G., Campbell, S. E., Falconer, S., Joyner, L. A., Huggins, J., Gilliland, K., & … Warm, J. S. (2002). Fundamental dimensions of subjective state in performance settings: Task engagement, distress, and worry. *Emotion*, *2*, 315–340.

Matthews, G., Szalma, J., Panganiban, A. R., Neubauer, C., & Warm, J. S. (2013). Profiling task stress with the Dundee Stress State Questionnaire. In L. Cavalcanti & S. Azevedo (Eds.), *Psychology of stress* (pp. 50–91). Hauppauge, NY: Nova Science.

Maxwell, S. E., & Delaney, H. D. (2004). *Designing experiments and analyzing data: A model comparison perspective* (2nd ed.). Mahwah, NJ: Lawrence Erlbaum.

Miller, G. E., Chen, E., & Zhou, E. S. (2007). If it goes up, must it come down? Chronic stress and the hypothalamic-pituitary-adrenocortical axis in humans. *Psychological Bulletin*, *133*, 25–45.

Molloy, R., & Parasuraman, R. (1996). Monitoring an automated system for a single failure: Vigilance and task complexity effects. *Human Factors*, *38*, 311–322.

Morgan, B. B., & Alluisi, E. A. (1965). On the inferred independence of paired watchkeepers. *Psychonomic Science*, *2*, 161–162.

Nickerson, R. S. (1992). *Looking ahead: Human factors challenges in a changing world*. Mahwah, NJ: Lawrence Erlbaum.

Nygren, T. E. (1991). Psychometric properties of subjective workload measurement techniques: Implications for their use in the assessment of perceived mental workload. *Human Factors*, *33*, 17–33.

Pop, V. L., Stearman, E. J., Kazi, S., & Durso, F. T. (2012). Using engagement to negate vigilance decrements in the Nextgen environment. *International Journal of Human Computer Interaction*, *28*, 99–106.

Reinerman-Jones, L. E., Matthews, G., Langheim, L. K., & Warm, J. S. (2011). Selection for vigilance assignments: A review and proposed new direction. *Theoretical Issues in Ergonomic Science*, *12*, 273–296.

Rook, K. S. (1987). Social support versus companionship: Effects on life stress, loneliness, and evaluation by others. *Journal of Personality and Social Psychology*, *52*, 1132–1147.

Rook, K. S. (2015). Social networks in later life: Weighing positive and negative effects on health and well-being. *Current Directions in Psychological Science*, *24*, 45–51.

Sawyer, B. D., Finomore, V. S., Funke, G. J., Mancuso, V. F., Funke, M. E., Matthews, G., & Warm, J. S. (2014). Cyber vigilance: Effects of signal probability and event rate. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *58*, 1771–1775.

Schachter, S. (1959). *The psychology of affiliation*. Stanford, CA: Stanford University Press.

Schafer, T. H. (1949). *Detection of a signal by several observers* (USNEL Report No. 101). San Diego, CA: U.S. Naval Electronics Laboratory.

Shaw, T. H., Funke, M. E., Dillard, M., Funke, G. J., Warm, J. S., & Parasuraman, R. (2013). Event-related cerebral hemodynamics reveal target-specific resource allocation for both "go" and "no-go" response-based vigilance tasks. *Brain and Cognition*, *82*, 265–273.

Strauch, B. (2002). *Investigating human error: Incidents, accidents, and complex systems*. Burlington, VT: Ashgate.

Thomson, D. R., Smilek, D., & Besner, D. (2015). Reducing the vigilance decrement: The effects of perceptual variability. *Consciousness and Cognition*, *33*, 386–397.

Vidulich, M. A., Wickens, C. D., Tsang, P. S., & Flach, J. M. (2010). Information processing in aviation. In E. Salas & D. Maurino (Eds.), *Human factors in aviation* (pp. 175–215). San Diego, CA: Academic Press.

Waag, W. L., & Halcomb, C. G. (1972). Team size and decision rule in the performance of simulated monitoring teams. *Human Factors*, *14*, 309–314.

Warm, J. S., Dember, W. N., & Hancock, P. A. (1996). Vigilance and workload in automated systems. In R. Parasuraman & M. Mouloua (Eds.), *Automation and human performance: Theory and applications* (pp. 183–200). Mahwah, NJ: Erlbaum.

Warm, J. S., Finomore, V. S., Vidulich, M. A., & Funke, M. E. (2015). Vigilance: A perceptual challenge. In R. R. Hoffman, P. A. Hancock, M. W. Scerbo, R. Parasuraman, & J. L. Szalma (Eds.), *The Cambridge handbook of applied perception research* (Vol. 1, pp. 241–283). New York: Cambridge University Press.

Warm, J. S., Matthews, G., & Finomore, V. S., Jr. (2008). Vigilance, workload, and stress. In P. A. Hancock & J. L. Szalma (Eds.), *Performance under stress* (pp. 115–141). Brookfield, VT: Ashgate.

Warm, J. S., Parasuraman, R., & Matthews, G. (2008). Vigilance requires hard mental work and is stressful. *Human Factors*, *50*, 433–441.

Wickens, C. D., Hollands, J. G., Banbury, S., & Parasuraman, R. (2013). *Engineering psychology and human performance* (4th ed.). Boston, MA: Pearson.

Wiener, E. L. (1964). The performance of multi-man monitoring teams. *Human Factors*, *6*, 179–184.

Williams, S. B. (1947). *The search factor in detecting weak radar targets* (Report No. 166-I-2). Baltimore, MD: The Johns Hopkins University Psychological Laboratory.

Wilson, K. A., Salas, E., Priest, H. A., & Andrews, D. (2007). Errors in the heat of battle: Taking a closer look at shared cognition breakdowns through teamwork. *Human Factors*, *49*, 243–256.

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