THE EFFECTS OF KNOWLEDGE OF RESULTS ON REACTION-TIME IN A VIGILANCE SETTING

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ABSTRACT

The first part of this study is a replication of an earlier one which was designed to assess the relative effects on reaction-time of providing and withholding knowledge of results of performance. In this earlier investigation superior performance was observed under the knowledge treatment but it could not be determined whether this was due to knowledge of results _per se_ or to the additional stimulation resulting from the way in which the knowledge was conveyed. The second part of the present study was carried out with the purpose of deciding between these alternatives.

In Experiment A 20 subjects participated on each of two consecutive days, knowledge being provided on one day and withheld on the other. Under the knowledge treatment a red light was presented following slow, and a green light following fast responses. These lights were not employed under the no knowledge condition. In Experiment B 20 additional subjects participated in a second no knowledge condition where the red and green lights were presented simultaneously following the elicitation of a response.

For both of the no knowledge treatments reaction-time increased as a function of task duration and decreased with length of interstimulus interval. Under the knowledge condition performance remained invariant with respect to both task duration and interval length. This

investigation thus demonstrates that knowledge of results *per se*, and not the more variable perceptual field resulting from the way in which knowledge is delivered, maintains performance at an optimal level throughout the duration of an experimental session.

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CHAPTER I

THE PROBLEM AND INTRODUCTION

Advances in remote control operations and pushbutton technology since the time of the second World War have directed the attention and interest of scientists toward the investigation of human functioning under conditions of isolation, monotony and prolonged monitoring. Detection tasks such as those employed in the operation of electronic devices in military and industrial systems have necessitated research in the area of vigilance where the capability of the human observer to maintain his attentiveness over relatively long periods of sustained observation is crucial. A vigilance task may be described as one in which the observer must detect and report any sensory changes which appear at infrequent intervals in his environment, and which are not predictable by him. There has grown a gratifying volume of research in this area which has been summarized by McGrath, Harabedian and Buckner (1959).

Mackworth (1948, 1950) was the original investigator in the area of human vigilance. He devised the Clock Test which consists of a plain black clock hand mounted on a vertical unmarked white surface, the hand moving to a new position once every second. At irregular intervals there is a double deflection which the observer must detect and report by pressing a key. Mackworth also developed an auditory Clock Test in which the observer's task was to detect differences in the duration of intermittently presented tones. A variety of other displays have since been employed, including variations of the Clock Test, as well as simulated radar and sonar screens, light signals and meters. Mackworth studied the effects on performance of such variables as time on watch, interpolated rest, size of clock hand, knowledge of results, "Benzedrine" and atmospheric temperature. His most consistent finding, as well as that of others who have performed subsequent studies, has been that percentage of missed signals has shown a reliable increase with time on task. He postulated that this decline in performance over time was due to an inhibitory process similar to that discussed by Pavlov (1927). Where reaction-time has been employed as the dependent variable, performance has also been observed to deteriorate over time on task and in sessions as short as 35 minutes (Baker, 1959; Garvey, Taylor and Newlin, 1959; McCormack, 1958, 1959, 1960; McCormack and Pryziazniuk, 1961).

A review of the vigilance literature reveals only three previous studies where the effects on performance of providing and withholding knowledge of results have been investigated (Baker, 1959a; Mackworth, 1950; McCormack, 1959). These have not been uniform in their designs; in one case knowledge was presented verbally, while in the other two, knowledge of results was delivered impersonally through an automatic feedback system. Two of these studies involved percentage of detected signals as a measure of performance, whereas latency of response was employed as the dependent variable in the third.

Mackworth (1950) was the first to explore this problem. He used his Clock Test, in which subjects were required to detect double jumps of the hand during four blocks of intervals of 3/4, 3/4, 1 1/2, 2, 2, 1, 5, 1, 1, 2, 3 and 10 minutes. Subjects performing without knowledge of results of their watch-keeping showed a significant decrement in their performance. However, when he immediately informed these subjects through a loudspeaker of the correctness or incorrectness of their responses, and of their failures to respond, no reliable performance decrement occurred. Mackworth's findings were consistent with his theory that performance decrement is due to the accumulation of inhibition which is generated only when responses are non-reinforced. Since providing knowledge of results presumably serves as a reinforcer, performance decrement would not be expected to occur. His findings, however, provide no conclusive evidence with respect to the influence on performance of knowledge of results _per se_, because of the possible confounding with motivational variables associated with the personal communication.

Baker (1959a), on the other hand, used a non-personal method of communicating knowledge of results. Using Mackworth's interval schedule, he presented his subjects with a simulated radar screen, the subjects reporting their signal detections by pressing a button. For the knowledge of results treatment a second display above the main one was employed, on which the words "correct", "missed" or "false" were appropriately illuminated. He compared three experimental conditions. The "No Information" treatment consisted of presenting signals with no information given whether detections were correct, missed or falsely reported. In the "Knowledge of Results" treatment this information was always presented. In the third or "Feedback" treatment no information was provided if a signal was detected or falsely reported, but if a signal was missed it was repeated at five second intervals until it was reported. Using percentage of missed signals as a measure of performance, Baker reported that a significant decrement occurred where no information was given about performance, but that no such decrement appeared under either the "Knowledge of Results" or simple "Feedback" conditions. It appears from the Baker study that it is not knowledge of results *per se* which is responsible for the lack of performance decrement under the "Knowledge of Results" treatment, but rather something common to both the "Knowledge of Results" and "Feedback" conditions.

McCormack (1959), like Baker, also used a non-personal method of communicating knowledge of results of performance. The dependent variable was response time to a light signal presented at random intervals through an aperture. Under the knowledge treatment a red light flashed on a panel alongside the aperture each time the subject made a response which was slower than the preceding one. If a faster response was made, a green light appeared. These lights were not employed in the no knowledge treatment. He reported that for both conditions, reaction-time increased systematically with time on task, the greatest amount of change occurring under the no knowledge treatment, and that reaction-time was a decreasing function of length of interstimulus interval. McCormack postulated that inhibition accumulates during an experimental session but at a faster rate under the no knowledge than under the knowledge condition, and that it dissipates between stimulus presentations, the rate of dissipation being the same whether or not knowledge of results is provided. However, he later indicated (McCormack and Pryziazniuk, 1961) that the findings of the no knowledge portion of the study were atypical in two respects: the slope of the function relating reaction-time to task duration was reliably steeper than that observed in one earlier (McCormack, 1958) and two later investigations (McCormack, 1960; McCormack and Pryziazniuk, 1961), and an interval effect was observed whereas such an effect was not obtained in the other studies. Because of these atypicalities, the knowledge portion of the study is also questionable.

None of the three investigations described above conclusively demonstrates that knowledge of results per se is responsible for the reported lack of decrement in performance. The possibility exists that what was actually responsible was the presentation of the additional stimulation provided by the verbal instructions (Mackworth, 1950), additional displays (Baker, 1959a) or the red and green pilot lights (McCormack, 1959). There have been no previous studies designed to investigate the relative importance of these alternatives. Relevant to this question is the suggestion made by Scott (1957) that changes in the structure of the perceptual field serve to maintain performance at an optimal level. Scott surveyed the experimental literature concerned with performance deterioration in the execution of repetitive tasks, and made the observation that rapid deterioration occurred when background stimuli were at a minimum and when only occasional critical stimuli were present. He proposed that the introduction of extraneous factors such as other stimuli, rest periods, knowledge of results or interpolated activity might serve to increase the variability of the stimulus field which would be directly responsible for the maintenance of the alertness of an observer.

Thus, there are two major purposes in conducting this study. The first is to replicate an earlier one (McCormack, 1959) where the findings were atypical. The second is to investigate Scott's suggestion that the increase in the variability of the stimulus field provided by the presentation of knowledge of results maintains performance at an optimal level rather than knowledge of results *per se*.

Experiment A was therefore designed with the purpose of reassessing the relative effects on reaction-time of providing and withholding knowledge of results of performance. Should little or no decrement be obtained under the knowledge condition, it would not be known whether this is due to knowledge *per se* or to the additional stimulation provided by the red and green pilot lights employed to convey the knowledge. Experiment B was therefore designed with the purpose of deciding which of these alternative hypotheses is most feasible.

CHAPTER II

EXPERIMENTAL METHOD

Subjects

Forty volunteer Introductory Psychology students served as subjects. Twelve males and eight females participated in Experiment A. In Experiment B, 14 males and six females were employed. No attempt was made to have an equal number of males and females in each experiment since it had been demonstrated previously (McCormack, 1960) that there are no appreciable sex differences in tasks of this type. The ages of the subjects ranged from 17 - 29 years, with 32 of the 40 falling into the 17 - 19 year age range.

Apparatus

The apparatus employed was identical to that used in previous studies (McCormack and Pryziazniuk, 1961). The relevant stimulus was the presentation of a light from a 15-watt bulb located in the back of a black box one ft. wide, 1 1/4 ft. high and two ft. long. The box was placed at a distance of 15 ft. from the subject. The light, appearing through a one cm. aperture in the centre front surface of the box, was presented for 100 msecs. sufficiently above threshold to be consistently detected. The subject's task was to depress a microswitch as quickly as possible each time the light appeared through the aperture. A red and a green pilot light, which could be used to provide knowledge of results of performance, were mounted on a panel alongside the black box.

The experimenter was located in an adjoining room where she controlled the onset and duration of the light with a switch and a Hunter Decade Interval Timer, and recorded reaction-time in millisecs. by means of a Hunter Klockounter. A second timer, set for two secs., indicated missed signals in which case the experimenter immediately presented the light for a second time in order not to disturb the interval sequence.

Procedure

The subject was seated comfortably in a sound-deadened room, his wrist-watch was removed, and he was told that the testing session would last approximately one-half hour, although its duration was actually 35 mins.

A five min. period of instruction and practice preceded each experimental session. The subject was told to hold his thumb very lightly on the switch and to depress it as quickly as possible each time the light appeared. He was also instructed to watch the aperture at all times since the light would be presented at infrequent intervals and there would be no way in which he could predict when the light was to appear. To insure that the subject understood the directions the light was presented and responded to seven times at 10 sec. intervals after which he was asked whether he had any questions relating to the instructions.

Following the instruction period the light was presented 36 times to each subject, the intervals between stimuli being 30, 45, 60, 75 and 90 secs. The overall interstimulus order was different for each, with the provision that all subjects experience each of the five intervals once in every five mins. The interval sequence in any five min. block was selected at random from the 120 possible combinations.

In Experiment A 20 subjects participated on each of two consecutive days. Ten were provided with knowledge of results of performance on the first day, while the remaining 10 received the knowledge condition on the second day. Under the knowledge treatment (K) the red or green pilot light was illuminated for three secs. immediately following each response. The red light indicated a reaction-time which was slower than the previous one while the green light signalled a faster response. These colored lights were not used under the no knowledge treatment (N).

The same apparatus was employed in Experiment B in which 20 different subjects participated in a single experimental session. The red and green lights were presented simultaneously immediately following each response to indicate to them that their reaction times had been recorded.

Non-qualifying subjects. Subjects were disqualified who, in any single experimental session, missed more than one stimulus or held their thumb down on the switch on more than one ocassion. Upon noting either of these events the experimenter immediately presented another stimulus. Seven subjects failed to qualify, two as a result of apparatus failure and five because of innatentiveness to the stimuli.

CHAPTER III

EXPERIMENTAL FINDINGS AND DISCUSSION OF RESULTS

I. EXPERIMENTAL FINDINGS

Results of Experiment A

The major findings of this part of the investigation are summarized in Figures 1 and 2 where reaction-time is plotted as a function of task duration and length of interstimulus interval for both the knowledge (K) and no knowledge (N) conditions. The highly variable performance over time on task for the subjects receiving the knowledge treatment precluded a combined analysis of these data.

Table I represents a summary of an analysis of variance of the data obtained under the no knowledge condition. A pooled error

TABLE I

Analysis of Variance of Reaction-time for all Subjects in Experiment A Experiencing the No Knowledge Condition

Source	df	Sum of Squares	Mean Square	F
Subjects (S)	19	923,918.0	48,627.3	
Time Blocks (T)	6	46,776.7	7,794.4	3.041*
Interstimulus interval (I)	4	38,804.5	9,701.1	3.785**
T X I	24	88,230.8	3,676.3	1.434
S X T	114	298,429.1	2,617.8	1.021
S X I	76	225,846.5	2,971.7	1.159
S X T X I	456	1,131,351.4	2,481.0	0.968
(pooled error)	(646)	(1,655,627.0)	(2,562.9)	
Total	699	2,753,359.0		

* $P < .01$
** $P < .001$

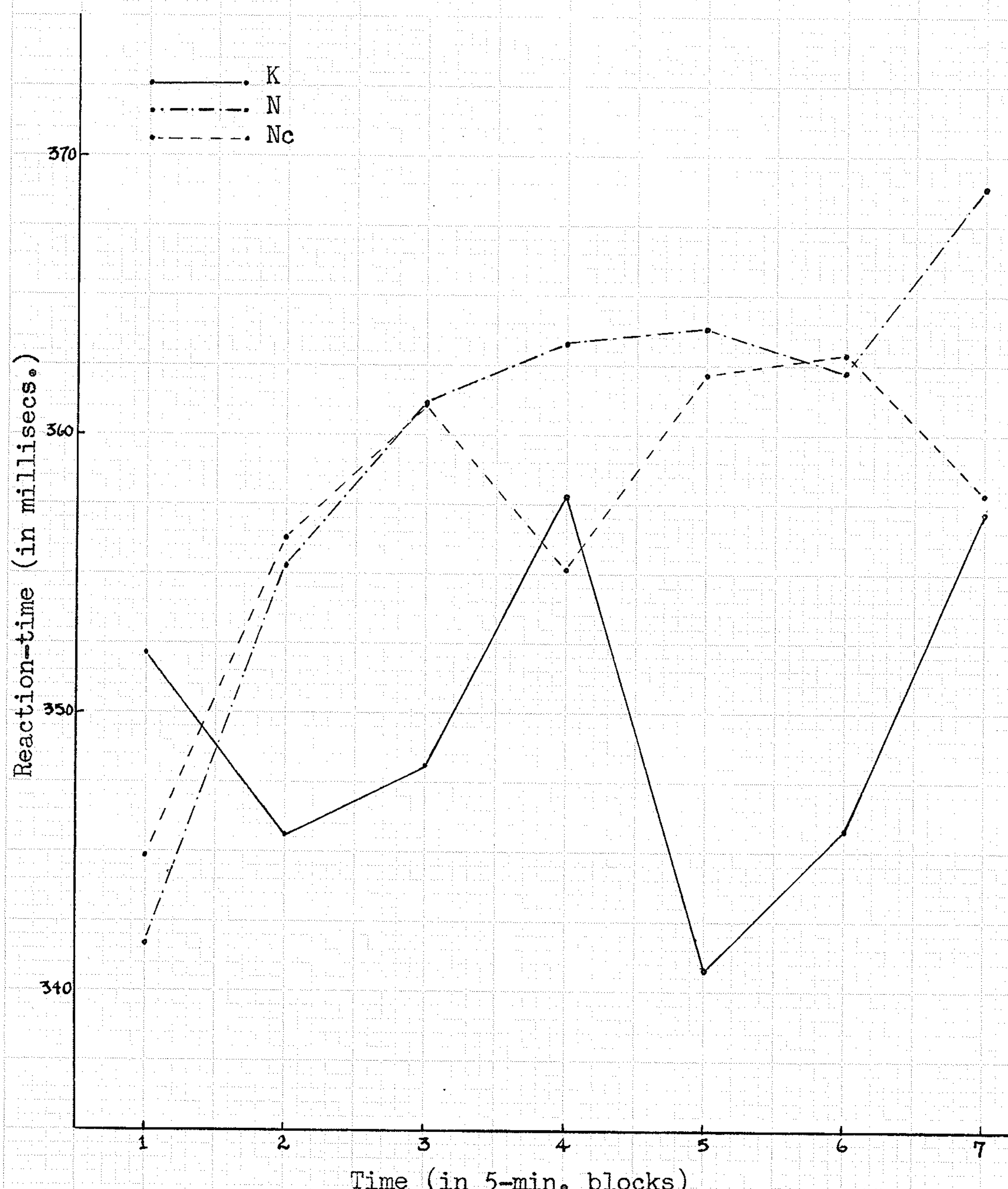

Figure 1. Reaction-time as a function of successive 5-min. time blocks

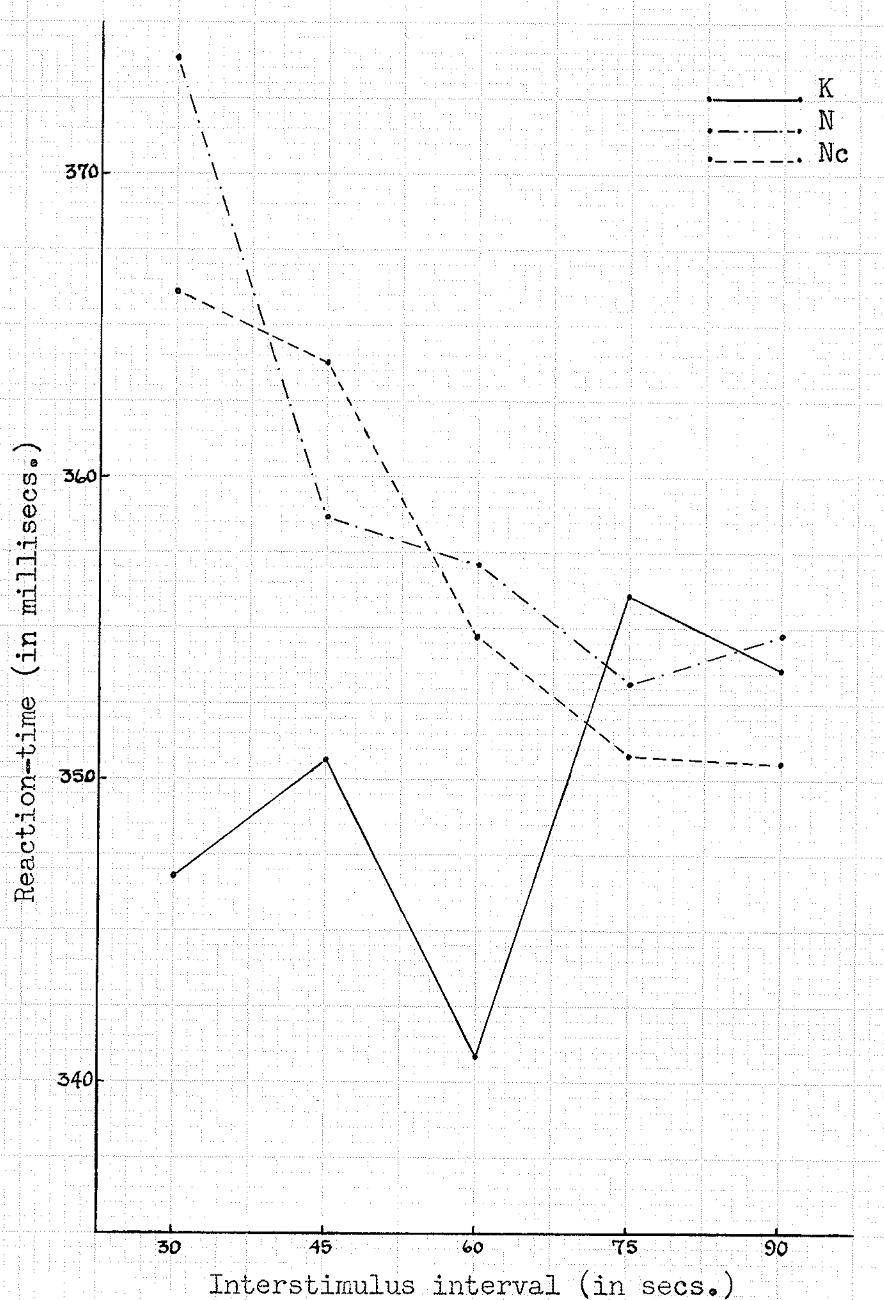

Figure 2. Reaction-time as a function of length of interstimulus interval

term was used since the subject interaction mean squares were relatively homogeneous. An examination of Figure 1 and Table I reveals a reliable systematic increase in reaction-time with time on task. The difference between the first and last trial blocks was found to be 27.19 msecs., the predicted difference being 23.05 msecs. (McCormack and Pryziazniuk, 1961). A highly dependable interval effect was also obtained, reaction-time being inversely related to length of interval. No other statistically reliable effects were observed.

Table II represents a similar analysis of variance of the data obtained under the knowledge treatment. No dependable main effects

TABLE II

Analysis of Variance of Reaction-time for all Subjects in Experiment A Experiencing the Knowledge Condition

Source	df	Sum of Squares	Mean Square	F
Subjects (S)	19	1,191,031.6	62,685.9	
Time Blocks (T)	6	23,967.8	3,994.6	1.699
Interstimulus interval (I)	4	20,019.3	5,004.8	2.128
T X I	24	55,948.9	2,331.2	0.991
S X T	114	398,346.1	3,494.3	1.486
S X I	76	184,411.1	2,426.5	1.032
S X T X I	456	936,258.7	2,053.2	0.873
(pooled error)	(646)	(1,519,015.9)	(2,351.4)	
Total	699	2,809,983.5		

or interactions were observed.

Thus it is apparent from Figures 1 and 2 and Tables I and II that under the no knowledge treatment, reaction-time is an increasing function of time on task and a decreasing function of length of interstimulus interval, whereas when knowledge of results of performance is provided reaction-time is invariant with respect to both task duration and interval length.

Results of Experiment B

The findings for the stimulation control (Nc) condition are also summarized in Figures 1 and 2. A summary of an analysis of variance of the data obtained under the no knowledge and stimulation control conditions is presented in Table III. This analysis represents

TABLE III

Analysis of Variance of Reaction-time for all Subjects Experiencing the No Knowledge and Stimulation Control Conditions

Source	df	Sum of Squares	Mean Square	F
Between Subjects	39	2,503,282.3	64,186.7	
Betw. Conditions (C)	1	1,812.6	1,812.6	0.028
residual	38	2,501,469.7	65,828.2	
Within Subjects	1360	3,694,570.7		
Time Blocks (T)	6	61,288.5	10,214.7	3.885**
Interstimulus interval (I)	4	62,904.5	15,726.1	5.981**
T X I	24	76,285.6	3,178.6	1.209
C X I	4	6,255.7	1,563.9	0.595
C X T	6	8,381.4	1,396.9	0.531
C X T X I	24	82,187.2	3,424.5	1.302
residual	1292	3,397,267.8	2,629.5	
Total	1399	6,197,853.0		

** $P < .001$

a combination of two separate factorial analyses, one for each of the two conditions. These data were combined only after it was apparent that the subject interactions were of the same order of magnitude in each of the separate analyses. The two residual mean squares of Table III were used as error terms.

Examination of Figures 1 and 2 and Table III indicates a highly dependable trials effect as well as a reliable intervals main effect for both of the no knowledge conditions. No other statistically dependable effects were observed. Thus, for both the no knowledge treatments, reaction-time increases with time on task and decreases with length of interstimulus interval.

II. DISCUSSION OF RESULTS

For the no knowledge (N) and stimulation control (Nc) treatments reaction-time is an increasing function of task duration. This finding is consistent with previous studies where no knowledge treatments have been employed (Adams, 1956; Baker, 1959; Mackworth, 1950; McCormack, 1958, 1960; McCormack and Pryziazniuk, 1961). It is also consistent with the Mackworth and McCormack postulates that inhibition accumulates over time on task under such conditions. These findings, however, do not support Scott's hypothesis that the efficiency and alertness of an observer are maintained at an optimal level when stimulus variation is introduced into the perceptual field.

Rather, they suggest that additional stimuli are more effective in maintaining efficiency only when they convey pertinent information such as knowledge of results of performance.

When knowledge of results is provided, reaction-time is invariant with time on task. This finding conflicts with an earlier study which was designed to assess the relative effects on performance of providing and withholding knowledge of results (McCormack, 1959). In this earlier investigation reaction-time was found to increase systematically over time on task for both no knowledge and knowledge treatments, the increase being less pronounced under the latter condition. To account for these findings, McCormack postulated that inhibition is generated at a faster rate when knowledge is withheld. However, results of a study performed subsequent to the preparation of this manuscript (McCormack, Binding, and Chylinski, 1962) are in agreement with the present investigator's findings. In the light of the observations of the present study and those reported subsequently, as well as of the highly questionable status of the earlier McCormack findings, the evidence for which has been discussed elsewhere (McCormack and Pryziazniuk, 1961), it may reasonably be concluded that the provision of knowledge of results of performance prevents any systematic increase in reaction-time during the course of an experimental session. This is consistent with the Mackworth hypothesis that knowledge of results serves as a reinforcer and that inhibition will build up only in the absence of reinforcement of the response.

For both the no knowledge and stimulation control treatments, performance is an increasing function of length of interstimulus interval, whereas an invariant relation is observed when knowledge of results of performance is provided. The findings for the no knowledge and stimulation control conditions are consistent with some studies (Dardano and Mower, 1959; Mackworth, 1948; McCormack, 1959), but inconsistent with others where invariant (Deese and Ormond, 1953; Jerison and Wallis, 1957; McCormack, 1958, 1960; McCormack and Pryziazniuk, 1961), decreasing (Bartlett, et al, 1955; Jenkins, 1958), or nonmonotonic relations (Kappauf and Powe, 1959; Mackworth, 1950) have been reported. This phenomenon is apparently a transitory one, the conditions under which it will appear having yet to be determined. Thus, when knowledge of results of performance is withheld, it appears that inhibition will sometimes dissipate between stimulus presentations. The observed invariant relation between reaction-time and length of interstimulus interval when knowledge of results of performance is provided is consistent with this notion, since there is no inhibition to dissipate under such a condition.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Experimentation in the area of vigilance is relatively recent, the major portion of the work being carried out in the last decade. Investigations concerning the effects on reaction-time of providing knowledge of results of performance have not yielded consistent findings nor have they contributed to the formulation of a systematic theory of vigilance. The present study is a replication of an earlier one which was designed to assess the relative effects on reaction-time of providing and withholding knowledge of results (McCormack, 1959), the findings of which were subsequently reported as being questionable (McCormack and Pryziazniuk, 1961). In addition, it could not be determined from the earlier investigation whether the relatively superior performance observed under the knowledge treatment could be attributed to the observers receiving knowledge of results *per se*, or rather, to a more variable perceptual field resulting from the particular way in which the knowledge was provided. The second part of this study was therefore carried out to decide between these two alternatives.

Forty Introductory Psychology students served as subjects, their task being to depress a microswitch as quickly as possible in response to the presentation of a light appearing on the average once per min., with the intervals between lights being 30, 45, 60, 75 and

90 secs. In Experiment A 20 subjects participated in 35 min. sessions on each of two consecutive days, knowledge of results being provided on one day and withheld on the other. Under the knowledge treatment a red or a green light was illuminated immediately following each response. The former indicated a reaction-time which was slower than the preceding one while the latter signalled a faster reaction-time. These lights were not employed under the no knowledge treatment. In Experiment B 20 different subjects served in a single 35 min. session under a second no knowledge condition in which the two lights were presented simultaneously following the elicitation of a response.

For both of the no knowledge treatments reaction-time increased as a function of task duration and decreased with length of interstimulus interval. Under the knowledge condition performance remained invariant with respect to both task duration and interval length. Thus, it may be concluded that performance deteriorates systematically with time on task when knowledge of results is withheld, but shows no change over time when knowledge is provided. These findings demonstrate that knowledge of results *per se*, and not the additional stimulation resulting from the way in which knowledge is delivered, maintains performance at an optimal level throughout the duration of an experimental session.

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