SOME RECENT STUDIES IN PSYCHOLOGICAL RFFRACTORY PHASE

K. B. LALL

Directorate of Psychological Research, New Delhi

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An attempt has been made to review the literature on psychological refractory phase. Experimental studies and their theoretical analysis have been discussed and the inadequacy of the existing theories has been brought out. Evidence for a single-channel decision mechanism has been emphasized.

The term "Psychological Refractory Phase" has been analogically derived from nerve physiology. It refers to the period of reduced sensitivity in nerves and muscles and was coined in 1876 by Marey, who discovered the refractoriness of cardiac muscle. When two stimuli are presented for reactoin the time taken to respond to the second stimulus is sometimes unduely long when the stimuli are closely spaced consecutive signals. This delay in the response to the second of a pair of closely spaced consecutive signals is now a well established phenomenon. The lengthening of reaction time is inversely related to the duration between the onset of the two stimuli provided this duration is less than about 250 milliseconds. The widely held suggestion that there is a refractory period of about half a second following the making of a response seems to have come from Telford[1]. Previous work on tracking-performance by Craik[2], Vince[3] and others suggests that the upper limit on the number of items that can be dealt with in a given time is largely due to three factors, *viz.*, reaction time, movement time and refractory phase. Once a response has been initiated the central mechanism goes, for a fraction of a second, into a refractory phase during which nothing fresh can be done. As a result, tracking consists of a series of discrete stimulus-response units, although the movements may run smoothly into one another and may not be distinguishable. One important effect of this is that each movement of the subject's pointer in a tracking task has to be made with reference not only to the position of the target-pointer at that time but also to the position it will occupy a fraction of a second later. The above fact of cyclic motor responses in continuous tracking tasks has been an indirect evidence in support of the hypothesis of a psychological refractory phase. The most direct evidence, however, comes from experiments in which two discrete stimuli have been presented in rapid sequence.

EXPERIMENTAL EVIDENCE

Davis[4] has classified the experimental evidence into three categories: (*i*) experiments on continuous tracking of a moving target in which corrections are made by the operator at his own discretion. These corrections are usually made at intervals of more than half a second (*ii*) experiments on step tracking which means distinct movements of definite length where the subject uses graded responses. The operator may be following a straight line with a pencil and be faced with a sudden jump in the line to a new position parallel to the first. He has to move the pencil over the new position. Vince[3] has shown that if another step back to the original position is required less than approximately half a second after the first, the second response is delayed. While using graded responses, such as step-tracking, feed-back from the response is necessary for correct performance and (*iii*) experiments on ungraded responses or on the stopping of movements by Poulton[5] such as key-pressing reactions to sounds with varying intervals between the stimuli. I, such experiments where feed-back though possibly utilised is not essential to practised subjects, Telford[1] has reported allowing of response when the stimuli are only half a second apart.

EVIDENCE OF A SINGLE CHANNEL DECISION MECHANISM (SCDM)

There is a single channel decision mechanism of limited capacity between the sensory input system (which can receive one, or a series of events) and the motor output system (which can initiate one, or a series of responses). Evidence of a single-channel mechanism is provided by the work of Welford [6,7] Vince[3,3], Fraisse[9], Hick[10], and Davis[4,11]. Both Vince[8] and Davis[11] showed that if one signal for action S_2 followed colsely upon another S_1, the response to S_2 was likely to be longer than was normal for a signal well separated from others in time. Davis's[11] results indicated that delay occurred when S_2 arrived during a period nearly equal to the reaction time of S_1 *i.e.*, TR_1 but not if it arrived later. Vince's[8] results, however, showed that substantial delays also occurred when S_2 arrived during or shortly after the movement M_1 made in response to the previous signal. The fact ascertained by Vince[8] were incorporated, along with others, in a theory by Welford[6], that the delays were due to a single-channel decision mechanism somewhere in the subject's central mechanisms which could be occupied either by dealing with signals from the outside or by monitoring the subject's responding movements—a process which Hick[10] suggested would almost inevitably occur. It seemed that the channel dealt with items in the order of their arrival to the extent that if S_2 arrived before the end of TR_1, it was dealt with as soon as TR_1 had ended but that if M_1 had started before S_2 appeared, some monitoring of M_1 had to be completed before the single-channel began to process the information from S_2.

Davis's[11] conclusion that no delays occurred when S_2 arrived after the end of TR_1, has been supported by Marill[12]. Elithorn and Lawrence[13], and Fraisse[9]. The interpretation of all these results is doubtful because if delays occur due to the monitoring of M_1 we should expect them to bear some relation to its duration, but this has never been measured since Vince's[8] work. Interpretation and analysis have, indeed, been excessively difficult in all the work previously reported because much of the theory has been couched in terms of the time at which S_2 arrived in relation to TR_1 or M_1 but the results have been analyzed in terms of the time between S_1 and S_2. If TR_1 is variable in length, as it always is, there is a zone of intervals between S_1 and S_2 over which it is uncertain whether S_2 arrived before or after the end of TR_1. The results of Welford's[7] experiment taken as a whole confirm his hypothesis of a single-channel decision mechanism. His main findings can be taken as evidence for the following:

(*a*) The response to a signal, arriving during the reaction time to a former signal, will be delayed by an amount approximately equal to the time elapsing between the arrival of the signal and the level of the reaction time to the former signal.

(*b*) An exception to this may occur when two signals arrive close together. In this case the two signals may be responded to as a single group.

(*c*) Delays can be occasioned by the monitoring of responses as well as by reactions to signals.

(*d*) "Grouping" of signals and monitoring may occur when a signal arrives close to the beginning of the movement made in response to a previous signal.

Davis[14] confirms his suggestion that there may be a common analysing and classifying system for auditory and visual information and also illustrates a new point, *viz.*, it is paying attention to a signal rather than performing any overt response to it which gives rise to delays in subsequent responses.

THEORETICAL ANALYSIS

Five types of theory have been advanced to account for the delays in responding to a signal which closely follows a previous signal:

First theory:

The first theory enunciated by Welford[6], and elaborated by Davis[4], is based on (*a*) the central processes concerned with two separate stimuli not being able to co-exist and (*b*) there is a single channel of limited capacity in the central mechanisms. Essentially this theory assumes: (*i*) a number of sensory input mechanisms each capable of receiving data and storing it for a limited period so that, a short series of signals can be received as a unit (*ii*) a number of effector mechanisms containing both central and peripheral elements and capable of carrying out a series of actions such as the pressing and release of a key or a series of taps as a single unit and (*iii*) it also postulates a single-channel decision mechanism between these two. Thus it is regarded as being of limited capacity in the sense that it takes a finite time to process information and deals with a limited amount of information in a given time.

It is further implied that sensory input data can be accumulated while the decision channel is occupied by dealing with previous data, and can be passed together to the decision channel as soon as it is free. Similarly the decision channel can "issue orders" to the effector side for a series of responses the execution of which can overlap with the decision channel's dealing with fresh input. Sensory feed-back data from responsding actions may, however, "capture" the decision channel, *i.e.*, responses may be monitored.

Thus if a man, as Broadbent[15] argues, is following a line with a pencil, and a step to a new position appears, there will be a short delay before the pencil begins to move up. If a second step reversing the first appears during the delay, the pencil will begin to move up, but will then reverse the movement after an interval of one reaction time from the start of the movement. This is the normal refractoriness appearing with inter-signal intervals of less than one reaction time. But if the inter-signal interval is slightly longer or if the second step occurgjust after the beginning of the movement, the central process will be occupied with feed-back information and the reversal of the movement will not occur until one reaction-time from the end of the time spent on feed-back information. A similar situation will apply just after the end of the movement. Thus there will be three values of the inter-signal interval at which the second stmulus will give long reaction times. One will be at very small values, other at values just longer than one reaction time, and the third at values just longer than one reaction time plus the time taken to reach the end of the movement. In between these points there are two values of the inter-signal interval at which the second signal will have a nearly normal reaction time : (*i*) when it occurs just before the start of the movement and (*ii*) when it occurs just before the end. The experiments of Quastler[16] , Davis[4] and Welford[7] confirm the same. But when the interval between the signals is less than a given amount, queueing or grouping occurs. When such intervals are present, the second reaction-time under such circumstances is liekly to be longer than usual. Welford[7] suggests that this may occur either because response is deliberately with held for a short time to ensure that no second stimulus is about to arrive or because some irrelevant central activity occupies the analysing mechanisms until a short period after the arrival of the first stimulus. If the second stimulus occurs during this period reactions to both stimuli may be initiated together.

This theory of Welford[7] does not have the disadvantages of the others although it has its own difficulties, the most pertinent of which are :

Some additional postulate is needed to account for "grouping". Except Broadbent's[15] theory almost all theories are unable to explain satisfactorily this "grouping" phenomenon. A possible line of approach to the problem of grouping is to link it with the need to collect data over a period of time in order to distinguish a signal from "neural noise"[17], or with the fact noted in a study by Pieron[18], that perception of a stimulus can in certain circumstances be modified or prevented by another stimulus coming a little later.

(*ii*) The question arises of why movements are sometimes monitored and sometimes not. Welford[6] has suggested and Davis[4] reiterated that monitoring may be unnecessary when the accuracy required of the responding action is sufficiently low for it to be made ballistically without there being any appreciable likelihood that it will fail to be effective. If highly accurate movements are required, however, monitoring may be inevitable, and even when not strictly necessary it may give the subject confidence. It is understandable that monitoring for either of these reasons would tend to drop out with practice, and we may note in support of this view that Davis's[4] original subjects and Marill's[12] subjects who are the two groups failing to show delays when S_2 came after the end of TR_1, were substantially more practised than others. Experiements comparing delays at various stages of practice could settle whether this explanation is correct.

(*iii*) The theory fits the evidence well if we take the time for which the single channel is assumed to be occupied as equal to the total TR_1. But as Davis[11] has pointed out, such a formulation neglects the fact that appreciable time is required for data to reach the cortex from sense organs and for efferent nerve impulses and muscular action to make a response effective. The theory would certainly not work if this time was deducted from TR_1, as at first sight it would seem they should be, in order to arrive at the supposed time required for the decision mechanism to act in response to S_1.

Welford[7] points out that any suggestion to overcome this difficulty must at present be speculative, but we may note that the difficulty would cease to exist if it could be shown that some minimum feed-fack from the responding action, indicating that it had begun, was necessary for the decision mechanism to be "cleared". If this were so the time taken to initiate a movement would automatically be included in the decision time and there would be added a new time component of a few milliseconds for the feed-back signals to get back from the responding member to the brain. If this time was approximately the same as that required for a stimulus to reach the brain from an exterceptor it would mean that reaction time would be a reasonable measure of decision time although the equating of the two would be in a sense fortuitious. An indication in favour of such a scheme is contained in the findings of Fraisse[8] that delays following an S_1 to which no response had to be made, and for which presumably the feed-back did not occur, were shorter than when S_1 was followed by an overt responding movement.

Second theory:

This is a variant of the first theory in which Davis[11] suggests a 'rest period' following the processing of the first signal in that delay remains a function of the first reaction time. This means that the central processes require a brief rest after handling the information from each stimulus. But Davis[11] has suggested it as an explnation for the fact that refractoriness of normal length appears between a visual and an auditory signal, despite the fact that reaction time to auditory signals is shorter than that to the visual signals normally employed. Thus in this case refractoriness is of more than one reaction time; it could be explained by supposing that the central mechanism becomes refractory after each item of information passes through them. Another explanation given by Davis[11] is that the extra time is occupied in shifting from one channel to the other.

Third theory

This theory by Broadbent[15] suggests a kind of quantising of perception into samples about a third of a second long. It postulates a perceptual sampling process, the delay in dealing with a particular signal depending on where in a sampling period it happens to arrive. Broadbent[15] suggests that the subject can begin a new sample when S_1 arrives and that delays to S_2 are due to the data having to wait until the next sample before they can be dealt with. This is because, according to North[19], no stimulus can act instantaneously, rather, there is a continuous sequence of changes in the sense-organs and each decision to respond is taken on the basis of a sample of these changes over a finite period of time.

A version favoured by Broadbent[15] involves closure of a sample immediately after the arrival of the first signal so that the delay in responding to the second signal is given by the difference between the sampling interval and the interval between signals. On such a theory, as Borger[20] points, our delay in the handling of the second signal becomes independent of the reaction time to the first.

The above point of view is essentially a modification of Welford's[7] but it has two advantages. Firstly, it allows grouping of stimuli without reversal of the order of response, since the capacity of the decision process is not the only factor limiting the speed of information handling. Secondly, the theory explains why refractoriness lasts a full reaction time and not merely the central organizing time: it does so by regarding the equivalence of sampling time and visual reaction time as a coincidence.

But this theory has the severe disadvantage that it requires an adhoc quantity to be postulated for the refractory period or quantized interval. If all the existing experimental evidence is to be accounted for such a quantity would have to be assumed to vary with circumstances in some way not as yet understood.

Fourth theory

Broadbent[15] refers to this theory as "parsimonious", states that all the results can be accounted for by the instantaneous probability of the stimuli : the second stimulus does not normally arrive immediately after the first, so when that does occur the response time is long. This theory regards delay as the consequence of subjective uncertainty about the time of arrival of the second signal. Thus delay is independent of the first reaction time, and moreover of the occurrence of the first response.

In another varient, we can say that the delay to S_2 is due to the "Mowrer effect". Mowrer [21] found that in a serial reaction time task signals arriving before (or after) a modal or mean interval were reacted to more slowly and he "explained" the effect by saying that the subject's "expectancy" of a signal was then lower. This idea was initially proposed by Hick[10] and was emphasized by Poulton[5] and later on adopted by Elithorn and Lawrence[13].

The main disadvantage of the theory is its lack of quantitative precision that makes this theory non-predictive and is at present purely descriptive. The effect of "expectancy" can only be observed post hoc from empirical data.

Fifth theory:

The fifth view is that output from the nervous system is withheld while feed-back information is being handled not because of the limited capacity of the perceptual system but because a new output may blur environmental changes. In compensatory tracking, we can see a clear example where a target has to be held in the centre of a sight or on the middle of a cathoderay-tube. But this theory is clearly not applicable to the case of ungraded responses and thus cannot be satisfactory by itself.

Finally, we may consider the probability modification of Elithorn & Lawrence[13] The main position that they take is that different stimulus—response processes can coexist. When stated in terms of the information theory, it means that human beings can operate as several parellel and independent channels rather than as only one. Thus when operating as two independent channels, reaction time to a stimulus is determined solely by the probability of that stimulus and unaffected by the processes in the other channel. But Broadbent[15] advances two evidences against independent channels. The first comes from step-tracking experiments and the second fact is the result of control experiments by Elithorn & Lawrence[13] in which only the second stimulus was presented. Broadbent[15] is finally of the opinion that the organism cannot be perfectly represented by two independent channels.

CONCLUSION

Refractoriness, as the position now stands, is thus a phenomenon of single-channel of limited capacity. Even if it were possible to train a man who can handle information in two independent channels, the capacity of each of the channels would be little less than that for a man trained to act as a single-channel.

From the point of view of learning of new skills, it may be necessary that there is a refractory phase of greater than one tenth of a second. Refractoriness and discontinuity are useful in the sense that while an individual is learning a new skill, he may respond, wait for knowledge of results, then respond again. But for tasks in which the individual has had long practise he can continue them without any interruption or nearly so.

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