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Experimental Analysis of Artificial Signal Type and Performance Feedback Delivery Schedule in Attenuating Vigilance Decrement

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Abstract

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Past research has suggested that artificially increasing the number of signals that require a response will increase detection performance in a vigilance task. The present study examined the effect of adding artificial signals that were either identical to or distinctly different from true signals in a controlled two-hour monitoring task. Immediate machine-generated feedback was also paired with artificial signals. Signal probability for true signals was 2% and all artificial signal probabilities were 8%. The dependent measures were true signal hits, true signal hit variance, true signal hit decrement, variance for true signal hit decrement, residual variance for true signal hit decrement, false alarms and false alarm variance. Eighty-two university students participated in the study. A significant main effect due to Identical Artificial Signals was found for mean true signal hits ($F_{1,69} = 6.273$, $p < .025$). A significant main effect due to Feedback was found for mean false alarms ($F_{1,71} = 8.150$, $p < .01$) and a significant interaction was found in the mean true signal hit decrement ($F_{2,69} = 4.221$, $p < .025$). The results suggest that immediate feedback and artificial signals that closely resemble the true signal can improve detection performance.

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Experimental Analysis of Artificial Signal Type and Performance Feedback Delivery Schedule in Attenuating Vigilance Decrement

Tasks that require an observer to respond to infrequent stimuli in the environment have been the focus of study for over 50 years. Radar operation, assembly line inspection, surveillance and vehicle operation are some of the tasks where such sustained attention is required. Initial interest in the field of sustained attention grew during World War II (Mackworth, 1948). Concern was focussed upon the ability of personnel manning watch stations, such as radar or sonar displays, to maintain a high level of accuracy for identifying relatively infrequent targets. The problem with the displays being monitored was that in addition to signals representing air or sea vessels, there was also background "noise." Part of the task of the individuals who monitored these displays was to determine what information was noise and what was a true signal, which required an immediate and accurate response.

The first published laboratory study of sustained attention was conducted by N. H. Mackworth, who first used the term "vigilance" to describe the field of sustained attention. He defined vigilance as "...a state of readiness to detect and respond to certain specified small changes occurring at random time intervals in the environment" (Mackworth, 1957, p. 389). In what came to be known as the Clock Test, participants were required to watch the hand of a clock as it moved around an unmarked clock face. The hand was designed to move sixty times every hour, with an inter-signal interval ranging from .75 minutes to 3 minutes.

The hand usually moved 0.3 inches each time (noise), but occasionally moved 0.6 inches (signal). During the 2-hour task, the participants were required to identify these larger motions of the hand by pressing a key.

Mackworth's results were consistent with observations made in applied situations. When individuals were required to perform monitoring tasks for extended periods of time, declines in detection rates began soon after the onset of the task and continued for the remainder of the task. Specifically, the number of missed signals increased the most between the first and second half hour of the task. After this period, performance continued to decline throughout the remainder of the time on task, but at a much lower rate (Mackworth, 1948). The stereotypic decline in detection performance over time is referred to as the "vigilance decrement" (Davies & Parasuraman, 1982 p. 5). The main focus of research in vigilance has been to develop an understanding of the variables involved with the vigilance decrement so that effective countermeasures can be developed which will help observers maintain a high level of performance.

Performance Measurement

Although monitoring tasks can vary greatly between experiments, there are three common measures of performance that allow researchers to compare findings across studies: detection rate, false alarm rate and detection latency (Davies & Parasuraman, 1982). Detection rate (or hit rate) is a measure of the percentage of critical signals that have been detected. False alarm rates are a measure of the percentage of detection responses an observer makes to a nonsignal event. Detection latency is a measure of the time taken from signal onset to the detection response. Latency is inversely correlated with detection rate; as detection latency increases, the overall number of signals identified declines (Davies & Parasuraman, 1982).

Although the preceding measures are widely used in vigilance research, some studies may only use one or two of these performance measures, depending on the specific aspect of performance that is being studied. In addition, other measures may be used depending upon the unique characteristics of the vigilance task in a particular study. Two examples are unlimited hold and sensitivity decrement. In an "unlimited hold" task, the critical signal is presented repeatedly or is presented and stays on until the observer makes the required response (e.g., Broadbent, 1958). The number of critical signal presentations (or the duration of signal presentation) needed to elicit the required response would be an additional variable in studies which incorporate an unlimited hold. Sensitivity decrement is a measure of the decline in the observer's ability to distinguish between signals and background noise (i.e., discriminability) over time. The false alarm rate, hit rate, and sensitivity decrement are three measures that have been borrowed from Signal Detection Theory (SDT) and applied to vigilance.

Signal Detection Theory

Based upon SDT, detection of a signal occurs when an observer makes an observation within a fixed time interval and decides whether a given instance was due solely to background noise (N) or noise plus a signal (SN). This decision results in one of four possible outcomes: correct detection (hits), correct rejections, incorrect detections (false alarms) and incorrect rejections (misses; see Figure 1). Measures of performance are based upon the conditional probability of hits (P(H)) and false alarms (P(FA)).

The first measure, d', determines the distance between the means of the signal and noise distributions and is computed by the formula: $d' = Z[P(FA)] - Z[P(H)]$ (Warm & Jerison, 1984). Z[P(FA)] and Z[P(H)] are the standard normal scores associated with P(FA) and P(H). This measure is not affected by an individual's decision criterion. It provides an unbiased measure of the discriminability of the signal. d' can take on any value equal to or greater than 0. The value of d' is used to determine the difficulty that subjects have in differentiating between noise and signals. A value of 0 indicates an individual's complete inability to differentiate between a signal and a non-signal (i.e., responses are equal to chance). In any given situation, a larger value of d' implies a greater distance between the N and SN distributions, thereby increasing the chance of correctly identifying the presence or absence of a signal. d' assumes a parametric model of detection is applicable, and that the

Figure 1. Stimulus-response matrix of the yes-no procedure.

Response Alternative

Stimulus Alternative		S	N
	s	$P(S\|s)$ Hit	$P(N\|s)$ Miss
	n	$P(S\|n)$ False Alarm	$P(N\|n)$ Correct Rejection

$$P(S|s) + P(N|s) = 1$$

$$P(S|n) + P(N|n) = 1$$

S = Report a Signal is Present

N = Report No Signal is Present

s = Signal is Actually Present

n = No Signal is Present

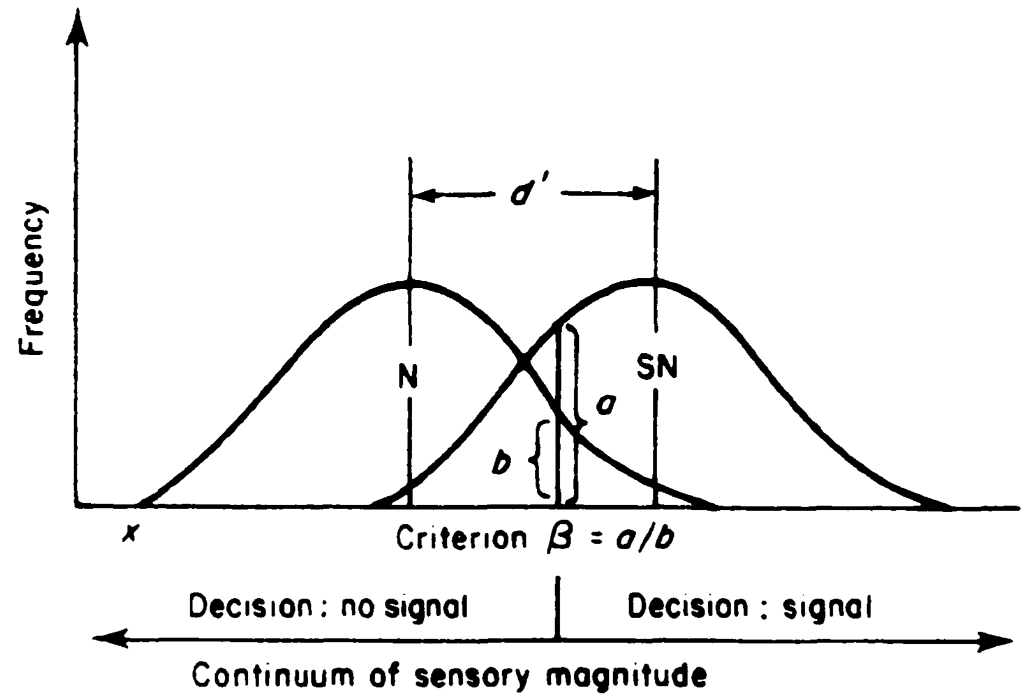
two distributions (N and SN) are normal and have equal variance (See, Howe, Warm, & Dember, 1995).

The second measure of performance, β, determines the observer's response criterion, and is computed by the formula: β = F[P(H)]/F[P(FA)] (Warm & Jerison, 1984). F[P(H)] and F[P(FA)] are ordinates of the normal curve corresponding to P(H) and P(FA) respectively (see Figure 2). This measure reflects the value the observer places on correct decisions (hits and correct rejections) against the costs of errors (misses and false alarms). As the response criterion used by an observer becomes increasingly conservative, the value of β increases. The observer favours reporting fewer signals in order to make fewer false alarms.

Within- and Between-Group Differences

Recent research has examined both individual and group differences in detection performance. Methot and Huitema (1998) examined individual performance decrements during the vigilance task with the linear model $Y_{i,t} = \beta_0 + \delta_i t + \varepsilon_{i,t}$. In this model, $Y_{i,t}$ is the average hit score for subject i at time block t, β_0 is the regression intercept, δ_i is the decrement coefficient and $\varepsilon_{i,t}$ is the error term. The decrement coefficient (δ_i) provides an estimate for the average change in the dependent variable Y per unit of time and the MS residual provides an estimate of the variation in individual performance that is unpredictable from the performance decrement equation.

Figure 2. Signal detection theory diagram of noise and signal probabilities.



Summary

The variation in performance measures across studies can be partially attributed to the lack of an established theory for the vigilance phenomenon. One of the challenges faced by researchers is to develop a theory that consistently predicts performance and provides a framework in which the vigilance decrement can be attenuated (i.e., maximize performance). Research on vigilance, as previously noted, began atheoretically from the need to improve performance in an applied setting. Over the years, several researchers have attempted to define vigilance using different theoretical approaches, such as learning models, neurological models, and psychophysical models.

Davies and Parasuraman (1982) noted that all of the theories attempted to explain two things: what determines the observed drop in performance? and what determines the overall level of performance? Usually, it has been the first of these questions that has received the most attention by theorists. To date, no one theory has been found to explain the vigilance phenomenon better than any of the others. Each theory proposed fails to completely encompass the entire set of behaviours observed in a sustained attention task. Several researchers have suggested that one theory may not be adequate to explain the vigilance phenomenon and perhaps a combination of theories would be better suited for the task (e.g., Berch & Kanter, 1984; Loeb & Alluisi, 1984). This possibility has only been recently considered and additional research is needed to determine if a combination of theories will be more effective in explaining vigilance.

Individual Differences in Performance

A significant amount of research has been conducted in the hopes of identifying specific characteristics that would ensure that the people selected for vigilance tasks have a better chance of maintaining a high level of performance. Researchers have attempted to identify significant, consistent performance differences based on personality factors, organismic factors and subjective states (Berch & Kanter, 1984). Research on individual differences relating to performance in a vigilance task has, essentially, failed to identify any one single factor that accounts for a significant portion of the variance under controlled conditions. It is very unlikely that people possessing all of the required personality traits, at the levels suggested by research to increase performance on a vigilance task, are easy to find (Davies & Parasuraman, 1982). Based upon a review of the research on individual differences, Berch and Kanter (1984) developed a newspaper advertisement attempting to recruit ideal candidates for a vigilance task. The advertisement read:

> **Help Wanted**
>
> For auditory monitoring position – Prefer a blind, introverted, middle-class male or female, with an average to above average IQ, who exhibits a coronary-prone behavior pattern, is field independent, has an internal locus of control, does not daydream, is a good reader and an experienced meditator. (p. 169)

Davies and Parasuraman (1982) have noted that, even if a single individual trait is found to predict better performance on a vigilance task, it is unlikely that a single test can be developed that will accurately predict performance in all of the different vigilance tasks that exist in the workplace. With the development of more automated equipment, monitoring tasks will become more common and increasingly diverse in their characteristics, further reducing the chances of developing "the one test" to predict performance across all possible situations.

The apparent lack of progress over the last 50 years has been the focus of some criticism (see Appendix A). After decades of research in individual differences with very few significant findings, the question to be asked is why has a consistent predictor for performance on a vigilance task not been found? The fact that a complete theory of the vigilance process has not yet been developed would seem to be part of the answer. Davies and Parasuraman (1982) believed that the failure of any one theory to completely explain the vigilance phenomenon is due to the use of improper measures of performance and a focus on the observer to the exclusion of environmental factors.

In an attempt to identify the environmental factors than have an influence on vigilance, Davies and Parasuraman presented a classification system for vigilance tasks (Davies & Parasuraman, 1982; see Appendix B). Personal characteristics were not included in this classification system. Recent studies suggest that proper design of the workplace will minimize the need to identify groups of people who would be more likely to perform well on a vigilance task (e.g., Methot and Huitema, 1998). Based on these findings, focus on the environmental characteristics of the task and how these can be manipulated to enhance observer performance appears to be the method with the most potential for success.

Attenuation of the Vigilance Decrement

Potential methods to attenuate the vigilance decrement through environmental manipulation, which have received attention from researchers include: (a) orienting of attention (e.g., Bahri, 1994), (b) social facilitation (e.g., Klinger, 1969; Hollenbeck, Ilgen, Tuttle, Dale, & Sego, 1995), (c) signal probability (e.g., Baker, 1960; Fortune, 1979; Methot & Huitema, 1998) and (d) the availability of knowledge of results (e.g., Antonelli & Karas, 1967; Drury & Addison, 1973). The effects of these interventions on the vigilance task under controlled conditions will be discussed below.

Orienting of Attention

Because signals in a vigilance task are inherently low in frequency and cannot be predicted, using cues to alert the observer that a signal is about to appear cannot be used to directly enhance performance on the job. They have, however, been suggested as a method of training individuals for a better level of performance.

Bahri (1994) studied the effect of cues prior to signal presentation as a means of ensuring attention, thereby reducing the vigilance decrement. The intent was not to ensure that the observer's eyes were focussed upon the display - Mackworth, Kaplan, and Metlay (1964) found that eye movement was not correlated with performance on a vigilance task - but rather to alert the observer that a signal is about to appear. Posner and Cohen (1984) found that peripheral visual cues decreased reaction time in identifying target stimuli only if the cue was presented within 300 milliseconds and in the same location as the actual signal. Bahri's results showed that, with low event rates, cues that were valid (i.e., correlated with the presentation of a signal) increased the observers' hit rates and lowered their false alarms.

An unexpected result of this experiment was that the invalid cues reduced the performance decrement (Bahri, 1994). Bahri speculated that the inaccurate information from the invalid cues breaks the monotony when compared to a vigilance session with valid cues. If the cues were valid, then the observer would not have to maintain a constant watch. He or she would only have to direct his or her attention to the display when the cue appears.

Another explanation for the differences between valid and invalid cues could be Posner, Rafal, Choate and Vaughan's (1985) inhibition of return. Posner et al. suggested that observers would successively focus their attention on small areas of a display while searching for a signal. As a result, they will be unlikely to focus their attention on the same specific location of a display twice within a short period of time. If the observers do re-orient to the same location (e.g., due to a valid cue) they may not detect a signal due to a temporary inhibition effect. Posner, Cohen, Choate, Hockey, and Maylor (1984) suggested that this inhibitory effect, over the long term, is what is responsible for the vigilance decrement. Additional research is needed before the effectiveness of signal cues as an aid to the vigilance task can be determined.

Social Facilitation

Klinger (1969) evaluated vigilance performance of individuals when they were in the presence of other participants. He compared performance when people were alone, in pairs where each individual only received information about his or her own performance ("mere coaction" group), and when the paired individuals received information about his or her own performance as well as information about the other subject's performance ("potential evaluation" group). When subjects were in the potential evaluation group, they were not instructed to pay attention to the other's performance, nor were they instructed to compete with the other subject.

Experimental results showed a significant decrease in false alarms in the potential evaluation group when compared to the mere coaction and isolation groups. The correlation between the presence of another and error rate was .53 and .01 for the potential evaluation and mere coaction groups respectively (Klinger, 1969). This difference between the two groups occurred without an increase in false positive errors, suggesting that subjects did not adopt a less stringent criterion (β) for reporting a signal. Klinger concluded that the presence of another person is not sufficient to increase performance in a vigilance task. The additional person must have access to the performance of the observer, suggesting that potential evaluation, even if only assumed, must be present in order to facilitate performance.

Hollenbeck, Ilgen, Tuttle and Sego (1995) hypothesised that teams, as opposed to individuals, involved in a vigilance task can reduce the chances of missing a critical signal. Statistically, an individual may have a high probability of missing a signal (e.g. .75). The presence of other individuals performing the same task greatly reduces the chances that a critical signal will be missed by all members of the team ($.75^4 = .32$). The results of Hollenbeck et al.'s (1995) study failed to support their hypothesis.

Hollenbeck et al.'s (1995) experiment showed that the rare stimulus events negatively affected team performance as the task continued. The authors believed that the main reason for this was that the presence of others distracted the individuals from their task. Each team member was seated in an isolated booth with a computer terminal. Each team member was assigned a specific complimentary task for the duration of the experiment. Signals were presented simultaneously on all four computer displays. The computers also allowed the team members to communicate with one another through typed messages.

As the experimental session progressed, the messages sent among the team members became more social in content than task related. In addition, when a signal was missed, communication increased among participants attempting to determine what went wrong. This further distracted the team members from the monitoring task at hand. As this was a controlled situation with university students over three sessions, the long-term behaviour of teams performing a vigilance task still needs to be examined. Real, rather than simulated, repercussions of team performance may have an effect on vigilance performance that cannot be easily replicated in a controlled environment.

Signal Probability

The probability of a signal occurring during a vigilance task has been shown to affect the level of performance of the observers (e.g., Deese, 1955; Jenkins, 1958; Methot & Huitema, 1998). Performance can be affected by the signal probability through one or more of the following methods: (a) changing the number of noncritical signals (event rate) without changing the number of critical signals, (b) changing the probability of a signal occurring without changing the event rate, and (c) by presenting the observer with similar or different signal probabilities during training and the actual vigilance task

Changing the number of noncritical signals. Jerison (1965) found a lower percentage of signal detections when the noncritical signals increased in frequency with no proportionate increase in critical signals. This suggests that the signal rate of both critical signals and noncritical signals affect performance on a vigilance task. As noted previously, Mackworth identified noncritical signals as having an important effect on vigilance performance (Mackworth, 1950).

Parasuraman (1979) compared the memory load of simultaneous and successive vigilance tasks in conjunction with different event rates (15 or 30 events per minute). Successive tasks would put a higher memory load on the observer, as he or she must remember the characteristics of the signal while observing each successive stimulus. As with other studies, a higher event rate reduced the detection rate. Performance on the successive discrimination task indicated a decline in discrimination (*d'*) only in the high event rate group. The rest of the experimental groups exhibited an increase in response criterion (β).

Parasuraman (1979) attributed this change to the processing demands of the successive task. As the event rate increases, more comparisons must be made with less time for a response. Eventually, the observer cannot keep up with this pace, resulting in a sensitivity decrement. This reduction in sensitivity results in the vigilance decrement.

For the three remaining experimental groups in Parasuraman's study, the observers' sensitivity (*d'*) remained constant, while their response criterion (β) increased as the vigilance task progressed. This increased conservatism for responding is what brought about the vigilance decrement in these situations (Parasuraman, 1979). Parasuraman's findings suggest that the vigilance decrement is not determined by event rate alone, and that both the memory load and event rate can interact to influence sensitivity changes during a vigilance task.

Changing the signal probability. An examination of the effects of signal probability on vigilance performance in a controlled and applied setting was conducted by Fortune (1979). The first study was conducted in the laboratory with trained students. The second study was conducted on the National Center for Toxicological Research (NCTR) worksite with the Center's employees. One of the empolyees' primary tasks was to examine tissue slides from deceased animal organs to determine if the tissue sample was abnormal and warranted further investigation. The probability of a tissue sample requiring further investigation was estimated to be .001 (Fortune, 1979).

Both of Fortune's studies presented the observers with 60 slides. The two groups in each study had signal probabilities of .10 and .35 respectively. Fortune found a significant between-group difference in signal detections in both experiments. As the signal probability dropped, fewer signals were detected. Although not reaching statistically significant levels, Fortune also found that a lower signal probability increased the false alarm rate (Fortune, 1979). Fortune concluded that controlled experimental findings regarding signal rate are comparable to the effect of signal rate in an applied setting.

It should be noted, however, that compared to the estimated signal probability at the NCTR worksite, Fortune's signal probabilities were quite high. Fortune used probabilities of .10 and .35. These were 100 to 350 times greater than the probability normally encountered by the employees. This difference between the experimental and worksite signal probabilities may raise some questions regarding the amount of generalization that is possible. Since a higher signal probability has already been shown to have a positive effect on performance, Fortune's exaggerated probabilities may have resulted in attenuated performance. It is unknown how these employees would perform if they participated in a similar study with a signal probability of .001.

Signal probability and training. Colquhoun and Baddeley (1967) compared performance on a vigilance task after their training session had either a high (p=.18) or low (p=.02) probability of signal occurrence. The study compared four groups: high practice and high task probabilities, high practice and low task probabilities, low practice and high task probabilities and low practice and low task probabilities. In line with Deese's (1955) expectancy theory, the researchers hypothesised that the high probability of signals in the training session would result in a steeper decrement during the actual vigilance task.

The results of the experiment supported this hypothesis. When the task began, both of the high probability practice groups detected a larger percentage of signals than did the two low probability practice groups. However, since these two groups were originally detecting a higher percentage of signals, the steeper decrement still resulted in an end-of-session detection rate that was better than or equal to the low probability practice groups.

Using the SDT framework, Colquhoun and Baddeley (1967) calculated d' and β. There was no difference between the groups with respect to their ability to distinguish noise and signals (d'). This common value indicated that the task difficulty was similar across all groups. There was a significant between-group difference in β. This indicated that the groups that had experienced a low probability of signals during the training were more conservative in their detection criteria in the actual task, resulting in fewer signal detections and a smaller decrement in performance.

An analysis of β within each group throughout the task indicated that the high practice and low task probability group became more conservative in their decision criteria as the task progressed (i.e., β increased over time). The opposite was found in the low practice and high task probability group (Colquhoun & Baddeley, 1967). As the task progressed, this group became less conservative in their decisions. The authors concluded that the signal probability during a practice session plays a part in the magnitude of the vigilance decrement during the actual task.

In another experiment, Baddeley and Colquhoun (1969) matched the practice session's signal probability for each group with the signal probability each group would experience during the actual task. The signal probabilities used were .02, .06, .18, .24 and .36. Comparison between the 5 groups was consistent with their earlier study (Colquhoun & Baddeley, 1967). All of the groups exhibited similar levels of discrimination (d') but differed in their decision criterion (β). The most conservative criterion was present in the p = .02 group and the least conservative in the p = .36 group (Baddeley & Colquhoun, 1969).

With the exception of the $p = .02$ group, the vigilance decrement was not as steep as that found in their earlier (1967) study. Williges (1969) believed that the observed decrement was due to a change in an individual's decision criterion (β) towards his or her optimal decision behaviour. This suggests that performance at the beginning of a vigilance task is above normal and that the individual slowly moves to his or her normal level of performance.

The authors did note that the $p = .02$ group had several differences in performance when compared to the other groups (Baddeley & Colquhoun, 1969). These differences make it difficult to confidently extend the observed effects of signal probability to this low level of signal occurrence. Baddeley and Colquhoun suggested that the low occurrence of signals ($p <= .02$) is too low for pre-training/expectancy to attenuate the vigilance decrement.

Signal probability and individual performance. Most of the vigilance literature has reported group differences when studying environmental and personal factors. In many cases, this does not reflect the true nature of the vigilance task. Many of the applied situations involving sustained attention are isolated, individual tasks (e.g., sonar, security, nuclear power station). When attempting to apply research findings to actual situations, group level analysis may not be sufficient. Recently, research has begun to focus on individual performance within groups (e.g., Kolega, Brinkman, Kendriks & Verbaten, 1989; Methot & Huitema, 1998). These studies have demonstrated that analysis of individual performance will identify a large amount of variance that may be masked by a group-level analysis.

Methot and Huitema (1998) demonstrated that the signal probability affects individual performance levels on a vigilance task. They compared performance on a visual vigilance task with signal probabilities of .01, .04 and .12. The results indicated a vigilance decrement in each group. Consistent with past research (e.g., Baddeley & Colquhoun, 1969), as the signal probability increased, the decrement decreased. Breaking down the performance data further, within-group variance increased as the signal probability decreased. Within-subject variance for hits in the p = .12 group was 92% less than the variance in the p = .01 group (Methot & Huitema, 1998). The researchers suggested further investigation into the manipulation of signal probability in order to reduce the performance variance between and within individuals.

Artificial signals

One thing that has been consistent among the studies on signal probability is the fact that, up to a point, increased performance was observed with an increase in the signal rate. Baker (1960) suggested that artificially increasing the rate of signals, thereby increasing the signal probability, could be an effective countermeasure for the vigilance decrement in applied settings. He also suggested that the artificial signals not be discriminably different from true signals and knowledge of results be provided with respect to the individual's detections of the artificial signals. Baker found a significantly improved level of performance when these countermeasures were implemented (92 and 230 missed signals for the experimental and control groups, respectively).

Hypothesis 1: Detection performance on a vigilance task will be improved when artificial signals are added to the task.

One question that remained unanswered from Baker's (1960) study is how different from the true signals the artificial signals could appear or sound before they no longer have a positive effect on performance (Baker, 1960). Perceptually, identical artificial signals would increase the signal rate. As Baddeley and Colquhoun's (1969) study showed, an increase in signal rate will result in improved detection performance. Wilkinson (1964) found that identical artificial signals and full knowledge of results increased detection of true signals from 40% to 90%, identical artificial signals with partial knowledge of results increased detection to 72%, while different artificial signals and full knowledge of results improved performance to 62%, and identical artificial signals with no knowledge of results did not significantly affect performance (47%).

Further analysis revealed that identical artificial signals increased the false alarm rate less than different artificial signals and the different artificial signals were detected less frequently than the identical artificial signals. These results support Baker's (1960) suggestion for not using distinctly different artificial signals. Overall, Wilkinson concluded that artificial signals with knowledge of results, whether identical or different, could improve performance on a vigilance task. The potential drawback of different artificial signals lies in the fact that fewer true signals were detected and more false alarms were reported when compared to the identical artificial signal group.

Signal detection theory would suggest that an increase in both signal detection and false alarms would indicate that the individual's criterion for accepting a stimulus as a signal (β) has decreased, thereby increasing the level of signal responding. An increase in signal detections without a corresponding increase in false alarms would indicate that an individual was better able to discriminate between true and false signals (d'). Comparison of the results from Wilkinson's (1964) identical and different artificial signal groups would suggest that both types of artificial signals increased the observers' willingness to make a signal response, while the identical artificial signals also had the effect of increasing an individual's ability to discriminate between true and false signals.

Hypothesis 2: Identical artificial signals will increase detection performance to a greater degree than distinct artificial signals.

The effects of artificial signals and knowledge of results has not been consistently beneficial. Murrell (1975) found that identical artificial signals with knowledge of results increased both the detection of signals as well as false alarms. As noted above, this pattern of responding would imply that the subjects adopted a more lenient decision criterion (i.e., a drop in the value of β).

When comparing Murrell's study to the others involving artificial signals, it should be noted that the task used in Murrell's study was quite different from the usual type of vigilance task. Subjects had to scan four sets of displays for a signal and then press a series of keys. Even if there was not a signal, the subjects still had to press one of two "no" keys, indicating if they were certain or doubtful of the accuracy of the negative response. If a signal was detected, the subjects had to first indicate if they were certain or doubtful of the positive response. The subjects then had to indicate in which of the four display sets the signal was located, as well as its position within the indicated set. This would warrant using Davies and Parasuraman's (1982) optional classification that categorises vigilance tasks on the type of response the observer is required to make (simple or complex; see Appendix B).

When comparing the task requirements of most vigilance studies with Murrell's, there is a distinct difference in the method of responding he required from his subjects. The knowledge of results, displayed next to the stimuli, may have increased the amount of information that the subject had to keep track of to a level that might have masked any positive effects that may have resulted from the artificial signals and knowledge of results.

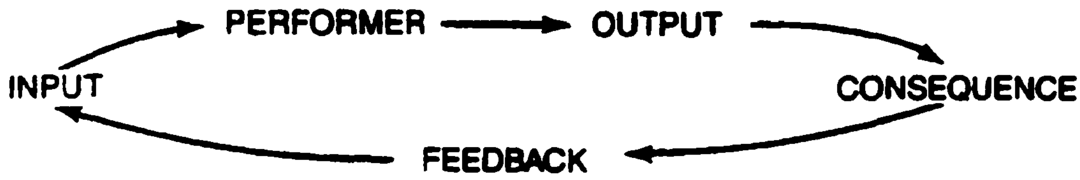
Feedback

Performance feedback, or knowledge of results (KOR), is arguably one of the most common methods used by organisations in an attempt to increase and maintain performance. It has been defined as information provided to individuals about the quantity or quality of their past performance (Prue & Fairbank, 1981). The appeal of performance feedback comes from the fact that: (a) it requires very little investment by the organisation compared to other interventions, (b) minimal training is required, (c) structured feedback programs reduce the use of aversive rewards (e.g., punishment), and (d) feedback interventions are one of the most flexible interventions available, allowing implementation in the presence of various organisational constraints such as legal, union, or budget (Prue & Fairbank, 1981). Within the field of human factors, feedback is one of the basic components of a human-machine system (Geis, 1986; see Figure 3).

Since feedback is widely used in a variety of situations, comparison between programs is not straightforward. Within the general term "feedback," there can exist many variations and distinctions between any two feedback programs. Prue and Fairbank (1981) reviewed the work on performance feedback and developed a set of criteria with which to classify and compare the feedback literature. Their main categories were: (a) the recipients of the feedback, (b) the feedback mechanisms employed, (c) the content of the feedback, (d) the temporal characteristics of the feedback and (e) the source of the feedback (see Appendix C).

In addition to the characteristics of the feedback reviewed by Prue and Fairbank (1981), the presence or absence of goals and rewards can influence the effectiveness of feedback in a given situation. Balcazar, Hopkins and Suarez (1986), have noted that in many cases, research on feedback has not differentiated between feedback in isolation and feedback in conjunction with other methods intended to modify behaviour (e.g., goal setting) or with behavioural consequences (i.e., rewards and punishment). Balcazar et al.'s

Figure 3. Elements of a human-machine system.



(1986) review of research on feedback in the previous ten years examined feedback alone, feedback with goal setting procedures, feedback with behavioural consequences and feedback with both goal setting procedures and behavioural consequences (see Appendix D).

According to Balcazar et al. (1986), a system of "functional differential consequences" would be the most effective method for improving targeted behaviours (Balcazar et al., 1986; p. 83). A functional consequence is essentially something that, when received as a result of specific behaviours, will increase the chances of the associated behaviours to be repeated in the future (i.e., a reinforcer). To ensure the practicality of the functional consequence, it must be something that is desired by the majority of the employees (e.g., money).

Differential consequences imply that the rewards are contingent upon performance of the desired behaviours. In order for the employees to develop this association, the rewards should be delivered as close as possible to the completion of the desired behaviour. Once these components of the system have been established, quantitative feedback should be provided biweekly at the very least.

Vigilance and Feedback

Self-recorded versus verbal feedback. Warm, Kanfer, Kuwada, and Clark (1972) conducted an experiment to determine the nature of the incentives from self-recorded feedback and feedback provided by the experimenter and how knowledge of results affected performance on a one-hour vigilance task. The results of their experiment supported past findings that knowledge of results helps improve performance on a vigilance task when response time is used as a measure. This improvement occurred both when the subject him- or herself provided the feedback or when the experimenter provided the feedback. The self-recorded feedback, however, was found to be less accurate than the experimenter-provided feedback. This inaccuracy did not improve as the experimental session progressed.

The most common error in the self-recorded feedback group was that subjects tended to believe that their performance was consistent rather than increasing or decreasing (96.05% of the equal performance estimates were incorrect; Warm et al., 1972). The authors suggested that when subjects could not clearly determine a difference in their performance (e.g., faster or slower), they grouped these uncertain instances into the equal performance category. 77.81% of the self-estimates of faster or slower performance were correct. This suggests that performance differences which can be easily identified and distinguished by the performer would provide an environment in which self-evaluations come close to being as effective as feedback provided by another individual.

Immediate versus delayed feedback. Mason and Redmon (1992) compared the effects of immediate and delayed feedback and task pacing on a vigilance task. They compared four groups: self-paced, immediate feedback; self-paced, delayed feedback; machine-paced, immediate feedback; and machine-paced, delayed feedback. The immediate feedback was presented less than .01 seconds after a response was made. The delayed feedback was presented ten to fifteen minutes after the completion of a set of responses. All sessions were run on a computer simulation where the subjects had to search for "faulty" computer hard disk drives. Each item had a 50% chance of containing a defect, which could be in one of ten locations.

Subjects were required to respond to the presented image by using the mouse to click on the appropriate response (located to the right of the image). Each subject went through the following progression: presentations 1-10, 16-20 and 26-30 were self-paced; presentations 11-15 and 21-25 were machine paced. For each of his or her 4 trials, each subject was randomly assigned to an immediate or delayed feedback session (2 trials each). Group performance, from highest to lowest, was self-paced, immediate feedback; self-paced, delayed feedback; machine-paced, immediate feedback; and machine-paced, delayed feedback. These groups had accuracies of 96.39%, 94.17%, 90.41% and 86.83% respectively. Overall, it was found that each subject performed better with immediate feedback (Mason & Redmon, 1992).

The impact of these results in applied settings is uncertain. As noted above, the chance of a signal occurring was .5. In an applied setting (e.g., an assembly line) this would be an unrealistically high chance for a defect to occur. With lower rates of signal occurrence, would the same levels of performance be seen, or would there be a change consistent with past vigilance research using a low signal probability? Would feedback, either immediate or delayed, produce the same changes in performance? Further research is needed to answer these questions.

Partial versus complete feedback. Antonelli and Karas (1967) studied the effects of partial and complete (20%, 30%, 50% and 100%) knowledge of results on reaction time in a vigilance task. In addition, they compared the effects of true and false knowledge of results. The results showed that there were no performance differences between the groups due to the accuracy of the feedback. The results also indicated that increasing the level of feedback could affect performance; however this increase is not a perfect linear correlation. As the knowledge of results comes closer to 100% there is a reduced effect on performance (i.e., diminishing returns). Although some of the authors state that some of the results may be an artifact and replication is necessary, it appears that performance improves on a vigilance task with at least 30% knowledge of results.

Feedback and cueing. Wiener and Attwood (1968) studied the effect of signal cueing with knowledge of results during training on performance one week later. Their four groups were a control group, KOR only, cueing only and cueing with KOR. The post-training session provided neither cues nor KOR for any of the subjects. The results indicated that both the KOR and cueing with KOR groups performed at a similar level. Cueing with KOR during training is no better than

KOR alone. The cueing alone group performed similarly to the control group, showing that cueing during training did not transfer to the performance test one week later. One positive effect was that cueing did reduce the number of false alarms when compared to the KOR group.

Feedback as a training aid. Wiener (1968) studied the effect of knowledge of results as a training aid on repeated vigilance training sessions. The training was conducted over five consecutive days. Each session was 48 minutes in duration, with eight signals appearing within each 12-minute block. One group received knowledge of results and the other did not. The subjects were required to detect a larger than normal deflection of a voltmeter. A non-critical signal was a deflection of 20 degrees, while a critical was a deflection of 30 degrees. The meter was set for 50 deflections per minute. Knowledge of results was provided by the illumination of a pilot light in the room. Subjects were informed when they made a correct response (green light), a false alarm (red light) and missed a signal (amber).

Five weeks after the training sessions, both groups were given a vigilance task without the pilot lights and their performance was compared to the training sessions. Although the KOR group consistently performed better than the control group, both groups showed an increase in performance over the five training sessions, indicating a practice effect. The KOR group exhibited a greater retention over time, as indicated by a higher level of performance during the five-week follow-up. The KOR group's performance did drop compared to their performance during training, indicating that the beneficial effect of the training begins to deteriorate over time. This drop in performance may have been partially due to the fact that the subjects did not have the opportunity to perform the vigilance task for five weeks.

Hypothesis 3: Feedback will increase the positive effects of both the identical and distinct artificial signals.

Feedback and rewards. Sipowicz, Ware, and Baker (1962) compared performance on a three-hour vigilance task with and without knowledge of results and/or a monetary reward. The subjects were required to detect interruptions in a 12-volt continual light source positioned at eye level by pressing a button to indicate detection. The apparatus was set for 12 signals per ½ -hour (72 in total). For the KOR group, a 6-volt pilot light to the side of the target light would illuminate for two seconds if the subject did not detect the presence of a signal within five seconds of the signal's onset. The reward group was told that they would be given $3.00, but every signal missed would reduce this reward until it reached $0.00 (after missing 6 or more signals, a performance level of 93% or less). The feedback plus KOR group was given the same instructions as the reward group.

Results of the study showed that performance, from worst to best, was the control group, KOR group, reward group and KOR with reward group. These groups missed 24.3%, 12%, 8.4% and 4.3% of the signals, respectively, showing that although KOR and rewards both individually improve performance, the presence of both of them increased performance even further, suggesting an interaction between feedback and rewards. False alarms, although not statistically significant, differed between the four groups. The average false alarm rate was 1.05 for the KOR group, .84 for the control group, .72 for the reward group and .25 for the KOR with reward group. One question that remains unanswered is whether or not feedback will interact with environmental manipulation other than the presence of rewards, such as artificial signals.

Hypothesis 4: An interaction between feedback and artificial signal type is expected. Based on previous research (e.g., Darr, 1999), feedback is expected to improve true signal hits and the decrement coefficient when identical artificial signals are present and disrupt true signal hits and the decrement coefficient when distinct artificial signals are present.

Present Study

Feedback has been shown, in some instances, to be an effective countermeasure for the vigilance decrement. Sipowicz et al. (1962) also believed that feedback, in conjunction with a reward for maintaining a predetermined level of performance, is an effective method of reducing between-subject variance. One difficulty faced with providing feedback on performance at a vigilance task is that, in applied settings, the true signal rate is rarely known. An example would be a security guard monitoring video displays. Signals may occur several times in one shift or not at all. Did the guard properly identify all of the signals that occurred? How many signals were missed? How severe were the consequences of missing a signal? Providing accurate feedback to the observer with respect to signal occurrence in an applied situation requires knowledge of signal rates and temporal location. Were this knowledge available, there would be no need to monitor.

One method for providing a more accurate level of feedback in an applied setting is by introducing artificial signals to the vigilance task. Artificial signals would increase the number of responses an observer would be required to make. In effect, this would increase the signal rate, which has already been shown to improve detection performance and reduce between-subject variance (e.g., Baker, 1960; Wilkinson, 1964; Baddeley & Colquhoun, 1969; Methot & Huitema, 1998). In addition, the supervisor would have control over the timing and placement of these artificial signals, which would make the task of integrating this form of intervention into the work setting quite easy. Prior knowledge of the artificial signal schedule would also allow a supervisor to provide accurate feedback to the observers.

Baker (1960) suggested that artificial signals should be identical to the true signals. When artificial signals are identical to true signals, their introduction is perceived as an increased signal rate. While artificial signals are, for the observer, perceptually indistinguishable from true signals, they are placed in predetermined time and/or space by the experimenter. This allows a real-world simulation of feedback associated with the identical artificial signals.

An example of a real-world situation where identical artificial signals could be used is in the manufacture of aircraft parts. Machined parts for aircrafts are examined for flaws before being sent for assembly. The inspector is required to manipulate each item in order to examine all of its surfaces for defects. A supervisor could have a supply of known defective parts on hand to use as artificial signals. At predetermined times, these defective parts can be inserted into the production line. After the parts have gone past the inspector, any artificial signals the inspector did not identify can be removed from the production line for future use. The supervisor can then provide the inspector with feedback on the number of artificial signals correctly identified.

Using identical artificial signals to increase the observer's response rate is not always feasible. For example, in an automotive assembly line, deliberately misaligning the frame and body of a car on the assembly line would be very costly for the organisation if production needed to be halted in order to remove the artificial signal. If a distinctly different artificial signal could be used to effectively maintain observing behaviours in situations like this, integration of a performance improvement program based upon artificial signals would be much easier and cost effective.

Can a distinctly different artificial signal improve the performance of individuals who are required to observe complex stimuli (e.g., assembly line, security monitor)? If the artificial signals were to be presented at or near the physical location(s) that an individual is required to observe, could the detection of these improve that individual's ability to detect true signals when they occur without increasing his or her false alarm rate? The present study examined the effects of artificial signals on the performance of monitors who were observing a complex visual display.

Detection performance (hits and false alarms) on a vigilance task with artificial signals, which are identical to the true signal, were compared to artificial signals that were distinctly different from the true signal. In addition, the effect of these two types of artificial signals when combined with immediate, machine-generated feedback was evaluated. Based upon the preceding review of the literature, the following hypotheses were tested.

Hypothesis 1

Detection performance on a vigilance task will be improved when artificial signals are added to the task.

Hypothesis 2

Identical artificial signals will increase detection performance to a greater degree than distinct artificial signals.

Hypothesis 3

Feedback will increase the positive effects of both the identical and distinct artificial signals.

Hypothesis 4

Feedback is expected to improve true signal hits and the decrement coefficient when identical artificial signals are present and disrupt true signal hits and the decrement coefficient when distinct artificial signals are present.

Method

With the inclusion of a control group, the research design was an incompletely crossed 2X3 mixed factorial (see Figure 4). The random independent variable was the type of artificial signal (identical or distinct) and the fixed independent variable was the presence or absence of feedback. The following dependent variables were used to describe detection performance on the vigilance task: (a) the within-condition mean for true signal hits, (b) the within-condition variance for true signal hits, (c) the performance decrement coefficient mean for true signal hits, (d) the performance decrement coefficient variance for true signal hits, (e) the pooled within-subject residual variance for true signal hits, (f) the within-condition mean for false alarms, and (g) the within-condition variance for false alarms. An effective intervention would change the preceding performance measures in the direction indicated in Figure 5.

In order to determine the level of similarity between observer detection performance for true and artificial signals, correlations were calculated for mean signal hits, the performance decrement coefficient means and the MS residuals for true and artificial signals. In addition, a Signal Detection Theory analysis of

Figure 4. Depiction of the research design.

		Feedback (α)	
		Present (α_1)	Absent (α_2)
Artificial Signal (b)	None (b_1)		Control
	Identical (b_2)	Group IF	Group IN
	Distinct (b_3)	Group DF	Group DN

Note: Subsequent Tables and Figures make use of the above group designations.

Figure 5. Desired direction of change for performance measures.

	Mean True Signal Hits	True Signal Hit Variance	True Signal Hit Decrement Coefficient	Decrement Coefficient Variance	Unexplained Variance (MS Residual)	Mean False Alarms	False Alarm Variance
Desired Direction of Change	+	-	+	-	-	-	-

the detection performance data was carried out in order to compare the task difficulty and the response criterion of observers within each group

Participants

Eighty-two students registered at Saint Mary's University were recruited by placing sign-up sheets in the Psychology department as well as placing an advertisement in the university student newspaper. All participants had normal or corrected to normal vision.

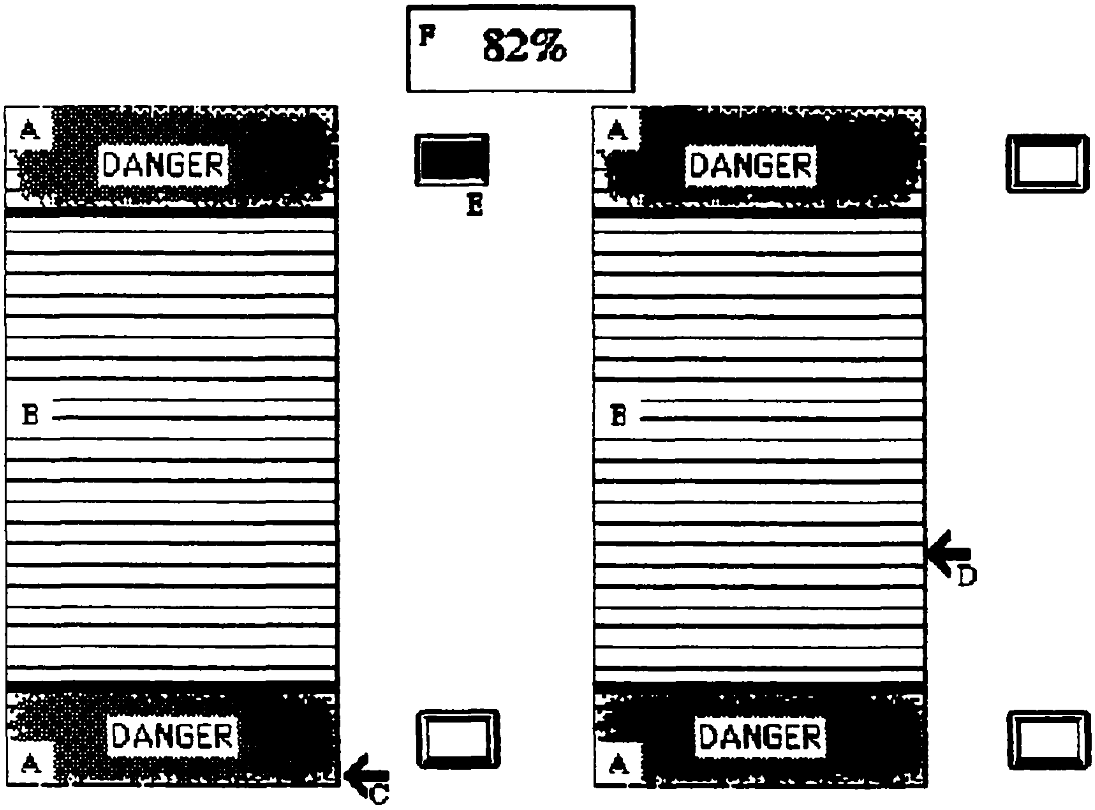
Materials

The monitoring task was similar to the one used in Methot and Huitema's (1998) study. The computer monitor displayed two vertical rectangular gauges. Each gauge had two "danger zones" and one neutral area (see Figure 6). Participants were required to press the space bar on the keyboard whenever an arrow appeared beside any of the four danger zones. Responses within 1.5 seconds of the appearance of a target or artificial signal were recorded as a hit. Any depressions of the space bar without a signal appearance or after the 1.5 seconds had elapsed were recorded as a false alarm. The program monitored and recorded the subject's hits and false alarms for later analysis.

Artificial Signals

The true signal rate for all experimental groups was 2%. The identical and distinct artificial signal rates were 8%. Perceptually, the identical artificial signals group experienced a signal rate of 10%. The distinct artificial signals were the following event: a white rectangle was located to the side of each danger zone

Figure 6. Depiction of the monitor display for the vigilance task.



Legend: A = target stimulus zones (4 possible arrow positions per zone, 4 zones)
B = noise zones (16 possible arrow positions per zone, 2 zones)
C = target stimulus event (or "identical" artificial signal event)
D = noise event
E = visually distinct second stimulus event (artificial signal-different)
F = feedback field showing percentage of correct artificial signal responses

(see Figure 6). The artificial signal was a brief change of a rectangle from white to black and back to white. Subjects were required to respond by pressing the space bar when a signal (i.e., arrow in the danger zone) or an artificial signal occurred.

Feedback

For the two groups who received feedback, immediate, machine-generated feedback was provided to the subjects throughout the experimental session. This was displayed on the computer screen above the meters (see Figure 6). The percent of correct responses (hits) to the artificial signals were indicated here. For the distinct artificial signal group, the subjects perceived this feedback to be a FR 1 schedule. For the identical artificial signals, subjects perceived the feedback to be updated randomly (i.e., a VR schedule).

Procedure

The 82 subjects were randomly assigned to five conditions (Control; Identical Artificial Signals With Feedback; Identical Artificial Signals Without Feedback; Distinct Artificial Signals With Feedback; Distinct Artificial Signals Without Feedback). Upon arrival, subjects were provided with an informed consent form describing the general nature of the task. Subjects were asked to surrender their watches and were directed to the testing room where they were shown the computer set-up and instructed to follow prompts on the computer to receive a brief tutorial on the monitoring task before beginning the vigil (see Appendix E). Definitions for distinguishing signal from noise stimuli and instructions for using the keyboard to make detection responses were presented during a self-paced training session, which required approximately five minutes to complete. Once the training session was completed, the subjects were able to start their experimental sessions by pressing the "A" key on the keyboard or review the instructions again by pressing the "L" key. The mouse and all but the space bar key were inoperative during the experimental sessions.

Each session was divided into 12 continuous 10-minute watch periods. Subjects were exposed to approximately 5,000 stimulus changes (including signals and noise) per session (i.e., approximately 420 stimulus changes per 10-minute block). When the session was completed, a message flashed on the screen informing the subjects that the task was finished. The subjects were then asked to initial a form confirming payment for the study and were paid fifteen dollars.

Results

For all statistical tests, $\alpha = .05$ unless otherwise noted. Due to computer error, data from seven subjects were not recorded. The following analysis is based on the data recorded from seventy-five subjects (15 per group). For each individual, true signal hits, false alarms and artificial signal hits (where applicable) for each 10-minute time block were recorded. The following analysis refers to the summary data in Table 1. Individual performance scores are presented in Appendix F.

Table 1

Summary of Performance Data

	True Signal Hits					False Alarms	
	Within-Condition Mean	Within-Condition Variance	Performance Decrement Coefficient Mean	Performance Decrement Coefficient Variance	Pooled Within-Subject Residual Variance	Within-Condition Mean	Within-Condition Variance
Group C	82.51	324.21	-0.58	1.55	248.67	0.36	0.15
Group IF	92.33	48.30	0.48	1.67	142.31	3.27	39.85
Group IN	89.73	85.76	-0.71	1.54	125.59	1.05	2.30
Group DF	77.57	356.52	-1.25	3.76	254.00	2.79	14.26
Group DN	83.21	192.49	-0.34	1.03	187.33	0.81	0.77

Grouped Data Collapsed Across All 12 Periods

Within-group means and variances for true signal hits and false alarms were calculated by averaging the individual scores collapsed across the 12 time periods. As seen in Figure 7, the presence of identical artificial signals with feedback, identical artificial signals without feedback and distinct artificial signals without feedback increased the mean detection rate. The distinct artificial signal with feedback group was the only group whose mean true signal hits did not change in the desired direction as noted in Figure 5.

Using the effect coding shown in Table 2 and multiple regression, the amount of variance accounted for by the two independent variables and the interaction term were determined (see Table 3). These values were used to develop the source tables in Table 4. A significant main effect due to identical artificial signals was found for true signal hits ($F_{1,69} = 6.273$, $p < .025$) while the presence of distinct artificial signals appeared to have a negligible effect on true signal hits ($F_{1,69} = 2.859$, $p > .05$). The standard deviations for the identical artificial signal groups were much smaller than the control and distinct artificial signal groups. Compared to the control group, the presence of identical artificial signals reduced the within-condition variance for true signal hits by 85.1%.

Figure 8 displays the mean false alarms for each group. The changes observed in false alarms were opposite to the desired direction of change indicated in Figure 5. All experimental groups had a mean false alarm rate that was greater than the control group. This increase in false alarms was greatest

Figure 7. Mean true signal hits.

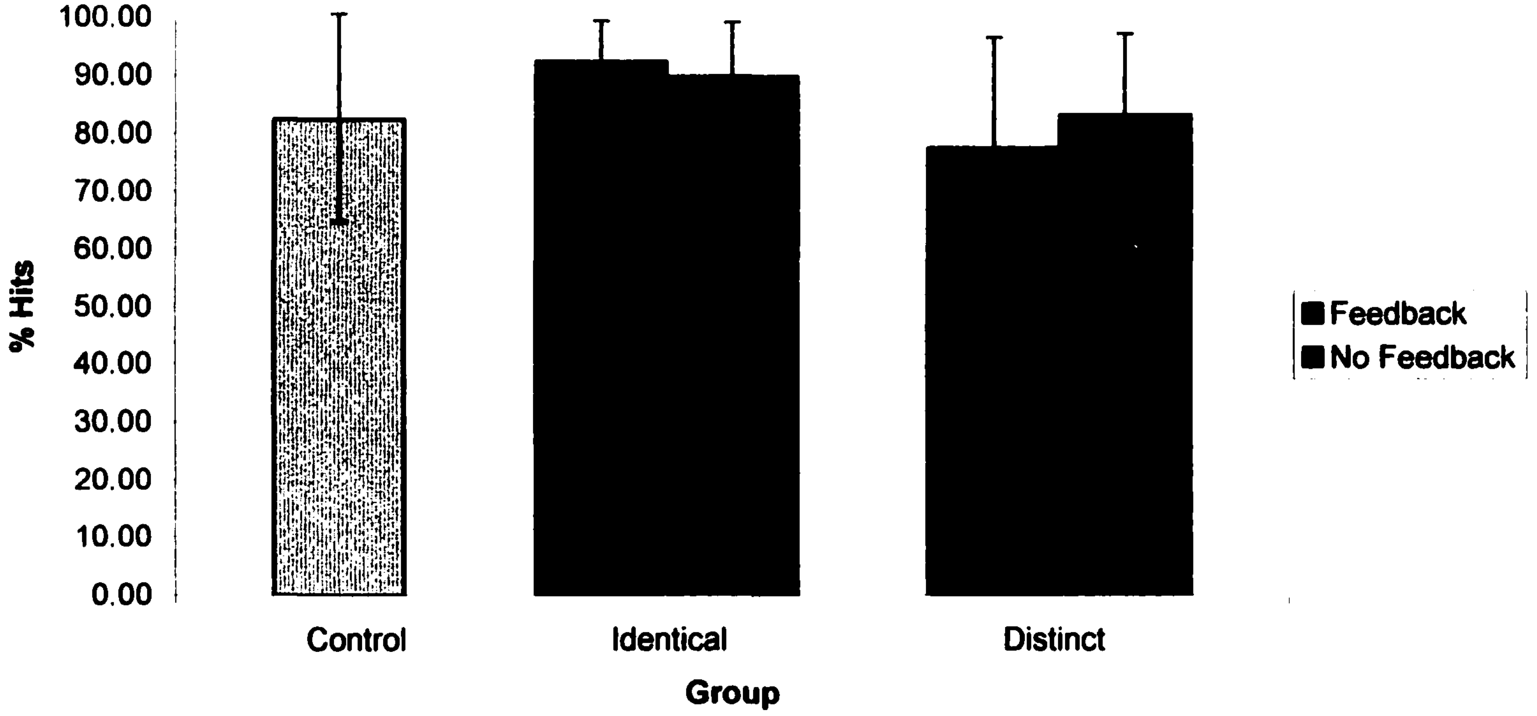


Table 2

Effect Coding for Multiple Regression

Cell	A_1	B_1	B_2	AB_{11}	AB_{12}	Group
a_1b_1	1	1	0	1	0	IF
a_1b_2	1	0	1	0	1	DF
a_1b_3	1	-1	-1	-1	-1	
a_2b_1	-1	1	0	-1	0	IN
a_2b_2	-1	0	1	0	-1	DN
a_2b_3	-1	-1	-1	1	1	C

A_1 = Feedback Present
B_1 = Identical Artificial Signals
B_2 = Distinct Artificial Signals
AB_{11} = Feedback Present * Identical Artificial Signals
AB_{12} = Feedback Present * Distinct Artificial Signals

Table 3

Partial Correlations and SS_{tot}

	R^2	Variance Accounted for by Feedback	Variance Accounted for by Identical Artificial Signals	Variance Accounted for by Distinct Artificial Signals	Variance Accounted for by Feedback X Artificial Signal Interaction	SS_{tot}
True Signal Hits	.131	.000	.079	.036	.016	16212.274
False Alarms	.111	.105	.006	.000	.000	902.502
True Signal Hit Beta	.150	.003	.020	.023	.104	157.304
True Signal Hit MS Residual	.039	.000	.036	.001	.002	5373290.300

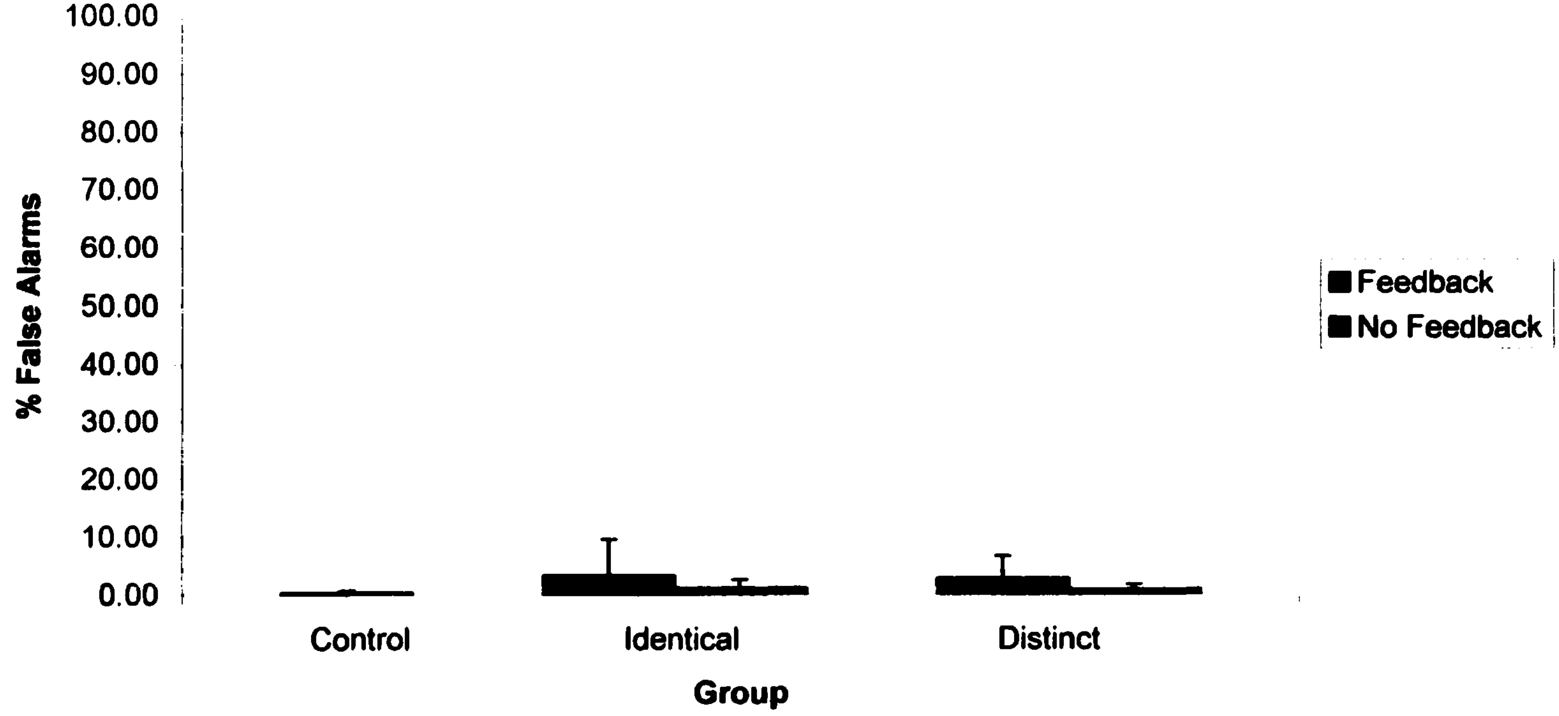
Table 4

Source Tables for True Signal Hits and False Alarms

Measure	Source	SS	df	MS	F	p	ω^2
True Signal Hits	Feedback	0.000	1	0.000	0.000	n.s.	0.000
	Identical Artificial Signals	1280.770	1	1280.770	6.273	< 2.5%	0.066
	Distinct Artificial Signals	583.642	1	583.642	2.859	n.s.	0.023
	Feedback X Artificial Signals	259.396	2	129.698	0.635	n.s.	0.000
	Residual	14088.466	69	204.181			
	Total	16212.274	74				
False Alarms[1]	Feedback	94.763	1	94.763	8.150	< 1%	0.091
	Identical Artificial Signals	5.415	1	5.415	0.466	n.s.	0.000
	Distinct Artificial Signals	0.000	1	0.000	0.000	n.s.	0.000
	Residual	802.324	71	11.628			
	Total	902.502	74				

[1] Since 0% of the variance was accounted for by the interaction (See Table 3), the interaction and residual terms were combined.

Figure 8. Mean false alarms.



when feedback was introduced.

A significant main effect due to feedback was found for false alarms ($F_{1,71} = 8.150$, $p < .01$). Compared to the artificial signal groups without feedback, feedback for identical artificial signals increased false alarms from 1.05% to3.27% and feedback for distinct artificial signals increased the false alarm rate from 0.81% to 2.79%. Within-group variance for false alarms also increased when feedback was provided. Feedback for identical artificial signals increased the variance from 2.30 to 39.85, while feedback for distinct artificial signals increased the variance from 0.77 to 14.26.

<u>Individual Subject Performance Decrements</u>

Following Methot and Huitema's (1998) analysis, average changes in true signal hits and artificial signals hits (where applicable) were estimated for each subject by regressing $Y_{i,t}$ on the 12 time blocks of the experiment using ordinary least squares. The individual linear regressions for true signal hits are shown in Figure 9 and the group linear regressions are in Figure 10.

<u>Group Performance Decrement Data</u>

Using the effect coding and multiple regression outlined in Tables 2 and 3, the source tables in Table 5 were derived for the true signal hit coefficient decrement and MS residual comparisons. A significant interaction was found in the decrement coefficient for true signal hits ($F_{2,69} = 4.221$, $p < .025$). The presence of identical artificial signals with feedback produced a positive slope to

Figure 9. Individual regressions for true signal hits.

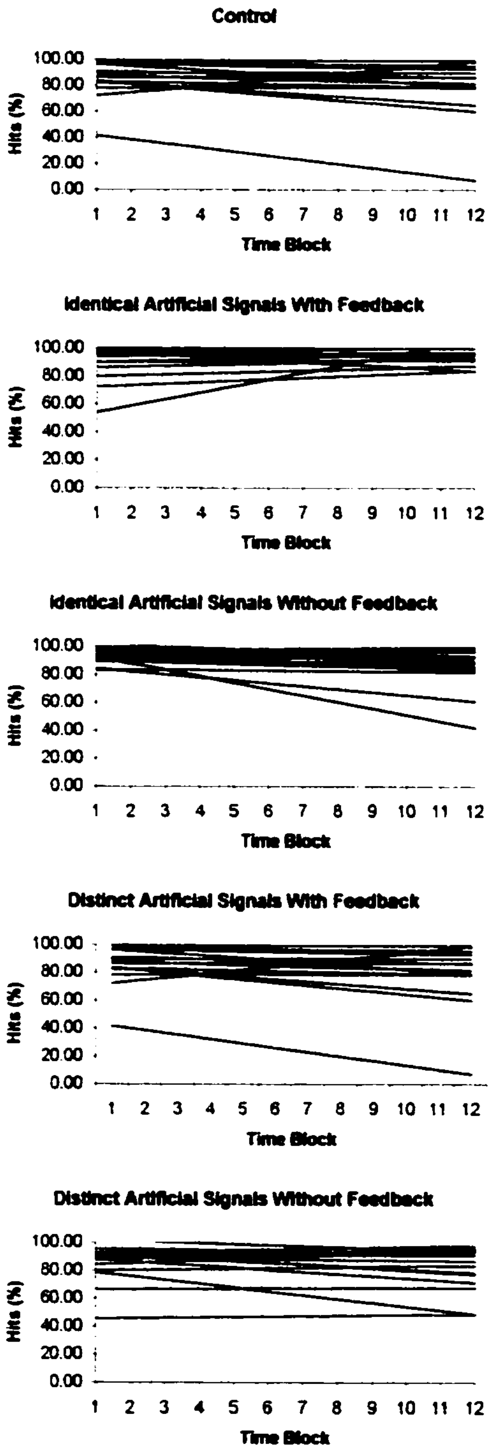


Figure 10. Group regressions for true signal hits.

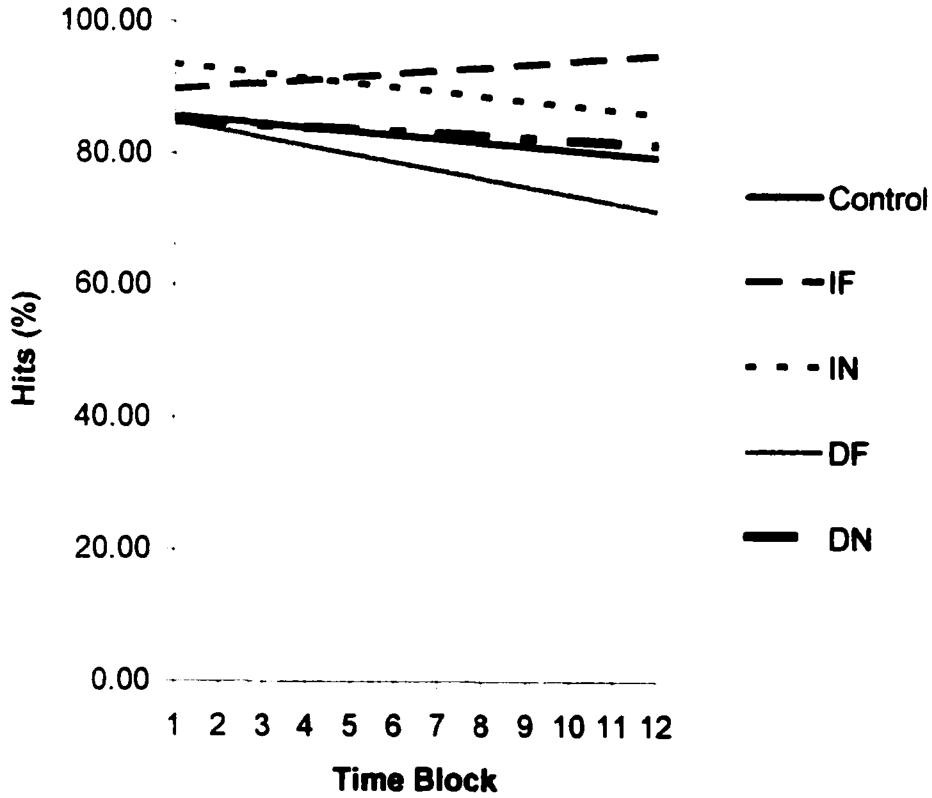


Table 5

Source Tables for True Signal Hit Decrement Coefficient and True Signal Hit MS Residual

Measure	Source	SS	df	MS	F	p	ω^2
True Signal Hit Decrement Coefficient	Feedback	0.472	1	0.472	0.058	n.s.	0.000
	Identical Artificial Signals	3.146	1	3.146	1.623	n.s.	0.008
	Distinct Artificial Signals	3.618	1	3.618	1.867	n.s.	0.011
	Feedback X Artificial Signals	16.360	2	8.180	4.221	<2.5%	0.078
	Residual	133.708	69	1.938			
	Total	157.304	74				
True Signal Hit MS Residual	Feedback	0.000	1	0.000	0.000	n.s.	0.000
	Identical Artificial Signals	193438.451	1	193438.451	2.585	n.s.	0.022
	Distinct Artificial Signals	5373.290	1	5373.290	0.072	n.s.	0.000
	Feedback X Artificial Signals	10746.581	2	5373.291	0.000	n.s.	0.000
	Residual	5163731.978	69	74836.695			
	Total	5373290.300	74				

the regression equation (0.48). As can be seen in Figure 11, this was the only experimental condition that had a positive slope for the decrement coefficient. The remaining decrement coefficients ranged from -1.25 to –0.34. The within-group coefficient variance was lowest for the distinct artificial signals without feedback group (1.03), equivalent for the identical artificial signals without feedback and control groups (1.54 and 1.55 respectively), slightly higher for the identical artificial signal with feedback group (1.67) and highest for the distinct artificial signal with feedback group (3.76).

<u>Pooled Within-Subject Residual Variance</u>

The error term (MS residual) in the decrement equations provided an estimate of the variance in detection performance that was unpredictable from the regression equation. Comparison of the within-group pooled MS residual terms provides a means for identifying the treatment condition for which individual performance is relatively more or less predictable. The means MS residual values displayed in Figure 12 indicate that the identical artificial signal groups had the least amount of unexplained variance. The average MS residual scores, in increasing order, were 125.59 for the identical artificial signal without feedback group, 142.31 for the identical artificial signal with feedback group, 187.33 for the distinct artificial signal without feedback group, 248.67 for the control group and 254.00 for the distinct artificial signal with feedback group.

Figure 11. Mean decrement coefficients for true signal hits.

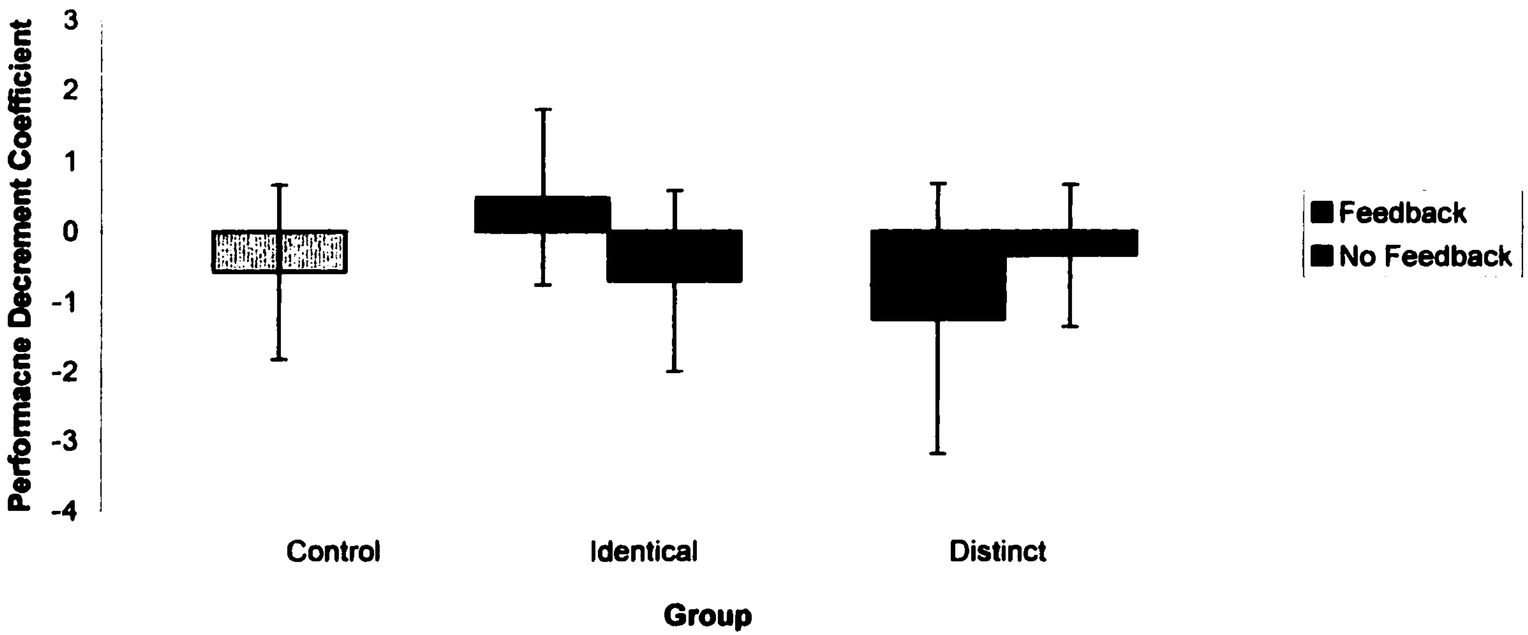
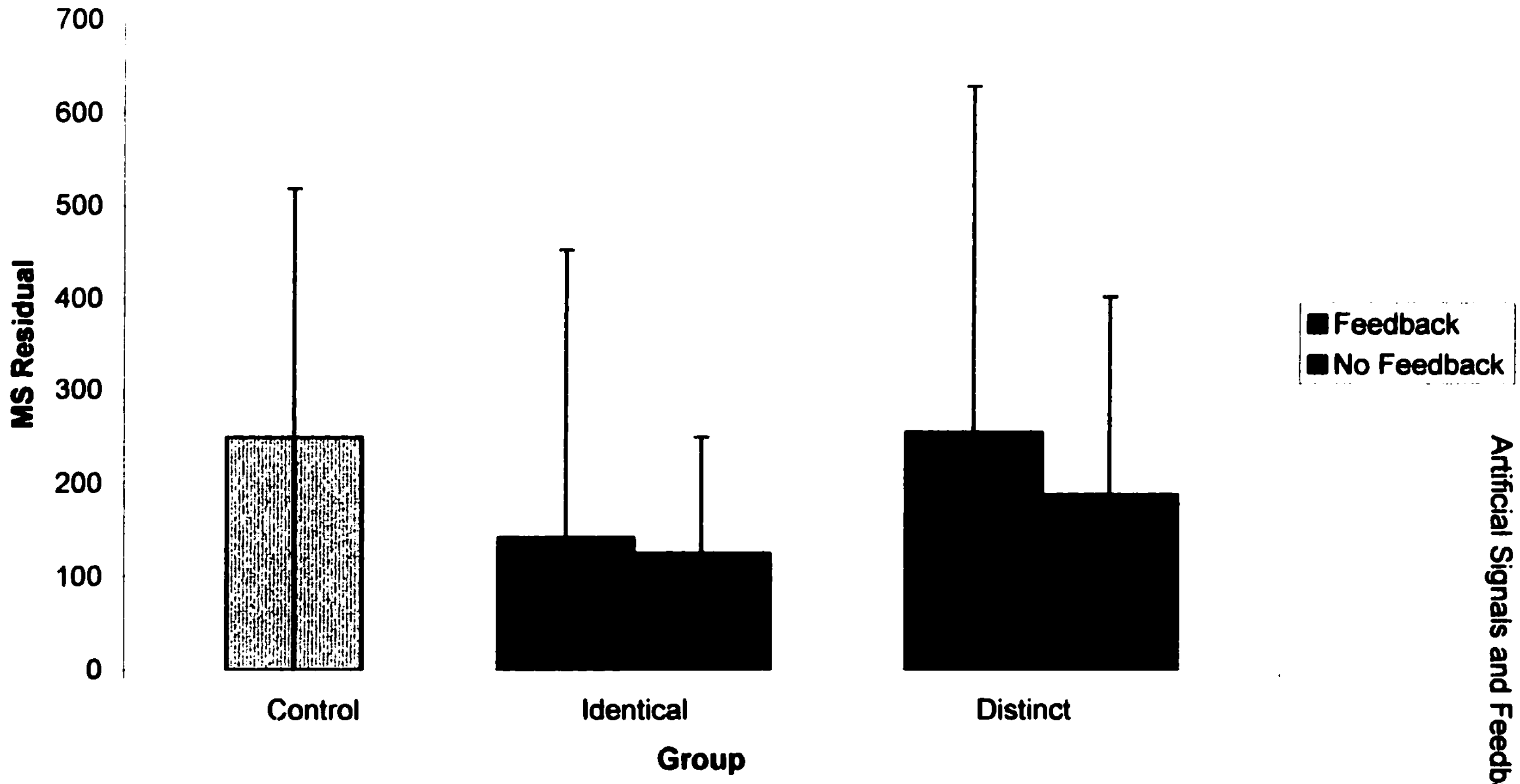


Figure 12. Mean MS residuals for true signal hits.



Summary of Detection Performance Measures

The preceding analysis examined seven aspects of vigilance performance, namely: within-group mean true signal hits, within-group true signal hit variance, within-group mean true signal hit decrement, within-group variance for true signal hit decrement, pooled within-subject residual variance for true signal hit decrement, within-group mean false alarms and within-group false alarm variance. A successful intervention would have affected these performance measures in the manner indicated in Table 6, which also compares the experimental groups' changes in detection performance with respect to the control group. Although significant performance changes were observed, none of the conditions in the present study exhibited all of the desired changes.

Comparison of Detection Performance Between True and Artificial Signals

In order to examine the relationship between the detection performance for true and artificial signal hits, correlations were calculated for hits, decrement coefficients (δ_i) and MS residuals. These correlations are presented in Table 7. True signal hits were significantly correlated with identical artificial signal hits, both with ($r = 0.668$, $p < .01$) and without feedback ($r = 0.991$, $p < .01$). Significant correlations for the decrement coefficients (δ_i) were found for the average change in hits for identical artificial signals with feedback ($r = 0.915$, $p < .01$), identical artificial signals without feedback ($r = 0.832$, $p < .01$) and distinct artificial signals with feedback ($r = 0.870$, $p < .01$). True signal hit performance

Table 6

Change in Detection Performance Relative to Control Group C

	Mean True Signal Hits	True Signal Hit Variance	True Signal Hit Decrement Coefficient	Decrement Coefficient Variance	Unexplained Variance (MS Residual)	Mean False Alarms	False Alarm Variance
Group C	82.51%	324.21	-0.58	1.55	248.67	0.36%	0.15
Group IF	+ 9.82%*	- 275.91	+ 1.06*	+ 0.12	- 106.36	+ 2.91%*	+ 39.70
Group IN	+ 7.22%*	- 238.45	- 0.13	- 0.01	- 123.08	+ 0.69%	+ 2.15
Group DF	- 4.94%	+ 32.31	- 0.67	+ 2.21	+ 5.33	+ 2.43%*	+ 14.11
Group DN	+ 0.70%	- 131.72	+ 0.24	- 0.52	- 61.34	+ 0.45%	+ 0.62
Desired Direction of Change	+	-	+	-	-	-	-

* = Significant difference

Table 7

Correlations Between True and Artificial Signals

	Performance Measure		
	Signal Hits	Performance Decrement Coefficient Mean	MS Residual
Group IF	0.668**	0.915**	0.981**
Group IN	0.911**	0.832**	0.777**
Group DF	0.169	0.870**	0.930**
Group DN	0.413	0.321	0.770**

** = significance at the .01 level (2-tailed) variance unaccounted for by the decrement equation (MS residual), was significantly correlated with the MS residual for identical artificial signal hits with feedback ($r = 0.981$, $p < .01$), identical artificial signal hits without feedback ($r = 0.777$, $p < .01$), distinct artificial signal hits with feedback ($r = 0.930$, $p < .01$) and with distinct artificial signal hits without feedback ($r = 0.770$, $p < .01$).

Signal Detection Theory Analysis

d' and β were found for each subject using Freeman's (1964) interpolation tables. The means and standard distributions of the measures for each group are summarised in Table 8. Analysis of the performance data using the Signal Detection Theory (SDT) framework was only conducted between groups due to the fact that individual values of d' and β were not consistently available. During the two-hour task, subjects often had perfect or close-to-perfect scores within individual time blocks (see Appendix F). According to SDT, when a subject correctly identified 100% of the true signals within a single time block the distribution of noise and signals plus noise did not overlap at all. When this lack of overlap occurs, calculation of d' and β is not possible. As a result, only the average d' and β values for the entire session could be calculated for 74 subjects.

As seen in Figure 13, d' was fairly consistent across groups, indicating that the difficulty of the task was equal across conditions. β was not as consistent across groups. As Figure 14 shows, all of the experimental conditions

Table 8

Group Values of *d′* and *β*

	d′		*β*	
Group	Mean	S.D.	Mean	S.D.
Control	3.98	0.96	34.11	31.39
IF	3.74	0.88	5.50	5.40
IN	3.92	0.87	9.68	5.14
DF	3.20	0.96	9.99	7.82
DN	3.65	0.86	15.79	8.72

Figure 13. Mean sensitivity decrement.

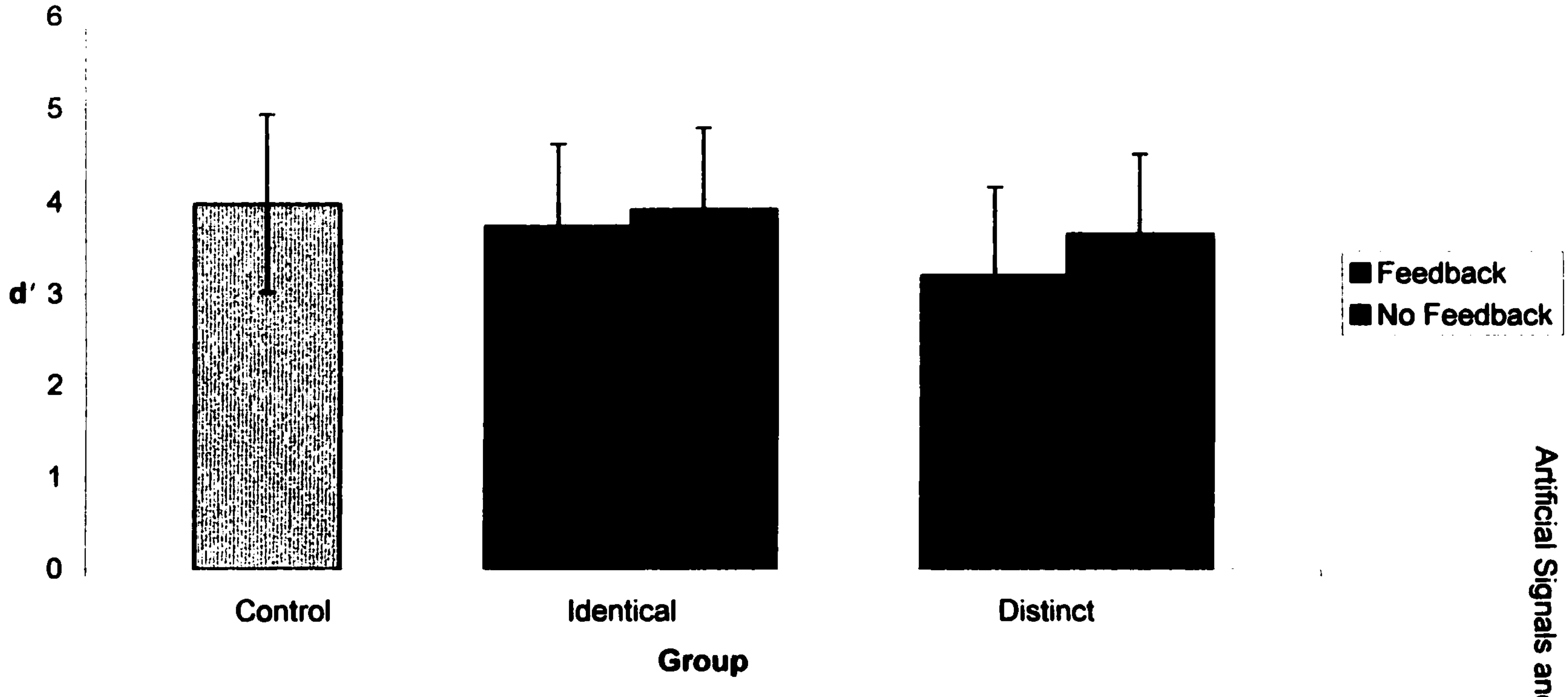
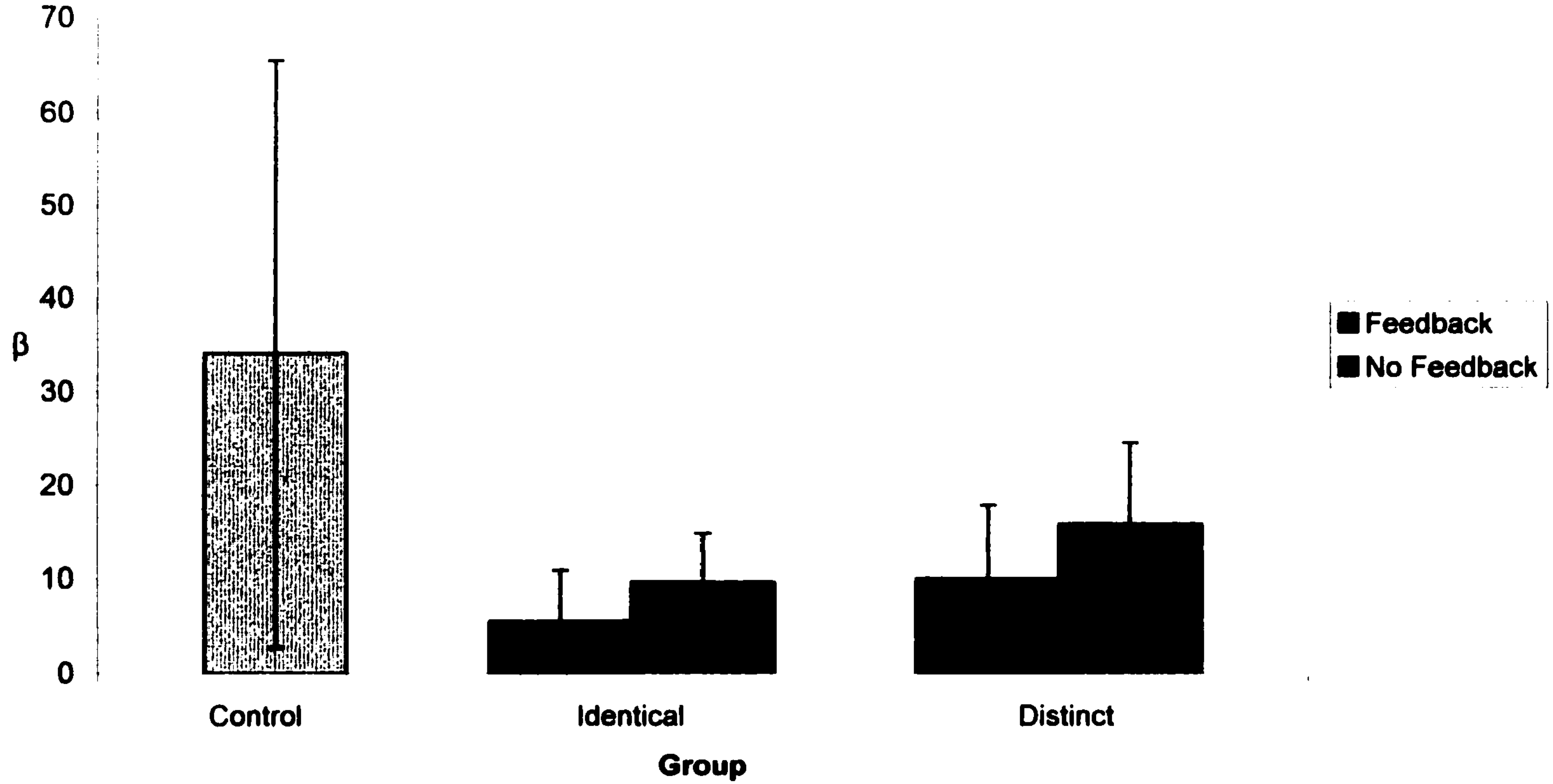


Figure 14. Mean response criterion.



displayed a response criterion that was considerably less conservative than the control group. The Identical Artificial Signals With Feedback group had the least conservative and the Distinct Artificial Signals Without Feedback group had the most conservative response criterion.

The mean values of *d′* and *β* for each group were compared using a one-way ANOVA (see Table 9). No significant differences were found for *d′* ($F_{4,69}$ = 1.717, p = 0.16). A significant between-group difference was found for *β*, indicating differences in response criterion across conditions ($F_{4,69}$ = 7.913, p = 0.00). In addition, the standard deviations for all of the experimental conditions were much smaller than the control group, indicating less within-group variance. Using α_{PC} = .01, a Scheffé Post Hoc analysis indicated that the decision criterion (*β*) for the identical artificial signals with feedback, identical artificial signals without feedback and distinct artificial signals without feedback groups were significantly different from the control group (p = .000, .002 and .002 respectively). According to the Scheffé test, all three of these conditions were grouped into one homogeneous subset.

Discussion

The present study tested the following hypotheses:

Table 9

Source Tables for Signal Detection Theory Analysis

Measure	Source	SS	df	MS	F	p	ω^2
d'	Between Groups	5.684	4	1.421	1.717	0.156	0.141
	Within Groups	57.101	69	0.828			
	Total	62.785	73				
β	Between Groups	7550.466	4	1887.616	7.913	0.000	0.351
	Within Groups	16459.690	69	238.546			
	Total	24010.156	73				

Hypothesis 1

Detection performance on a vigilance task will be improved when artificial signals are added to the task.

Hypothesis 2

Identical artificial signals will increase detection performance to a greater degree than distinct artificial signals.

Hypothesis 3

Feedback will increase the positive effects of both the identical and distinct artificial signals.

Hypothesis 4

Feedback is expected to improve true signal hits and the decrement coefficient when identical artificial signals are present and disrupt true signal hits and the decrement coefficient when distinct artificial signals are present.

Based upon the experimental results, Hypothesis two was supported and Hypothesis four was partially supported. Hypotheses one and two proposed that detection performance would increase when artificial signals were present and this increase in performance would be the greatest when identical artificial signals were used. The failure of the distinct artificial signals to change detection performance for true signals to the same degree as the identical artificial signals appears to be due to the differences in the stimulus characteristics of the artificial signals. Even though the only statistically significant difference in the detection measures was for true signal hits when identical artificial signals were present, the presence of both identical and distinct artificial signals reduced the variance associated with several detection performance measures.

Compared to the values obtained from the control group, the presence of both identical and distinct artificial signals reduced the variance associated with true signal hits and the decrement coefficient. Identical artificial signals reduced the true signal hit variance to a greater degree (238.45) than distinct artificial signals (131.72). Conversely, distinct artificial signals reduced the decrement coefficient variance to a greater degree (0.52) than identical artificial signals (0.01). In addition, based upon the MS residuals, the presence of identical and distinct artificial signals reduced the amount of variance that was unaccounted for by the performance decrement regression equation (123.08 and 61.34, respectively). The only increased variance due to artificial signals was for false alarms, which increased 2.15 and 0.62 for the identical and distinct artificial signal groups, respectively.

Compared to the control group, the observers in the identical artificial signals without feedback group were perceptually monitoring a display with a 10% signal rate. The detection performance of this group is similar to Baddeley and Colquhoun' s (1969) study, where an increased signal rate increased the hit and false alarm rates, reduced β and did not change d'. Contrary to Baddeley and Colquhoun's results, the artificial signal without feedback group's decrement coefficient was steeper than the control group by 0.13.

The same effect was not found in the distinct artificial signals without feedback group. Although the overall response rate was still 10%, the observers could perceive a difference between the true and artificial signals. As Baddeley and Colquhoun (1969) suggested, it is the signal rate and not the response rate that appears to be the critical factor. The relative difference in signal rates between the true and artificial signals may have been perceived as two distinct tasks by the observers. As Table 7 indicated, only the MS residual values were significantly correlated between true and artificial signal hits for this group. As the true signal hit regression equations for these two groups appear to be similar (see Figure 10), the observers may have been treating the two signals as separate tasks.

Hypothesis three stated that the presence of feedback would increase the positive effects of both identical and artificial signals. The results of the present study did not support this. The only significant change in detection performance due to the presence of feedback was an increase in the false alarm rate. Although this result is contrary to Hypothesis three, it is consistent with Murrell's (1975) study; performance feedback, without being tied to rewards, increased the false alarm rate. This consistency shows that Murrell's complex response requirements were not responsible for the observed increase in false alarms.

Since the feedback provided to the observers did not reflect the number of false alarms (feedback = # artificial signals detected / # artificial signals presented), it is difficult to attribute the increased false alarms solely to the presence of feedback. Many of the recorded false alarms could have been delayed responses to a signal outside of the allotted 1.5 seconds. If the time in which a response could be made was increased, the false alarms may more closely resemble the values for the control group. An axiom of performance management is "what gets measured gets done." If feedback were also provided for the amount of false alarms, it is possible that the additional information may have helped to ensure that the observers' false alarm rate remained low.

The presence of feedback did change many of the performance measures. When compared to identical artificial signals without feedback, identical artificial signals with feedback increased the mean true signal hits by 2.60%. True signal hit variance dropped by 37.46, the decrement coefficient variance increased 0.13 and the unexplained variance from the decrement regression equation was greater by 16.72. Feedback for distinct artificial signals resulted in a change in all detection performance measures that were worse than those for distinct artificial signals without feedback (see Table 6). Between these two groups, the greatest measured change was found in the decrement coefficient variance, which was 2.73 greater when feedback was present.

As Figure 14 shows, β for both identical and distinct artificial signals decreased when feedback was present. According to the Scheffé post hoc test, the change in β for identical artificial signals was not significantly different from the identical artificial signals without feedback group, while the change for the distinct artificial signals with feedback group was significantly different from the control and distinct artificial signals without feedback groups. As the drop in β would suggest, false alarms for the two feedback groups increased.

Hypothesis four stated that an interaction effect on correct signal detections would occur between feedback and artificial signals. More specifically, feedback was expected to improve true signal hits and the decrement coefficient when identical artificial signals were present and disrupt true signal hits and the decrement coefficient when distinct artificial signals were present. The one significant interaction in the performance data was for the "decrement" coefficient. A positive coefficient was found for identical artificial signals with feedback. Effectively, the vigilance decrement was not present for this group; as time on task continued, detection performance improved. Since true and artificial signal detection performance was highly correlated in the artificial signals without feedback group, the addition of the feedback on the artificial signals appears to have aided in the detection of true signals, resulting in an attenuated vigilance decrement.

The feedback provided for the distinct artificial signals appears to have increased the perceived differences between true and artificial signals. Observers were provided with information only on their detection of artificial signals. As previously noted, the presence of distinct artificial signals did not appreciably change the true signal hit decrement coefficient. Feedback on distinct artificial signal detection apparently increased this distinction, thereby negating any positive effects the distinct artificial signals may have provided. The true signal hit decrement coefficient for the distinct artificial signals without feedback group appears to support this. As more attention was given to the detection of distinct artificial signals, fewer true signals were detected. These results are different from Wilkinson's (1964) study, which found an improvement in detection performance when either identical or distinct artificial signals were used.

Future Research

The degree to which an artificial signal has to resemble the true signal in applied settings is still unknown. The distinct artificial signal used in the present study was only varied with respect to its shape and location. There are many characteristics along which the signal could be varied (see Figure 15). In addition, results from two-dimensional tasks such as that used in the present study may not accurately predict performance on three-dimensional tasks, such as examining an automobile frame for proper alignment. It may be that physically distinct stimuli located at critical observation points would be an effective intervention in some real-world situations.

The many ways in which an artificial signal can be manipulated could increase the number of situations in which artificial signals could be used. For example, if the psychophysical characteristics of the artificial signal cannot be

Figure 15. Characteristics of visual artificial signals.

I	**Modality**			
	Same as True Signal		Different	
II	**Psychophysical Characteristics**			
	Colour	Brightness	Shape	Size
III	**Physical Location (only if artificial and true signal modalities are both visual)**			
	On Critical Points		Off Critical Points	
IV	**Type of Response**			
	Fixed Time Interval		Unlimited Hold	
V	**Frequency of Artificial Signal Presentation**			
VI	**Feedback (Prue & Fairbank, 1981)**			
VII	**Rewards (Balcazar, Hopkins and Suarez, 1986)**			
VIII	**Cueing (Wiener & Attwood, 1968)**			
	Present		Absent	

changed, then the physical location of the artificial signal, the type of feedback or the type of reward associated with the artificial signal can still be manipulated. As Prue and Fairbank (1981) noted, the flexibility of feedback is one of the main reasons that feedback is one of the most widely used methods of maintaining and increasing performance. Vigilance situations that employ artificial signals and feedback likewise have a great degree of flexibility when determining how to incorporate the intervention into the worksite.

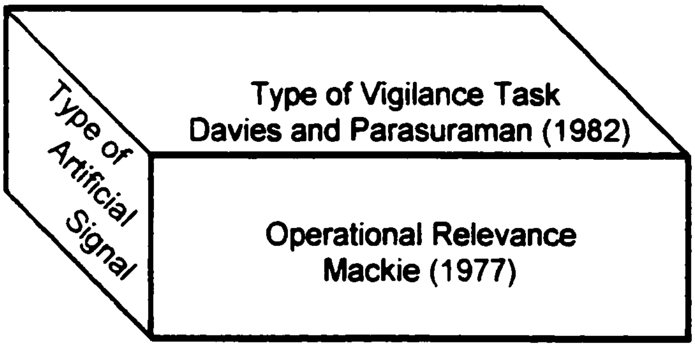
As noted previously, the increase in false alarms cannot be directly attributed to the presence of feedback. Many factors in the study could have accounted for the observed change in false alarms. For example, the instructions provided to the subjects were quite neutral. In an applied situation, observers would be aware of the costs associated with a high false alarm rate and would adjust their decision criterion accordingly. Also, not all vigilance tasks require as immediate response as the present study. Many tasks would give an observer more than 1.5 seconds to respond to a signal. The high false alarms could have been an artifact of this short time frame.

According to Mackie's (1977) classification scheme for vigilance studies, the present study would be classified as an abstract task in a conventional laboratory setting, usually short-term, with non-repeated sessions. This type of task is low in operational relevance but high in degree of experimental control. Future studies should attempt to assess the effects of artificial signals in situations that have more operational relevance. Also, the stimulus characteristics of artificial signals, identified in Figure 15, require further examination. Adding this perspective to vigilance studies adds another dimension upon which they can be classified (see Figure 16).

Another component related to feedback, which was not examined in the present study, was Balcazar et al.'s (1986) functional differential consequences. As Sipowicz, Ware and Baker (1962) demonstrated, the potential for rewards increased true signal hits and minimized false alarms. This would be an effective method of performance management in applied situations. Since an organization is already paying its employees, incentives can be offered for achieving and maintaining a desired level of performance. The increase in wages could be greatly offset by the savings achieved through increased efficiency. Since, as previously noted, not all vigilance tasks are equal, the costs and benefits of each individual situation must be considered.

Examining the effectiveness of different feedback durations could help to identify the most effective time frame. In the present study, feedback was based upon all of the responses the observer had made since the beginning of the task. As a result, each correct response contributed less to the feedback as the task progressed. For example, correctly identifying the first artificial signal presentation in the task would result in a change in the feedback from 0% to 100%. In contrast, if the observer correctly identified 327 out of 350 artificial signal presentations (93.4%), correctly identifying the next two artificial signals would only increase the feedback to 93.5%. In the present study, once an

Figure 16. Three classification schemes for vigilance tasks.



artificial signal has been missed, it would be impossible for the observer to bring the feedback display back up to 100%, regardless of the amount of effort expended. Resetting the feedback after a specified interval would provide an observer with the opportunity to improve upon his or her last session, if necessary. A potential effect of resetting the feedback is that it would provide the observer with a cue for elapsed time.

A second feedback option that would not provide any information with respect to time on task would be to provide the observer with a dynamic form of feedback that is based on the most recent detection performance data, for example, the last 100 artificial signals that had been presented. In this situation, during the first 100 artificial signal presentations, the feedback would proceed as it had in the present study (i.e., cumulative). From the 100^{th} signal on, the feedback would no longer be cumulative. Instead, it would be based on the last 100 artificial signals that had been presented up to the present point in time. Therefore, if 465 artificial signals had been presented, then the feedback would be based on the observer's detection performance for artificial signals 366 to 465.

This dynamic feedback would provide the observer with a more stable frame of reference with which to gauge his or her detection performance. Since the total amount of artificial signal presentations used in the calculation will never exceed 100 (or any other pre-determined number of signal presentations), the decreasing impact of each successive stimulus event on the feedback mentioned above would not be an issue. In addition, it would be possible for an observer to increase his or her detection performance back up to 100% after a decline in signal detection occurred.

Implications

The results of the present study indicate that identical artificial signals with continuous, machine-generated feedback will attenuate the vigilance decrement. If, for the moment, false alarm data is ignored, identical artificial signals with feedback improve most of the remaining performance measures. The one unaffected measure, the decrement coefficient variance, is at least no worse than the variance for the control group. The next best intervention is identical artificial signals without feedback, followed by distinct artificial signals without feedback. Based upon the changes in detection performance for the distinct artificial signals, the observers apparently treated the distinct artificial signals, either with or without feedback, as a separate task. The correlations between artificial and true signal hits would seem to support this (see Table 7).

Even though the decrement coefficients for true signals and artificial signals were significantly correlated for distinct artificial signals with feedback, the actual decrement coefficient for this group was the worst in the present study (see Table 6, Figure 11). Detection performance would actually be hindered with this intervention since, compared to the control group, the distinct artificial signals with feedback group detected fewer true signals and had a significant increase in false alarms. The significant correlation between true signal hits and identical artificial signal hits lends support to Baker's (1960) suggestion that artificial signals resemble the true signals as much as possible.

Before implementing this intervention in an applied setting, careful consideration should be given to the entire worksite and how the feedback and artificial signals will integrate. Other areas in human factors have cautioned against using a proven countermeasure indiscriminately. For example, research on shiftwork and its potentially negative effects have determined several methods for helping people adjust to the demands placed upon them. Before any intervention is used, researchers have suggested that a number of questions be answered in order to determine the applicability of the intervention (see Rosekind, Gander, Miller, Gregory, Smith, Weldon, Co, McNally & Lebacqz, 1994). Given the small effect sizes found in the present study, alternative interventions may prove more useful in certain situations. Until more information is collected and evaluated, the full potential of artificial signals as a means of attenuating the vigilance decrement in a variety of applied settings is unknown.

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Appendix A

Criticisms of Vigilance Research

Criticism directed at vigilance research have generally used one of two arguments: (a) in the real world, the vigilance decrement is very rare and (b) the controlled studies that have been conducted have little practical value because they are not easily generalized to the real world (Adams, 1987). In his reply to the first issue, Adams acknowledged the fact that the vigilance decrement has been absent in some of his own research as well as in some operational settings. This does not mean that the problem does not exist. Wiener (1987) believed that the reason the vigilance decrement is not very obvious in the real world is because managers may already be doing things that remove the decrement (e.g., task rotation) or proper measures are not available to confirm the presence of the decrement.

Adams believed that the frequency of the occurrence of a vigilance decrement is not the main issue. Instead he considered the location of the decrement when it happens to be an important issue to consider. How critical to a given process is a performance decrement? Does it occur in a non-significant area that does not warrant attention, or does the decrement have a direct impact on the quality of the desired output (e.g., identifying ships on radar, isolating defects, proper operation of equipment such as an aeroplane)? Attempts to solve the vigilance problem should be pursued if the potential impact of the decrement, when it does occur, is great enough (e.g., cost or safety factors). For example, Wiener (1987) referred to an issue of *Flight International*, which stated that human factors were involved in 70% of aviation accidents and that automation may have aggravated the problem.

In response to the second criticism directed at vigilance research, Adams (1987) agreed with the lack of generalizability of the research findings. He believed that any solutions found in the laboratory would have very little relevance in applied situations. Wiener (1987) stated the following: (a) it is difficult to determine actual performance in an applied setting as a comparison; (b) rarely is monitoring the only task an individual does for an entire shift, resulting in a job not quite as boring as researchers imply; and (c) the social and physical environment in applied settings is not as isolated as those used in laboratory studies. Ensuring increased realism in studies would facilitate the needed transfer of information from the lab to the real world. Mackie (1977) presented a method of determining the realism of vigilance studies (see Figure A1).

Adams did not, however, believe that all of the laboratory research was a waste of time. He proposed that the research is following the "classical model" of the physical sciences. Studies are attempting to determine the relevant variables and express them in general, all encompassing laws. Researchers who focus on identifying these general laws usually have little interest in specific applied concerns. Their goal is to further our understanding of the underlying mechanisms, and this process takes a very long time.

Figure A1. Mackie's (1977) method of determining the operational relevance of a vigilance study.

Experimental Variables	Operational Relevance		
	High	Moderate	Low
Task	1. Actual operational task; motivation intrinsic	2. Simulated operational task; motivation intrinsic or extrinsic	3. Abstract task; motivation extrinsic
Environment	1. Actual operational setting; naturally occurring stressors	2. Simulated operational setting; selected controlled stressors	3. Conventional laboratory setting; operational stressors may or may not be included
Temporal Characteristics	1. Actual operational schedules	2. Realistic approximations of watch durations; work/rest cycles; task repetitiveness	3. Usually short-term, non-repeated sessions; dictated by experimental convenience
	Low --------Degree of Experimental Control--------High		

In his review of the vigilance literature, Wiener (1987) points out that most laboratory studies last two hours or less. Due to practical constraints, subjects cannot be expected to perform the vigilance task for extended periods of time. In order to collect enough data in this short time frame, the signal frequency during the two-hour vigil would have to be a fair bit higher than the signal frequency usually found in an applied situation. Wiener also states that these two-hour sessions are quite acceptable until individuals are found who would like to participate in a six-month vigil.

Adams believed that the intent of the theoretical research being conducted is valid. Even so, he did point out two mistakes. The first was that a large amount of research was conducted on a problem that did not exist (Adams, 1987). Adams believed that the researchers grabbed onto a potentially intriguing behavioural problem in applied settings and moved it to the laboratory for further investigation. Many of the articles reviewed by the author made reference to Mackworth's Clock Test. After this, there was no mention of any other applied situation that prompted the research. In all fairness, there have been some studies that have specifically examined the vigilance decrement in applied situations (e.g., McCarthy, 1978; Haga, 1984; Matthews, Jones, & Chamberlain, 1992; Mackie, Wylie, & Smith, 1994; Merrill, Lewandowski, & Kobus, 1994).

The second mistake Adams pointed out was that researchers believed that their work would solve the problem of the vigilance decrement in a timely fashion. This goal did not consider the historical evidence on the progress of research (as noted above), nor was the basic information available to make it possible. Vigilance deals with other behavioural constructs that are not yet completely understood (e.g., attention). If the underlying processes are not understood, what are the chances that we can solve more complex behavioural problems that incorporate these processes in an accurate and timely manner?

Research on vigilance began with an applied concern. Adams suggests that this focus has been lost. In order to re-establish a research focus, he believes that applied concerns be studied in semi-controlled conditions. Without this basis for research, experimenters should not attempt to solve real-world problems; they should focus on developing the theoretical framework for vigilance.

Appendix B

Classification of Vigilance Studies

No one consistent vigilance task has been used under the same environmental conditions throughout all of the past studies. The modality of the stimuli, the duration of the vigilance task, the type of response required by subjects, as well as the specific measures used in any given study are some of the between-study differences noted by the author. Without knowing the similarities and differences that exist between these studies, it is very difficult to determine if all of the significant findings from past research, when combined would positively affect an individual's performance on a vigilance task. Some of the factors that have produced increased levels of performance in isolation may, when brought together, cancel each other out or cause a drop in performance. The combinations of these factors could also produce significant interactions. If their combined effects were not additive, a clear interpretation of these factors would become increasingly difficult.

In the hopes of initiating the development of a method of classification, Davies and Parasuraman (1982) proposed a classification system for vigilance tasks that they believed to be unbiased by any theoretical assertions. The main dimensions of their proposed system were: (a) the sense modality to which events are presented for inspection, (b) the number of stimulus sources to be monitored, (c) the attention requirements of the task, (d) the type of response required and (e) the kind of discrimination involved in the detection of signals. The following sections describe these dimensions in more detail.

Sense Modality

In the past, studies of vigilance have used visual, auditory and tactile signals. The specific sensory modality that was used appeared to have affected the level of performance during the experiments (Warm & Jerison, 1984). Even though this performance difference was noted, the vigilance decrement, although varying in degree, was present in all three modalities. Vigilance tasks that used auditory signals showed the least amount of performance loss when compared to studies that used visual or tactile signals. In addition, acoustic signals elicited a shorter response time from participants than visual or tactile signals.

Concern was raised as to the ease of comparison between vigilance experiments that used different modalities for signal presentation. Was sustained attention during a vigilance task a general characteristic that was not dependent on the modality of the signal, or were there different processes occurring within each modality? In an attempt to answer this question, Hatfield and Loeb (1968) attempted to equate the differential "coupling" of the auditory and visual modalities. Coupling refers to the "...degree to which subjects are 'tied in' to the display on which the signal is presented, irrespective of their orienting or observing behaviour" (Loeb & Binford, 1971. p. 529). People are closely coupled with auditory signals, since these would be heard regardless of the orientation of an individual's body and/or head. Visual signals are said to be more loosely coupled, as detection of a visual stimulus depends a great deal on the orientation of an individual's body, head and/or eyes.

In their experiment, Hatfield and Loeb (1968) attempted to minimise the effects of blinking and eye movement. Participants were required to respond to changes in the illumination level of pulsed stimuli that were presented through their closed eyelids. Performance in this study was greater than that observed in "normal" visual monitoring tasks and was close to the level of performance in an auditory monitoring task ($0.65 < r < 0.76$, Hatfield & Loeb, 1968).

Hatfield and Loeb also demonstrated that past studies did not attempt to equate the difficulty of the discriminations between auditory and visual tasks. Since then, several studies have shown that equated tasks have a higher correlation between auditory and visual performance than was previously seen ($0.65 < r < 0.80$). In addition, vigilance tasks that used relatively strong signals (i.e., higher than threshold or near-threshold) showed a high correlation between auditory and visual stimuli (Warm & Jerison, 1984).

Experience with a vigilance task using one modality has shown to improve performance in a vigilance task using a different modality. When participants were required to monitor dual-mode displays with redundant signals (i.e., both auditory and visual), performance was better than equivalent tasks that required monitoring of single-mode displays (Warm & Jerison, 1984). Craig, Colquhoun and Corcoran (1976) provided evidence that this increase in performance was due to the integrative action of the two sensory modalities. Based upon these results, it seems that there is a common underlying process involved in sustained attention that does not differ across sensory modalities. There is still some debate over this issue and until sufficient evidence is collected to make a decision, classification by modality is a useful criterion.

Source Complexity

This dimension relates to the number of stimulus sources that an individual is required to monitor. Past research has distinguished between vigilance tasks with a single stimulus source and vigilance tasks with multiple sources (Davies & Parasuraman, 1982). This is a very superficial method of grouping studies. Separating studies according to single or multiple stimulus sources would imply that a vigilance task that had 2 sources is equal to one with 15 sources. It seems reasonable to assume that the demands placed on an observer in these two situations are not equivalent.

Gallwey and Drury (1986) compared performance on a 7.5-hour inspection task between students and industrial quality-control personnel. One of the independent variables in the study was the source complexity of the stimuli, which was manipulated by the number of faults that may appear in a given sample (2, 4, or 6). As the number of potential faults increased, speed and accuracy of inspection decreased (Gallwey & Drury, 1986). These results show the need to develop a more detailed method of classifying tasks according to their differences in source complexity.

Attention Requirements of the Task

This dimension relates to the presentation rate of signals and non-signals (the event rate). As the rate of presentation increases, the observer needs to divert increasing amounts of attention to the monitoring task. The time course of events varies along a continuum ranging from slow to continuous presentation (Davies & Parasuraman, 1982). Several studies have shown that performance on a vigilance task varies inversely with the event rate (e.g., Davies & Parasuraman, 1982; Warm & Jerison, 1984).

Type of Response Required

Vigilance tasks vary in the level of responding required by the observer. A response to a signal may be as simple as pressing a button or switch, such as Mackworth's (1948) Clock Test. Other tasks may require the individual to decide on a course of action among several options when a signal is detected (e.g., Murrell, 1975). Davies and Parasuraman (1982) suggested that this method of classification be used only if the observer is required to perform a complex response to a signal. If a simple response, like pressing a button, is all that is required, then this component can be ignored.

Nature of Discrimination Required for Signal Detection

Two primary abilities for vigilance tasks have been identified: perceptual speed and flexibility of closure. These were derived from the perceptual-sensory domain of the abilities classification system, which has been identified as the ability domain most involved with performance on a vigilance task (Davies & Parasuraman, 1982). Perceptual speed refers to an observer's ability to compare a sequential series of stimuli (all within one sensory modality) and identify them or determine their degree of similarity. As each stimulus is presented, the individual must determine if it is a signal or a non-signal. Flexibility of closure refers to an individual's ability to identify a target stimulus, which was previously presented, when it is embedded within a more complex stimulus. In this situation, both the signal and non-signal are presented simultaneously within the same sensory modality.

Performance differences have been noted between these two ability classifications (Levine, Romashko, & Fleishman, 1973). Individuals who performed vigilance tasks that required flexibility of closure initially exhibited the vigilance decrement. However, after approximately 45 minutes, performance levels would begin to rise again. In contrast, individuals who performed vigilance tasks that required perceptual speed also exhibited the vigilance decrement, but their performance levelled off for the remainder of the task (i.e., the "classic" vigilance decrement).

The observed differences in performance suggest that vigilance tasks requiring flexibility of closure are less susceptible to the vigilance decrement than tasks requiring perceptual speed. Tasks involving perceptual speed are classified as successive tasks, since only one stimulus (signal or non-signal) is present at any given time. Tasks involving flexibility of closure present either non-signals or non-signals with signals. The observer is simply required to identify the presence or absence of the signal. This type of task is classified as a simultaneous task (Davies & Parasuraman, 1982).

Davies and Parasuraman (1982) proposed the dimensions discussed above as a first step in developing a comprehensive classification system for vigilance tasks. The four task characteristics that they found to have the most effect on performance have been included, but this is by no means complete. Recently, Koelega, Brinkman, Hendriks & Verbaten (1989) identified performance differences between sensory tasks (i.e., signals were a predetermined change in the physical characteristics of a stimulus) and cognitive tasks (i.e., signals are symbolic or alphanumeric). A meta-analysis of the vigilance literature by See et al. (1995) supported the inclusion of the sensory-cognitive discrimination. Since most of the empirical research on vigilance has used sensory tasks, there is currently a large gap in experimental research. Until more studies involving cognitive tasks are completed, the extent of the similarities and/or differences between these two types of vigilance tasks remains unknown.

One additional category identified by See et al. (1995) is the level of sensitivity associated with a vigilance task (d'). In the past, it has been suggested that sensitivity is most likely to change only in successive-discrimination tasks with a high event rate (e.g., Parasuraman & Davies, 1977). Kolega et al. (1989) have found that a decline in d' also occurs in other types of vigilance tasks. Contrary to much of the past research, See et al.'s meta-analysis suggests that a change in sensitivity (d') plays a significant role in vigilance performance. Based upon the meta- analysis, the following dimensions were suggested for classification of vigilance tasks: (a) type of discrimination (successive or simultaneous), (b) event rate, (c) type of stimuli (sensory or cognitive) and (d) the average level of sensitivity associated with the task (d'; See et al., 1995).

Appendix C

Classification of Feedback

Prue and Fairbank (1981) developed a classification system for comparing research on feedback. The first category identified by Prue and Fairbank (1981) was the recipients of the feedback. This identifies the method(s) used to present feedback to the intended recipient. Is the feedback delivered privately, on a one-to-one basis, is it delivered publicly, making an individual's co-workers aware of the feedback each individual receives, or is the method of delivery somewhere in between these two extremes, providing some private and some public feedback? The method used by any organisation must consider the potential impact and associated costs of the delivery methods available.

The repercussions of public feedback on the employee can be very unpredictable. Public feedback for a poor performer may result in physical or psychological separation by the rest of the work group. This separation could lead the poor performer to perform at an even lower level, lash out with acts of sabotage, terminate his or her employment, or motivate the poor performer to increase his or her efforts. Prue and Fairbank suggested that public feedback be used when: (a) baseline performance is low and public feedback may be aversive, (b) supervisors possess the skills needed to effectively deliver one-to-one feedback, (c) organisational resources allow for the increased costs associated with one-to-one feedback, (d) employees and supervisors work closely together, and (e) individual performance is being compared with an established standard.

Prue and Fairbank's (1981) second category, feedback mechanisms, refers to the format used to deliver feedback. Four types that have been identified are verbal, written, mechanical and self-recorded. The most common of these is verbal feedback. The benefits of verbal feedback are that it takes a short amount of time to pass on to the recipient and the feedback itself can be linked to any given individual's performance. Although the feedback itself is fairly easy to administer in verbal form, the context in which the feedback takes place must be considered. The type of relationship that exists between the employees and their supervisor (e.g. hostile, agreeable) and the communication skills that the supervisor possesses must be considered. If either of these contextual factors are deemed to be in a state where the potential benefits of verbal feedback may be overshadowed, then other forms of feedback and/or training should be considered.

Written feedback can be used in a variety of formats. Some of the formats of written feedback are written personal communications, memos, newsletters, public posting of information and annual performance reviews. The most commonly used format has been public postings, for which the potential impact on the employee must be considered (see above; Prue & Fairbank, 1981). Written feedback is beneficial because it provides a permanent record that can be tracked over time, individuals have the option of allowing the feedback to be seen by others (e.g., certification, excellent performance) and it is easy for the supervisors to monitor the feedback in this format.

As the name implies, mechanical feedback is provided to employees through some mechanical form (e.g. videotape, displays, printouts). One of the better-known examples of mechanical feedback is from the Hawthorne studies, where the group of employees who participated in the study received performance feedback in the form of a numerical display that kept track of the number of completed products. This form of feedback is advantageous because it is cost effective and the feedback is continuous and usually immediate.

There has not been a large amount of research into the effectiveness of mechanical feedback (Prue & Fairbank, 1981). One of the questions that still needs to be answered is whether or not mechanical feedback can maintain performance over extended periods of time or if the employees may eventually ignore this form of feedback, causing their performance to decline to the prior baseline. Once the long-term effects of mechanical feedback have been determined, and if it does indeed maintain a high level of performance alone or in conjunction with some of the other forms of feedback, integration into many worksites would be relatively easy. With the current level of technology, it would be a simple matter to add mechanical feedback to computer displays that already exist in the work environment.

Self-recorded feedback requires the employees to generate their own feedback. This form of feedback has been used mostly in clinical settings (e.g., for behavioural change) and has not received as much attention with respect to the workplace. The studies that have been done in a work environment have shown positive results (Prue & Fairbank, 1981). Self-recorded feedback seems to be suited for situations when employees have little or no direct supervision, there are no physical products to be evaluated, or when an efficient work flow (e.g., proper planning, efficient use of resources, etc.) directly affects productivity.

The content of the feedback is the third area identified by Prue and Fairbank (1981). The different types of information passed on to an employee are: (a) comparison of an individual's performance with his or her previous performance, (b) comparison of an individual's performance with a standard which is determined by the performance of a large number of individuals, (c) comparison of a group's performance with its previous performance, (d) comparison of a group's performance with a standard group performance and (e) presentation of individual's performance as a percentage of the group's performance. The actual content used in any situation depends on several factors.

First, the information available within an organisation could limit potential choices. Secondly, one has to determine if comparisons can be made among employees. More specifically, are there enough employees performing the same task, is the task performed frequently enough for accurate measurement, and can a fair comparison be made between different workers who may not perform each identified task to the same extent? The relationship among employees needs to be assessed. If an aversive environment exists, comparison between the employees may not be as effective as desired. Thirdly, the type of feedback should also be closely matched with the pay structure in an organisation.

The fourth factor to be considered is the way that the feedback message is prepared. The feedback needs to be clearly understood and focussed on behaviours and performance rather than stating personal characteristics. The feedback should provide employees with enough information to identify both appropriate and inappropriate goal-directed behaviour and classify the characteristics relating to the rate of behaviour. It has been suggested that feedback be accompanied by items such as supportive statements, social praise, constructive criticism and modelling (Prue & Fairbank, 1981). Wherever possible, the content of the feedback should be tied to a clearly defined performance standard.

The temporal characteristics of feedback are the next component in Prue and Fairbank's (1981) classification. There are two distinct areas relating to the temporal characteristics; the duration of the feedback and the time interval between behaviour and feedback. The duration of a feedback session is very dependent upon the total content of the feedback as well as the mechanism used. The potential range of time is from a couple of seconds (e.g., a glance at a display) to an hour or more (e.g., performance appraisal). Since the duration does depend on some of the previously discussed factors, this facet of feedback is a secondary concern with respect to its potential effectiveness.

The time interval between behaviour and feedback is the temporal characteristic of feedback that has a more direct relationship on the effectiveness of the feedback and can be manipulated independent of the other areas discussed. The first factor to be considered is the complexity of the behaviour for which feedback is to be given (Prue & Fairbank, 1981). Very simple and straightforward behaviours can be acquired and performed to specifications without immediate feedback while more complex behaviours would require timely feedback both during the learning stage and while the employees' behaviours are being evaluated against a set standard or criterion.

The second factor related to the timing of feedback is the organisational constraints. Immediate feedback may not be possible in an organisation for a number of reasons (e.g., high employee to supervisor ratio, physical separation between supervisors and employees). Studies have shown that immediate feedback may not be necessary (Prue & Fairbank, 1981). Feedback has been shown to be effective when delivered daily, weekly, bi- and tri- weekly and monthly. Prue and Fairbank (1981) suggested that the effects of feedback may follow a pattern similar to reinforcement schedules. If this were the case, then a variable interval or ratio schedule of feedback would produce the best results.

The final area identified by Prue and Fairbank (1981) is the source of the feedback. Feedback has been provided by supervisors of varying rank, subordinates, co-workers, outside consultants, the employee in question and by mechanical means. 360 ° feedback, a method of feedback that utilises most of these sources, has recently gained attention in the business community. By employing 360 ° feedback, an employee receives performance feedback from various individuals within the organisation as well as feedback from the organisation's customer(s). Each person would provide feedback only for the performance areas that he or she has directly observed. The intent is to provide as much information as possible with respect to an individual's performance. Since one person may not witness or have records about all of the activities performed by an employee, 360 ° feedback attempts to reduce the chances of missing significant behaviours by using multiple sources.

To date, there has not been much research comparing the effectiveness of these different sources of feedback. There are many interpersonal concerns to be considered when the feedback comes from another individual. The status of the individual providing the feedback can influence the effectiveness of the feedback. If the individual providing the feedback is high-ranking, the employee receiving the feedback may take greater interest in the content of the feedback. Of course, the opposite reaction is possible if the employee believes that the individual providing the feedback has no clear idea about what the employee is actually required to do. When considering having the feedback come from another individual, the following items need to be evaluated: (a) the competence of the individual, (b) the amount of control the individual has over reinforcers and punishers, (c) the sincerity of the individual and (d) the past history of the individual's interactions with the employees (Prue & Fairbank, 1981).

Prue and Fairbank's (1981) review of performance feedback provides the beginnings of a framework with which to evaluate and compare studies on feedback. Potentially contradictory information between studies may be explained by the different characteristics of the feedback used in each study.

Appendix D

Feedback With or Without Goal Setting and/or Rewards

The findings of Balcazar, Hopkins, and Suarez's (1986) review of the feedback literature during the preceding ten years indicated that feedback alone is only sometimes effective. Balcazar and his colleagues believed that this is due to the stimulus properties of feedback. Feedback alone will only be effective if it is in some way linked to a primary consequence. For example, if a production graph were used for each individual on an assembly line that used a piece-rate method of remuneration, each individual could determine exactly how much his or her earnings were from the information provided by the graph. A direct relationship is made between the stimulus (feedback) and a reinforcer. In the above example, this would be the graph and pay, respectively.

Balcazar et al.'s (1986) review of feedback in conjunction with behavioural consequences found that the desired outcomes of feedback are more consistent with this pairing. This follows the above explanation of feedback as a stimulus. If the behavioural consequences are directly related to the feedback received, then the consequences will act as a reinforcer. The fact that this increases the chances of attaining the desired results of feedback is most likely due to the fact that this pairing was intentional and therefore more obvious. If a reward structure had been in existence for a time without any feedback, the introduction of feedback would lead to increased performance only if the employees perceived a relationship between the new source of feedback and the existing rewards. If the association is not made, then the feedback may not improve performance.

The type of behavioural consequences used can also affect the success of feedback. Balcazar et al. (1986) found that praise was used in 36 (69%) of the articles they reviewed. Out of these studies, only eight showed a consistent performance improvement. Fifteen other articles reviewed used more tangible rewards for the behavioural consequences (e.g., money, food, gasoline). Thirteen of these studies showed a consistent positive change in performance. Although tangible rewards appear to be better than praise, the choice of a behavioural consequence must be determined in each unique situation. The employees must desire the intended consequences -or not want them in the case of a negative reinforcer (e.g., a reprimand) – in order for the feedback to change the targeted behaviour.

Appendix E

Monitoring Task Instructions

The following sections outline the instructions given to the subjects in the present study. The text enclosed in this appendix was presented on the computer screen before the monitoring task began. Sample images of the computer simulation similar to Figure 6 were also presented on-screen with the text for clarification.

Control Group

Screen One

- This is called a meter.
- When the arrow is pointing to the white lines there is no need to respond.
- When the arrow is pointing to either "Danger" zone, press the SPACE BAR once.
- The screens on the monitoring task will have two meters appearing together. If will look like the next screen.

Screen Two

- When an arrow points to any of the four danger zones, press the space bar. Do not press the space bar if both of the arrows are adjacent to white spaces.

- Press "A" to review these instructions again or "L" to begin the monitoring session.

<u>Identical Artificial Signals Without Feedback</u>

<u>Screen One</u>

- This is called a meter.
- When the arrow is pointing to the white lines there is no need to respond.
- When the arrow is pointing to either "Danger" zone, press the SPACE BAR once.
- The screens on the monitoring task will have two meters appearing together. If will look like the next screen.

<u>Screen Two</u>

- When an arrow points to any of the four danger zones, press the space bar. Do not press the space bar if both of the arrows are adjacent to white spaces.
- Press "A" to review these instructions again or "L" to begin the monitoring session.

Identical Artificial Signals With Feedback

Screen One

- This is called a meter.
- When the arrow is pointing to the white lines there is no need to respond.
- When the arrow is pointing to either "Danger" zone, press the SPACE BAR once.
- The screens on the monitoring task will have two meters appearing together. If will look like the next screen.

Screen Two

- When an arrow points to any of the four danger zones, press the space bar. Do not press the space bar if both of the arrows are adjacent to white spaces.

Screen Three

- On the next screen you'll notice a box above the gauges. This box will tell you the percentage of times you pressed the space bar when an arrow was in the danger zone.
- The percentage will only be updated once in a while, so sometimes you will press the space bar and nothing will happen to the %.

- Press "A" to review these instructions again or "L" to begin the monitoring session.

Distinct Artificial Signals Without Feedback

Screen One

- This is called a meter.
- When the arrow is pointing to the white lines there is no need to respond.
- When the arrow is pointing to either "Danger" zone, press the SPACE BAR once.
- The screens on the monitoring task will have two meters appearing together. If will look like the next screen.

Screen Two

- When an arrow points to any of the four danger zones, press the space bar. Do not press the space bar if both of the arrows are adjacent to white spaces.

Screen Three

- The program is also going to include some other things for you to watch for. The next screen shows you the gauges with rectangles adjacent to each of the danger zones. Occasionally one will turn from white to black and back to white again. When this happens, press the space bar.

- Press "A" to review these instructions again or "L" to begin the monitoring session.

Distinct Artificial Signals With Feedback

Screen One

- This is called a meter.
- When the arrow is pointing to the white lines there is no need to respond.
- When the arrow is pointing to either "Danger" zone, press the SPACE BAR once.
- The screens on the monitoring task will have two meters appearing together. If will look like the next screen.

Screen Two

- When an arrow points to any of the four danger zones, press the space bar. Do not press the space bar if both of the arrows are adjacent to white spaces.

Screen Three

- The program is also going to include some other things for you to watch for. The next screen shows you the gauges with rectangles adjacent to each of the danger zones. Occasionally one will turn from white to black and back to white again. When this happens, press the space bar.

Screen Four

- You'll also notice a box above the gauges. This box will tell you the percentage of times you pressed the space bar when a rectangle flashes.

- Press "A" to review these instructions again or "L" to begin the monitoring session.

Appendix F

Table F1

Percent of True Signal Hits per 10-minute Time Block

	Time Block											
Subject	1	2	3	4	5	6	7	8	9	10	11	12
C1	100.00	91.67	100.00	100.00	100.00	92.86	100.00	84.62	93.33	100.00	100.00	90.91
C2	100.00	93.75	92.86	90.00	77.78	92.31	100.00	100.00	69.23	100.00	81.25	63.64
C4	85.71	68.75	28.57	38.46	54.55	15.38	0.00	0.00	0.00	0.00	0.00	0.00
C5	92.31	100.00	100.00	80.00	91.67	83.33	90.91	83.33	81.82	69.23	88.89	78.57
C6	100.00	90.91	71.43	93.75	76.92	85.71	93.33	91.67	100.00	91.67	81.82	100.00
C7	94.12	63.64	26.67	100.00	71.43	76.92	33.33	75.00	87.50	80.00	84.62	94.44
C8	92.31	100.00	100.00	93.33	100.00	100.00	91.67	100.00	80.00	81.82	25.00	61.54
C9	85.71	100.00	83.33	92.31	90.91	71.43	83.33	75.00	66.67	58.33	76.92	60.00
C10	80.00	100.00	88.24	100.00	92.31	80.00	84.62	58.33	86.67	85.71	90.91	66.67
C11	100.00	100.00	90.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
C12	83.33	100.00	100.00	57.14	58.33	60.00	80.00	90.91	88.89	80.00	66.67	100.00
C13	100.00	100.00	100.00	100.00	90.00	100.00	88.89	100.00	81.25	76.92	100.00	100.00
C14	100.00	91.67	90.00	72.73	78.57	57.14	83.33	80.00	16.67	30.00	76.92	83.33

Subject	Time Block 1	2	3	4	5	6	7	8	9	10	11	12
C15	100.00	94.74	84.62	100.00	93.75	92.31	100.00	100.00	93.33	100.00	93.33	100.00
C16	100.00	100.00	90.91	78.57	90.00	80.00	85.71	72.73	85.71	100.00	86.67	100.00
IF1	72.73	92.31	92.31	72.73	76.92	92.31	83.33	86.67	85.71	78.57	76.92	91.67
IF2	100.00	100.00	100.00	83.33	100.00	90.91	62.50	77.78	100.00	100.00	90.91	81.82
IF3	93.75	100.00	100.00	100.00	100.00	93.33	100.00	100.00	100.00	91.67	100.00	100.00
IF4	90.00	75.00	100.00	100.00	100.00	100.00	90.00	94.12	100.00	100.00	100.00	100.00
IF5	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
IF6	90.91	100.00	100.00	90.91	71.43	93.75	91.67	100.00	90.00	90.91	70.00	84.62
IF7	54.55	88.89	57.14	69.23	92.31	83.33	58.33	100.00	82.35	76.92	91.67	83.33
IF8	100.00	100.00	100.00	100.00	100.00	91.67	90.91	91.67	100.00	92.86	88.24	87.50
IF11	100.00	91.67	83.33	77.78	69.23	92.31	100.00	100.00	100.00	100.00	83.33	91.67
IF12	0.00	0.00	92.86	91.67	100.00	92.31	91.67	100.00	100.00	100.00	100.00	91.67
IF13	90.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
IF14	90.91	81.82	90.91	100.00	100.00	90.00	100.00	90.91	100.00	100.00	90.00	85.71
IF15	100.00	88.24	91.67	75.00	100.00	90.91	100.00	100.00	100.00	100.00	100.00	100.00
IF16	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	92.86
IF17	100.00	100.00	100.00	100.00	92.31	100.00	92.86	84.62	94.12	92.86	91.67	100.00
IN1	100.00	88.89	100.00	100.00	100.00	94.12	100.00	100.00	100.00	100.00	92.31	100.00
IN2	100.00	86.67	92.31	83.33	58.33	36.36	75.00	83.33	50.00	71.43	57.14	76.92

Subject	Time Block											
	1	2	3	4	5	6	7	8	9	10	11	12
IN3	92.86	80.00	75.00	92.31	91.67	86.67	100.00	76.92	61.54	60.00	81.82	92.86
IN4	90.91	100.00	71.43	53.85	50.00	15.38	61.54	50.00	57.14	70.00	85.71	100.00
IN5	100.00	100.00	100.00	87.50	82.61	100.00	90.00	57.14	100.00	90.91	75.00	84.62
IN8	100.00	100.00	91.67	83.33	100.00	100.00	85.71	78.57	91.67	91.67	91.67	100.00
IN9	100.00	92.86	100.00	100.00	92.31	100.00	100.00	100.00	91.67	92.86	100.00	100.00
IN10	100.00	94.12	100.00	88.89	100.00	100.00	93.75	90.91	91.67	100.00	100.00	100.00
IN11	88.89	76.92	90.91	46.15	100.00	80.00	83.33	100.00	100.00	100.00	100.00	100.00
IN12	100.00	100.00	92.86	91.67	100.00	92.31	90.91	86.67	90.91	100.00	94.12	100.00
IN13	90.91	80.00	92.31	100.00	100.00	83.33	100.00	92.31	53.85	93.75	81.82	72.73
IN14	66.67	100.00	100.00	86.67	94.44	70.59	92.31	100.00	91.67	100.00	100.00	100.00
IN15	100.00	90.91	90.91	81.82	83.33	92.86	92.86	100.00	100.00	100.00	87.50	100.00
IN16	100.00	100.00	100.00	100.00	100.00	83.33	90.91	100.00	100.00	88.89	92.31	100.00
IN17	100.00	100.00	100.00	100.00	100.00	90.91	100.00	100.00	100.00	91.67	100.00	90.00
DF1	76.92	90.00	71.43	86.67	46.67	60.00	46.67	54.55	18.18	16.67	64.29	41.67
DF2	100.00	100.00	100.00	100.00	100.00	91.67	91.67	100.00	100.00	100.00	100.00	87.50
DF3	50.00	27.27	33.33	30.00	75.00	50.00	53.85	35.71	41.67	41.18	33.33	61.54
DF4	90.91	100.00	88.24	50.00	0.00	50.00	0.00	0.00	75.00	92.86	73.33	93.75
DF6	83.33	93.33	76.92	69.23	63.64	66.67	64.29	81.82	84.62	90.91	90.91	100.00
DF7	100.00	100.00	88.89	91.67	90.00	90.91	85.71	100.00	69.23	78.57	70.00	90.91

Subject	Time Block 1	2	3	4	5	6	7	8	9	10	11	12
DF8	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
DF9	90.91	93.33	27.27	7.14	28.57	0.00	64.71	66.67	18.18	0.00	40.00	78.57
DF10	100.00	81.82	85.71	66.67	86.67	43.75	85.71	75.00	81.25	94.44	92.31	77.78
DF11	92.86	93.33	100.00	100.00	90.91	100.00	85.71	100.00	100.00	100.00	100.00	100.00
DF12	93.33	76.92	83.33	81.82	69.23	88.89	61.11	78.57	71.43	100.00	93.75	78.57
DF13	62.50	75.00	58.33	54.55	76.92	92.86	66.67	73.33	61.54	68.75	50.00	76.92
DF14	92.86	100.00	100.00	100.00	93.33	100.00	100.00	100.00	81.82	100.00	100.00	100.00
DF15	100.00	100.00	80.00	87.50	81.82	84.62	72.73	76.92	78.57	81.82	81.82	83.33
DF16	90.00	100.00	81.82	92.31	84.62	83.33	100.00	100.00	90.00	100.00	100.00	92.31
DN1	91.67	100.00	90.91	64.71	76.92	66.67	50.00	100.00	100.00	100.00	88.89	91.67
DN2	100.00	68.75	76.92	50.00	61.54	38.46	72.73	71.43	33.33	53.33	87.50	50.00
DN3	100.00	100.00	100.00	93.33	100.00	85.71	80.00	100.00	92.31	100.00	80.00	90.00
DN4	91.67	92.86	87.50	70.00	91.67	68.75	72.73	66.67	75.00	75.00	90.91	73.33
DN5	56.25	30.77	50.00	16.67	46.67	63.64	61.54	27.27	66.67	60.00	30.00	57.14
DN6	100.00	92.86	100.00	92.31	72.73	91.67	66.67	75.00	81.82	66.67	100.00	77.78
DN7	100.00	100.00	100.00	100.00	100.00	92.86	93.33	91.67	93.75	100.00	100.00	100.00
DN9	100.00	92.31	100.00	92.86	72.73	93.33	90.91	88.89	80.00	76.92	81.82	84.62
DN10	83.33	100.00	88.24	100.00	100.00	75.00	100.00	100.00	100.00	93.33	100.00	100.00
DN11	100.00	50.00	88.89	90.00	100.00	69.23	100.00	78.57	76.92	72.73	66.67	86.67

	Time Block											
Subject	1	2	3	4	5	6	7	8	9	10	11	12
DN12	84.62	69.23	90.91	84.62	90.00	86.67	100.00	92.31	100.00	92.86	83.33	100.00
DN13	92.86	100.00	91.67	100.00	83.33	100.00	90.91	75.00	100.00	91.67	81.82	84.62
DN14	100.00	100.00	90.91	100.00	92.86	78.57	92.31	100.00	100.00	100.00	81.82	75.00
DN15	78.57	100.00	92.86	92.31	92.31	100.00	91.67	100.00	84.62	90.00	80.00	100.00
DN16	70.00	100.00	81.82	80.00	92.31	88.24	78.57	45.45	40.00	85.71	10.00	33.33

Table F2

Percent of False Alarms per 10-minute Time Block

Subject	Time Block											
	1	2	3	4	5	6	7	8	9	10	11	12
C1	3.07	0.13	0.00	0.26	0.00	0.13	0.00	0.00	0.26	0.00	0.00	0.00
C2	0.00	0.13	0.13	0.00	0.13	0.26	0.00	0.00	0.52	0.65	0.13	0.39
C4	0.26	0.39	0.13	0.26	1.42	1.17	0.26	0.13	0.39	0.39	0.39	0.78
C5	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.13	0.00	0.00	0.26	0.13
C6	0.00	0.13	0.00	0.00	0.39	0.13	0.13	0.13	0.00	0.00	0.13	0.00
C7	0.00	2.55	6.61	0.00	0.26	0.00	0.00	0.13	0.00	0.13	0.00	0.13
C8	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.13	0.13	18.05	0.00	0.00
C9	0.13	0.13	0.39	0.00	0.26	0.39	1.04	0.52	0.39	0.78	0.52	0.65
C10	0.13	0.00	0.52	0.13	0.00	0.13	0.26	0.13	0.39	0.26	0.13	0.26
C11	0.26	0.00	0.13	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C12	0.13	0.26	0.00	0.39	0.39	0.13	0.26	0.52	0.13	0.13	0.13	0.13
C13	0.00	0.00	0.00	0.00	0.13	0.13	0.00	0.00	0.13	0.00	0.00	0.00
C14	0.26	0.00	0.26	0.26	0.39	1.93	0.65	0.26	0.65	0.26	0.39	0.00
C15	0.26	0.13	0.00	0.00	0.39	0.39	0.13	0.00	0.26	0.13	0.13	0.13
C16	2.44	0.13	0.00	0.39	0.13	0.26	0.26	0.26	0.13	0.00	0.00	0.26

	Time Block											
Subject	1	2	3	4	5	6	7	8	9	10	11	12
IF1	0.26	0.40	7.74	1.57	7.02	1.70	2.57	0.79	0.79	1.69	1.82	0.66
IF2	0.66	0.66	0.92	1.04	0.53	1.55	2.06	1.68	1.43	1.30	1.81	4.06
IF3	1.05	0.13	0.79	1.43	0.92	0.66	0.26	0.66	0.53	0.39	0.26	0.40
IF4	0.13	0.00	0.40	1.30	2.69	1.17	0.39	0.13	0.53	0.13	0.26	0.39
IF5	0.13	0.13	0.13	0.13	0.00	0.00	0.13	0.13	0.00	0.00	0.00	0.13
IF6	0.52	0.39	0.26	0.39	1.31	0.79	0.39	0.39	0.52	0.26	1.18	1.19
IF7	1.83	0.00	0.13	0.13	0.26	0.66	0.65	0.13	0.40	0.65	0.52	0.92
IF8	0.00	0.13	0.00	0.00	0.65	0.39	0.92	0.52	0.53	1.69	1.06	1.05
IF11	0.92	6.64	21.63	0.26	8.63	1.69	5.62	3.30	16.15	1.05	34.31	3.30
IF12	0.00	0.27	5.62	16.41	7.24	12.12	9.07	7.53	9.82	7.67	7.53	8.02
IF13	0.26	0.13	0.39	0.65	0.40	0.39	0.26	0.78	0.52	0.65	0.91	1.04
IF14	0.27	0.79	0.26	0.39	0.78	0.13	0.13	0.39	0.40	0.26	0.78	0.26
IF15	1.31	1.83	3.81	3.68	4.55	19.66	41.16	43.64	45.46	43.00	41.59	38.36
IF16	0.00	0.00	0.26	0.39	0.13	1.17	0.91	0.91	0.78	0.91	0.65	1.05
IF17	0.53	0.26	0.26	0.00	0.40	0.52	0.92	0.53	0.27	0.53	1.43	0.79
IN1	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.26	0.00	0.52
IN2	5.99	4.18	4.56	6.89	8.00	4.80	3.31	5.85	6.61	5.75	10.37	8.22
IN3	1.44	4.66	1.68	2.45	2.06	2.09	0.65	0.66	1.06	1.45	0.40	0.26
IN4	0.40	1.83	1.32	5.24	1.46	0.54	0.66	0.27	1.72	0.26	1.05	0.26

	Time Block											
Subject	1	2	3	4	5	6	7	8	9	10	11	12
IN5	0.26	0.13	0.79	0.52	0.67	0.92	0.92	1.19	2.33	1.18	1.19	1.06
IN8	0.00	0.53	0.53	0.13	0.66	0.26	0.53	0.66	0.39	0.53	0.39	0.26
IN9	0.13	0.13	0.00	0.13	0.13	0.00	0.00	0.00	0.00	0.26	0.13	0.13
IN10	0.79	0.40	0.13	0.65	0.13	4.87	0.40	0.13	0.26	0.13	0.13	0.13
IN11	1.04	0.52	0.92	0.79	0.66	1.05	1.18	0.91	0.52	0.13	0.65	0.52
IN12	0.26	0.39	0.26	0.39	0.00	0.13	0.26	0.26	0.39	0.13	0.27	0.40
IN13	0.65	0.91	0.26	1.17	0.79	2.19	1.31	2.08	1.82	3.09	1.94	2.57
IN14	0.13	0.26	0.13	0.13	0.26	0.13	0.39	0.65	0.13	0.39	0.26	0.26
IN15	0.27	0.66	0.52	1.93	4.65	0.92	0.92	0.52	0.52	0.39	0.66	0.78
IN16	0.00	0.00	0.26	0.91	0.13	0.00	4.78	0.00	0.26	0.00	0.13	0.13
IN17	0.13	0.13	0.26	0.13	0.00	0.13	0.00	0.00	0.26	0.13	0.00	0.00
DF1	2.07	2.05	5.47	5.49	4.06	4.03	2.19	1.80	5.11	10.28	6.47	2.45
DF2	0.13	0.13	0.00	0.26	0.00	0.13	0.26	0.00	0.00	0.00	0.13	0.26
DF3	5.88	3.06	1.43	1.05	3.33	4.87	3.44	2.84	1.56	1.70	1.59	1.59
DF4	0.00	0.00	0.66	1.95	0.14	0.66	0.00	0.00	0.92	0.13	0.40	0.13
DF6	0.13	5.50	0.26	0.66	1.30	0.00	1.44	0.13	1.31	0.39	0.39	0.66
DF7	1.30	0.00	0.39	0.00	0.26	0.26	0.26	0.26	0.40	0.26	0.65	0.13
DF8	0.26	0.65	6.72	7.07	18.08	28.28	16.68	27.39	18.42	12.98	11.38	12.57
DF9	0.53	4.44	2.61	0.95	3.54	0.27	0.93	1.04	1.60	0.00	1.20	4.80

	Time Block											
Subject	1	2	3	4	5	6	7	8	9	10	11	12
DF10	0.00	0.39	0.13	0.65	0.00	0.40	0.26	0.53	0.13	0.40	0.92	0.26
DF11	1.05	1.43	0.39	0.52	0.39	0.39	1.04	1.04	1.92	1.55	1.94	1.80
DF12	4.94	2.95	8.09	7.22	8.03	3.96	6.34	0.52	0.92	0.52	1.05	1.05
DF13	2.18	8.66	22.87	9.42	11.59	14.06	6.81	5.51	6.10	14.56	6.08	4.29
DF14	0.92	0.78	0.65	0.52	0.65	0.52	0.26	0.78	0.78	0.91	0.26	0.39
DF15	0.53	0.26	1.94	0.79	0.78	0.53	0.79	0.26	0.92	0.39	1.04	1.43
DF16	0.52	0.26	0.13	0.65	0.52	1.04	2.33	2.30	4.03	2.32	2.57	4.63
DN1	1.56	1.68	2.45	2.59	3.81	3.21	2.19	1.56	1.43	1.68	1.30	2.06
DN2	1.17	0.27	1.04	1.05	2.33	3.09	0.91	1.04	2.57	2.85	3.66	1.17
DN3	0.13	0.13	0.53	0.13	0.27	0.13	0.13	0.27	0.66	0.79	0.27	0.39
DN4	0.39	0.26	0.53	0.79	0.92	0.40	1.17	0.79	1.57	1.19	1.18	0.40
DN5	0.92	0.79	0.79	0.40	1.05	0.26	0.79	0.66	1.31	0.27	1.95	0.92
DN6	0.00	0.00	0.00	0.26	0.26	0.26	0.39	0.00	0.13	0.13	0.39	0.13
DN7	0.13	0.13	0.00	0.13	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.26
DN9	0.13	0.13	0.00	0.13	0.39	0.53	0.53	0.13	0.79	0.39	0.40	0.26
DN10	0.26	0.26	0.40	0.00	0.13	0.39	0.26	0.13	0.65	0.26	0.26	0.13
DN11	0.40	1.30	0.79	1.18	3.21	0.26	0.13	1.31	2.10	1.69	1.31	2.34
DN12	0.52	0.40	0.13	0.13	0.00	0.13	0.26	2.45	0.52	0.39	0.66	0.00
DN13	0.40	0.13	0.26	0.26	0.26	0.00	0.26	0.26	0.26	0.39	0.39	0.00

Subject	Time Block											
	1	2	3	4	5	6	7	8	9	10	11	12
DN14	0.13	0.13	0.39	0.39	0.00	0.40	0.26	0.13	0.65	0.00	0.78	0.26
DN15	0.40	0.13	0.13	0.13	0.13	0.13	0.39	0.26	0.13	0.00	0.13	0.00
DN16	8.34	6.40	6.87	2.56	1.82	1.58	1.70	1.97	1.06	1.85	0.66	1.73

Table F3

Percent of Artificial Signal Hits per 10-minute Time Block

	Time Block											
Subject	1	2	3	4	5	6	7	8	9	10	11	12
IF1	98.11	94.83	85.25	83.87	100.00	91.30	97.10	87.69	98.59	93.33	96.61	98.25
IF2	98.31	95.38	98.48	94.83	94.92	95.52	93.06	98.39	92.75	93.33	100.00	91.80
IF3	92.65	95.16	95.00	100.00	98.28	93.22	89.55	95.52	98.25	92.73	95.08	96.92
IF4	96.67	98.65	93.24	93.65	95.45	98.57	100.00	96.92	92.42	92.98	98.36	96.72
IF5	100.00	95.31	98.31	98.39	95.16	95.83	96.43	98.11	96.43	97.10	100.00	96.97
IF6	98.51	93.10	98.41	98.31	91.67	91.94	96.92	95.45	95.31	96.67	80.00	67.65
IF7	76.36	96.77	95.08	100.00	98.33	94.67	91.80	100.00	100.00	96.72	91.80	94.83
IF8	96.92	100.00	98.39	101.54	100.00	98.57	95.31	98.39	98.59	94.92	92.19	96.55
IF11	100.00	98.39	97.01	63.93	72.73	91.53	90.54	98.48	93.94	101.54	96.92	98.33
IF12	0.00	1.54	98.61	91.80	91.53	78.69	98.48	98.36	95.38	95.45	92.86	94.37
IF13	98.33	98.15	95.65	96.92	100.00	100.00	96.92	100.00	96.49	100.00	98.39	98.44
IF14	85.51	81.82	93.22	95.08	100.00	96.92	100.00	96.67	95.52	101.72	98.51	75.41
IF15	94.83	98.48	96.88	96.88	98.55	96.92	100.00	100.00	97.10	100.00	100.00	100.00
IF16	95.31	100.00	98.41	100.00	98.48	98.51	94.92	100.00	100.00	100.00	98.28	97.26
IF17	98.48	96.92	98.46	96.49	96.67	93.33	95.00	100.00	92.86	96.88	96.72	95.08

	Time Block											
Subject	1	2	3	4	5	6	7	8	9	10	11	12
IN1	98.25	100.00	98.48	100.00	100.00	100.00	98.25	98.36	100.00	95.38	100.00	98.41
IN2	93.55	96.77	89.71	83.87	65.75	78.79	93.55	92.42	79.71	88.14	61.11	71.43
IN3	100.00	96.77	101.59	96.88	98.04	98.41	100.00	93.55	67.57	73.24	95.52	93.94
IN4	94.03	83.33	65.57	39.68	35.94	15.87	61.02	68.57	41.79	88.24	91.94	90.62
IN5	93.22	92.65	96.88	94.83	89.71	91.94	88.73	86.67	93.44	80.60	77.42	81.43
IN8	100.00	95.08	83.33	96.55	96.49	96.67	89.71	85.94	98.41	91.04	98.46	95.31
IN9	100.00	97.14	100.00	98.48	100.00	100.00	98.48	100.00	100.00	98.28	95.52	100.00
IN10	98.59	96.43	97.18	96.97	95.59	98.36	96.61	98.28	95.59	98.39	98.36	96.92
IN11	96.77	98.53	92.06	76.92	81.08	86.89	91.67	95.08	96.67	92.31	94.64	96.77
IN12	100.00	97.06	92.06	98.39	101.49	93.44	97.14	101.56	98.41	96.92	94.20	96.83
IN13	100.00	96.36	98.41	100.00	100.00	100.00	97.37	92.19	94.03	93.33	85.92	88.52
IN14	95.45	90.91	98.48	101.75	98.48	96.88	96.77	100.00	95.16	100.00	96.55	100.00
IN15	97.18	95.59	95.00	95.00	96.49	96.83	98.28	97.06	98.53	96.77	100.00	95.00
IN16	97.06	95.24	96.88	96.92	101.52	100.00	92.98	98.68	95.24	98.39	98.48	96.43
IN17	96.77	100.00	97.01	100.00	100.00	98.57	100.00	100.00	98.28	100.00	100.00	100.00
DF1	88.71	90.91	90.16	88.52	81.25	90.62	80.33	84.62	84.21	80.33	89.66	91.67
DF2	98.41	100.00	100.00	98.48	100.00	98.33	98.46	100.00	98.46	100.00	98.36	100.00
DF3	96.49	98.53	91.07	84.13	98.53	95.08	96.55	91.67	88.71	85.19	76.56	70.00
DF4	98.36	100.00	98.53	68.75	3.08	64.52	0.00	0.00	80.36	95.00	96.49	98.25

Subject	Time Block											
	1	2	3	4	5	6	7	8	9	10	11	12
DF6	100.00	100.00	93.75	93.94	90.00	96.72	88.52	100.00	95.52	96.83	100.00	95.00
DF7	97.14	100.00	96.92	98.59	100.00	100.00	100.00	96.67	95.31	98.41	100.00	96.55
DF8	96.67	100.00	100.00	98.25	100.00	100.00	100.00	96.61	98.31	98.39	100.00	100.00
DF9	95.16	95.38	43.28	13.33	30.30	0.00	67.65	85.94	10.94	1.67	50.00	76.92
DF10	97.33	95.24	96.72	98.39	96.83	82.09	91.80	96.05	100.00	96.61	85.00	95.16
DF11	100.00	100.00	100.00	100.00	98.25	98.57	100.00	100.00	98.15	100.00	100.00	100.00
DF12	89.39	100.00	100.00	96.77	92.75	91.94	89.39	96.97	98.33	101.43	100.00	98.51
DF13	98.46	94.55	95.77	86.36	83.87	93.85	83.87	91.30	83.82	93.22	100.00	94.03
DF14	95.31	98.36	100.00	98.28	98.25	100.00	100.00	100.00	98.18	100.00	100.00	98.31
DF15	93.75	98.33	83.64	89.55	95.59	82.61	85.25	98.33	91.67	96.43	96.88	90.91
DF16	98.41	98.28	98.31	100.00	95.59	91.53	98.59	100.00	98.41	101.67	98.25	101.69
DN1	78.46	71.88	62.50	52.46	34.48	65.22	68.18	80.30	82.81	76.81	85.48	76.92
DN2	100.00	98.21	93.55	96.92	96.61	89.23	96.15	98.39	90.00	85.07	98.39	98.41
DN3	95.08	98.44	95.65	95.59	92.86	92.06	90.77	94.29	90.91	90.48	98.53	96.92
DN4	96.00	92.31	96.92	87.69	89.23	94.37	90.16	82.35	91.53	91.53	88.14	92.06
DN5	94.29	96.61	88.06	93.75	86.36	85.96	84.48	83.61	77.19	63.49	93.44	89.83
DN6	96.61	98.36	96.55	100.00	96.88	98.57	100.00	100.00	98.28	95.71	100.00	100.00
DN7	98.44	97.01	100.00	100.00	98.44	100.00	95.16	100.00	100.00	98.36	98.44	98.46
DN9	98.48	100.00	100.00	96.88	96.97	95.45	96.83	100.00	89.47	98.31	96.55	96.83

	Time Block											
Subject	1	2	3	4	5	6	7	8	9	10	11	12
DN10	100.00	98.31	100.00	100.00	96.92	97.01	101.43	95.31	98.61	100.00	100.00	100.00
DN11	92.31	93.85	95.38	95.31	95.08	98.18	90.00	92.31	87.32	94.12	96.55	88.00
DN12	96.36	95.65	96.61	100.00	98.46	96.97	100.00	98.67	100.00	98.39	98.41	98.28
DN13	96.55	100.00	98.53	95.38	100.00	100.00	96.83	96.83	92.45	100.00	98.39	100.00
DN14	93.33	98.28	100.00	94.92	98.41	96.49	96.83	98.57	98.21	98.04	100.00	98.48
DN15	96.88	98.21	100.00	100.00	100.00	98.46	96.67	98.48	98.61	100.00	96.92	98.48
DN16	100.00	96.55	100.00	96.77	95.77	93.44	86.30	82.46	75.00	74.19	71.19	56.52

Table F4

Mean Scores for Control Group

Time Block	True Signal Hits (%)		False Alarms (%)		Artificial Signal Hits (%)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	94.23	7.27	0.46	0.94	--	--
2	93.01	11.51	0.27	0.64	--	--
3	83.11	23.91	0.54	1.69	--	--
4	86.42	18.33	0.11	0.15	--	--
5	84.41	14.42	0.28	0.35	--	--
6	79.16	22.17	0.34	0.53	--	--
7	81.01	27.71	0.22	0.29	--	--
8	80.77	25.71	0.16	0.17	--	--
9	75.40	28.98	0.23	0.21	--	--
10	76.91	28.69	1.39	4.62	--	--
11	77.31	28.18	0.15	0.17	--	--
12	78.83	26.62	0.19	0.25	--	--

Table F5

Mean Scores for Identical Artificial Signal Group With Feedback (Group IF)

Time Block	True Signal Hits (%)		False Alarms (%)		Artificial Signal Hits (%)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	85.52	26.82	0.52	0.54	88.67	25.33
2	87.86	25.55	0.78	1.69	89.63	24.76
3	93.88	11.39	2.84	5.70	96.03	3.55
4	90.71	11.79	1.85	4.14	94.11	9.41
5	93.48	11.26	2.37	2.98	95.45	6.90
6	94.06	4.95	2.84	5.51	94.37	5.16
7	90.75	13.39	4.36	10.48	95.74	3.34
8	95.05	7.21	4.10	11.10	97.60	3.16
9	96.81	5.96	5.21	12.02	96.24	2.53
10	94.92	7.83	4.01	10.95	96.89	3.14
11	92.18	9.46	6.27	13.06	95.71	5.14
12	92.72	6.92	4.11	9.70	93.24	9.15

Table F6

Mean Scores for Identical Artificial Signal Group, No Feedback (Group IN)

Time Block	True Signal Hits (%)		False Alarms (%)		Artificial Signal Hits (%)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	95.35	8.97	0.77	1.50	97.39	2.45
2	92.69	8.45	0.99	1.47	95.46	4.12
3	93.16	9.04	0.77	1.16	93.51	9.00
4	86.37	16.29	1.43	2.03	91.75	15.83
5	90.18	15.88	1.31	2.21	90.71	17.93
6	81.72	24.53	1.20	1.64	90.18	21.38
7	90.42	10.77	1.02	1.32	93.37	9.63
8	87.72	16.18	0.88	1.49	93.89	8.48
9	85.34	19.05	1.09	1.68	90.19	15.98
10	90.08	12.75	0.94	1.55	92.74	7.62
11	89.29	11.91	1.17	2.60	92.54	10.60
12	94.48	9.28	1.03	2.09	93.44	7.86

Table F7

Mean Scores for Distinct Artificial Signal Group With Feedback (Group DF)

Time Block	True Signal Hits (%)		False Alarms (%)		Artificial Signal Hits (%)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	88.24	14.77	1.36	1.79	96.24	3.39
2	88.73	19.10	2.04	2.51	97.97	2.74
3	78.35	22.78	3.45	5.97	92.54	14.42
4	74.50	28.27	2.48	3.13	87.56	22.21
5	72.49	28.02	3.51	5.24	84.29	28.50
6	73.51	28.28	3.96	7.66	85.72	25.53
7	71.92	26.35	2.87	4.38	85.36	25.39
8	76.17	28.60	2.96	6.91	89.21	25.19
9	71.43	26.59	2.94	4.65	88.03	22.25
10	77.68	32.58	3.09	5.04	89.68	25.06
11	79.32	23.18	2.40	3.16	92.75	13.68
12	84.19	16.24	2.43	3.25	93.80	8.92

Table F8

Mean Scores for Distinct Artificial Signal Group, No Feedback (Group DN)

Time Block	True Signal Hits (%) Mean	True Signal Hits (%) S.D.	False Alarms (%) Mean	False Alarms (%) S.D.	Artificial Signal Hits (%) Mean	Artificial Signal Hits (%) S.D.
1	89.93	13.25	0.99	2.08	95.52	5.28
2	86.45	21.75	0.81	1.62	95.58	6.88
3	88.71	12.64	0.95	1.75	94.92	9.55
4	81.79	23.24	0.68	0.85	93.71	11.88
5	84.87	15.87	0.98	1.24	91.76	16.30
6	79.92	16.61	0.72	1.06	93.43	8.75
7	82.76	15.39	0.62	0.63	92.65	8.43
8	80.82	21.77	0.73	0.78	93.44	7.38
9	81.63	21.24	0.92	0.75	91.36	8.08
10	83.88	15.50	0.79	0.86	90.97	11.22
11	77.52	25.30	0.89	0.93	94.70	7.78
12	80.28	20.00	0.67	0.79	92.61	11.79

Table F9

Decrement Coefficient, MS Residual, d' and β Values

	True Signal Hits		Artificial Signal Hits			
Subject	Decrement Coefficient	MS Residual	Decrement Coefficient	MS Residual	d'	β
C1	-0.62	24.82	--	--	4.980	9.419
C2	-0.40	172.61	--	--	4.053	34.551
C4	-3.14	909.16	--	--	1.870	21.499
C5	-0.02	89.51	--	--	4.579	130.117
C6	-0.04	93.20	--	--	4.566	39.877
C7	-1.64	546.48	--	--	3.052	14.798
C8	2.38	466.55	--	--	3.181	5.825
C9	0.09	185.80	--	--	3.458	24.327
C10	-0.57	160.03	--	--	3.873	38.376
C11	0.03	9.15	--	--	5.679	18.443
C12	-0.40	295.35	--	--	3.720	44.157
C13	-0.37	75.78	--	--	4.998	71.368

	True Signal Hits		Artificial Signal Hits			
Subject	Decrement Coefficient	MS Residual	Decrement Coefficient	MS Residual	d'	β
C14	-2.13	627.97	--	--	3.235	28.414
C15	-0.18	25.52	--	--	4.629	13.592
C16	-1.64	48.07	--	--	3.827	16.885
IF1	0.69	58.89	-0.22	32.82	3.009	4.636
IF2	-1.29	137.48	-0.18	7.36	3.538	4.550
IF3	0.39	9.40	0.15	9.00	4.566	2.848
IF4	0.22	63.71	0.00	7.22	4.263	5.068
IF5	0.00	0.00	-0.21	2.32	--	--
IF6	0.61	103.72	0.66	86.77	3.794	10.322
IF7	1.06	235.97	1.04	30.35	3.348	20.477
IF8	0.10	29.33	0.30	6.09	4.263	5.068
IF11	0.16	116.95	-0.99	135.26	2.707	1.034
IF12	4.70	1236.90	4.54	1170.60	2.274	1.958
IF13	0.39	7.05	-0.06	2.53	4.902	1.843
IF14	0.61	40.03	0.84	63.30	4.128	11.330

Subject	True Signal Hits: Decrement Coefficient	True Signal Hits: MS Residual	Artificial Signal Hits: Decrement Coefficient	Artificial Signal Hits: MS Residual	d'	β
IF15	-0.09	66.94	0.03	3.38	2.351	0.332
IF16	0.13	4.45	0.11	3.41	4.838	1.568
IF17	-0.54	23.88	-0.20	4.21	4.327	5.960
IN1	0.20	16.06	0.15	1.79	5.144	14.380
IN2	-2.15	319.95	0.18	150.76	2.151	2.705
IN3	-0.15	175.47	-0.42	127.47	3.099	6.322
IN4	-4.59	366.43	-5.28	358.12	2.697	11.595
IN5	-0.65	182.20	0.62	36.82	3.541	8.230
IN8	-0.91	48.89	-0.35	28.63	4.128	11.333
IN9	-0.10	15.25	0.15	2.04	4.971	20.208
IN10	-0.74	13.37	-0.15	1.03	4.338	3.492
IN11	-0.25	281.60	-0.40	47.50	3.684	9.649
IN12	-0.99	11.24	0.17	9.39	4.393	11.273
IN13	-0.60	196.32	0.26	24.24	3.271	5.285
IN14	0.15	151.49	0.03	9.35	4.153	16.249

Subject	True Signal Hits		Artificial Signal Hits			
	Decrement Coefficient	MS Residual	Decrement Coefficient	MS Residual	d'	β
IN15	-0.11	49.95	0.06	2.64	3.802	5.038
IN16	0.02	37.75	-0.07	5.72	4.263	5.068
IN17	0.28	17.83	0.04	1.68	5.144	14.380
DF1	-1.58	585.90	-0.39	18.53	1.879	4.399
DF2	-0.13	22.17	-0.03	0.74	5.144	14.380
DF3	0.30	220.88	0.81	80.21	1.792	6.531
DF4	-7.28	940.03	-7.75	1035.06	2.905	32.611
DF6	-1.81	119.85	-0.43	14.13	3.168	10.504
DF7	-0.22	123.08	-0.06	3.20	3.827	16.885
DF8	-2.22	1248.65	0.00	1.96	2.081	12.576
DF9	-2.11	175.23	-2.29	1374.56	2.975	6.130
DF10	-0.10	26.56	0.05	32.22	4.629	7.437
DF11	-2.22	69.06	-0.12	0.46	3.204	10.182
DF12	0.80	143.54	-0.26	19.46	2.242	4.327
DF13	-0.50	30.57	-1.17	17.04	3.197	0.406

	True Signal Hits		Artificial Signal Hits			
Subject	Decrement Coefficient	MS Residual	Decrement Coefficient	MS Residual	d'	β
DF14	-1.34	50.40	0.13	1.96	3.507	14.310
DF15	-0.28	54.11	-0.46	32.04	3.885	6.125
DF16	0.00	0.00	-0.24	7.33	3.573	3.033
DN1	-1.40	279.57	-0.78	224.26	3.051	4.442
DN2	-2.73	320.87	-0.19	23.15	2.455	8.451
DN3	-0.39	67.01	-0.37	7.16	4.224	14.675
DN4	-1.50	84.08	-0.44	14.55	3.251	12.772
DN5	0.31	308.93	-0.40	88.32	2.334	18.149
DN6	-1.25	159.62	0.17	2.49	3.915	36.775
DN7	-0.79	4.74	0.07	2.35	5.248	19.964
DN9	-0.25	82.84	-0.35	7.22	3.923	21.864
DN10	0.46	75.51	-0.23	2.67	4.393	11.273
DN11	0.34	263.32	-0.22	11.66	3.113	7.353
DN12	0.95	72.90	0.21	1.79	3.857	12.137
DN13	0.10	76.69	-0.31	4.94	4.219	25.613

	True Signal Hits		Artificial Signal Hits			
Subject	Decrement Coefficient	MS Residual	Decrement Coefficient	MS Residual	d'	β
DN14	0.28	94.35	0.08	4.13	4.224	14.675
DN15	0.75	55.91	0.03	1.74	4.283	23.448
DN16	0.13	863.58	0.30	211.80	2.321	5.322

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