Journal of Experimental Psychology
1966, Vol. 71, No. 1, 9–15

PREMOTOR AND MOTOR COMPONENTS OF REACTION TIME [1]

JACK BOTWINICK AND LARRY W. THOMPSON
Duke University

Reaction time (RT) was fractionated into premotor and motor components based upon the difference between EMG and finger-lift responses. EMGs were recorded from the extensor muscle of the responding forearm during measurement of simple auditory RTs of 54 Ss. The premotor time was that period from the presentation of the stimulus to the appearance of increased muscle firing, while the motor time was that period from this change in action potential to the finger-lift response. 4 preparatory intervals (PI), 0.5, 3.0, 6.0, and 15.0 sec., were used in both a regular and irregular series. Premotor time and RT were highly correlated and showed comparable variations as a function of PI and type of series. Motor time was poorly correlated with RT and was independent of PI and type of series. It was concluded that set, as inferred from the relations between RT and PI and type of series, is a premotoric process.

One of the earliest investigations in experimental psychology included the observation that reaction time (RT) varied with the foreperiod or preparatory interval (PI). At least as far back as Breitwiesser (1911), the relations between PI and RT were under analysis, and for extended and more complex purposes, it continues to be under analysis during modern times (e.g., Botwinick & Brinley, 1962; Drazin, 1961; Hermelin & Venables, 1964; Hohle, 1965; Karlin, 1959; Klemmer, 1956). The variations of RT in relation to PI have been attributed to states of expectancy or preparatory set of *S* (e.g., Gibson, 1941), and it appears as if states of set, and states of alertness or arousal may have similar properties, at least with respect to RT (e.g., Lansing, Schwartz, & Lindsley, 1959).

There have been attempts to elucidate the locus of RT and RT set. Mowrer and his colleagues (Mowrer, 1940; Mowrer, Rayman, & Bliss, 1940), and Weiss (1965) argued for a central locus, while Davis (1940), Freeman (1937, 1938), and Freeman and Kendall (1940) have provided data which suggest peripheral involvements. It is of interest here that both Weiss (1965) and Davis (1940) employed recordings of muscle action potentials, but each emphasized a different locus of RT. Davis measured the amplitude of EMG and showed that higher potentials preceding the stimulus were associated with quicker RTs. Weiss (1965) measured the latency of the EMG and used this in a clever way to argue for a central locus.

Weiss fractionated total RT into two components. He measured the time from stimulus onset to the appearance of the muscle action potential which he labeled premotor time (PMT). The duration from muscle

[1] This study was supported in part by a Public Health Service Research Career Program Award (5153) from the Mental Health and the Child Health and Human Development Institutes, and by Public Health Service Research Grants MH-08244 and HD-01325 from the National Institutes of Health.

This study was also supported in part by Public Health Service Research Grants MH-900 and GM-05385 from the National Institutes of Health.

firing to the finger-lift response was considered the motor time (MT) component. Thus, RT = PMT + MT. He reported that MT was not a function of the PI, but that PMT was. In fact, PMT was in the same functional relation to PI as was RT. Therefore, the variation in set due to PI was seen to be a premotoric process. Weiss referred to these data and others in the literature and concluded that central contributions to RT and RT set were predominant.

The present study was an attempt to extend and elucidate Weiss' finding with respect to the premotor role of set in RT. The nature of this extension will be discussed following the results of this study.

METHOD

Subjects.—The *S*s were 34 men and 16 women undergraduate and graduate students at Duke and North Carolina Universities, plus 4 women *S*s with comparable education, but who were not students at the present time. Mean age of *S*s was 21.3 yr. (range 18–35), and mean education was 14.0 yr. (range 13–20). The *S*s either volunteered in order to fulfill the requirements of a first course in psychology, or in order to receive a nominal hourly fee.

Procedure.—The *S* kept eyes closed while in a semireclining position in a lounge chair and pressed down a telegraph response key to initiate an RT sequence. A minimum force on the key of approximately 106–107 gm. was necessary to do this. The key was placed on a side table, the height of which was approximately 1 in. above the arm of the chair. Two seconds after the key press, a warning signal of 0.5-sec. duration came on. This was followed by the PI and then the stimulus which was terminated by the finger-lift response. The stimulus was a 1000-cps tone approximately 85 db. measured at *S*'s position 5–6 ft. from the sound-source speaker. The warning signal which preceded the tone stimulus was a 400-cps tone of approximately 75 db.

Each *S* was assigned to one of four RT conditions which involved irregular and regular PI series. (In regular series PI is constant within a block of trials, and in irregular series PI is varied within a block of trials.) Each *S* either had (*a*) irregular series first and regular ascending series second (I_1A_2), (*b*) irregular first and regular descending second (I_1D_2), (*c*) regular ascending first and irregular second (A_1I_2), or (*d*) descending first, irregular second (D_1I_2). (An ascending series is one where the PI order of presentation is from the shortest to the longest duration; a descending series is of the reversed order.)

Four PIs, 0.5, 3.0, 6.0, and 15.0 sec., were used in both the regular and irregular series. In the regular series 21 stimulus presentations were administered for each of these PIs, making a total of 84 RTs. The order within irregular series was prearranged so that each PI duration would precede the other three PIs the same number of times. To accomplish this and to keep the number of RT measurements as comparable as possible to the regular series, 85 RT measurements were necessary with irregular PIs. In this way each *S* experienced 169 stimulus and RT sequences.

Simultaneously with the RT measurements, EMGs were recorded. Standard EKG electrodes were strapped on the responding forearm above the extensor digitorum communis, and the potentials were amplified and recorded with a Grass, Model III, eight-channel EEG. One channel was used to record the stimulus and RT sequences, and one channel was used to record the EMG. On the remaining channels EEGs were recorded for a different purpose. The *E*s were in one room monitoring the polygraph and setting the appropriate PI conditions by the use of Hunter interval timers, and *S* was in an adjoining room connected to the apparatus via lead wires.

EMGs were recorded only of the middle RTs within each PI context. Thus, of the 21 RTs per regular PI, EMGs were recorded for the 10 RTs of Trials 7–16 in the PI series. In this way 40 EMGs associated with 40 RTs in regular series were recorded, 10 for each of 4 regular PIs. Similarly, the EMGs were recorded for only the middle 42 RTs within irregular series, Trials 22–63. All together, therefore, 82 EMGs were recorded for each *S* individually. (Approximately 21 RT trials per PI were used instead of a lesser number in order to maximize the effect of the PI and the context of PI. However, only the middle RT trials were analyzed in order to minimize practice or learning effects during early trials, and fatigue or boredom effects during later trials.)

For each RT, the ink record was analyzed manually by measuring with a millimeter scale the distance between the point on the

EMG tracing where the stimulus began and the point of first increased muscle firing. This was the PMT. RT was the measured distance between stimulus onset and finger-lift response. The PMT measurement was subtracted from the RT measurement to give the MT. There were 9–11 measurements for each PI of each series. For each *S* the medians of RT, PMT, and MT were computed independently. This was done for each of four PIs in a regular series (A_1, A_2, D_1, or D_2), and in an irregular series (I_1 or I_2).

Results

The means of the median RTs, PMTs, and MTs may be seen in relation to the PI within regular and irregular series in Fig. 1. The means in Fig. 1 are of the pooled data of the four regular series (A_1, A_2, D_1, D_2) and of the two irregular series (I_1 and I_2). A variety of variance analyses were carried out on the data of men and women *S*s when considered separately, when compared, and when pooled. In no instance was a statistically significant difference found among the four regular series or between the two irregular series ($p > .05$). The median values of individual *S*s underlying the curves of Fig. 1 were subjected to variance analyses and the results which follow are of these pooled data.

Reaction time.—The four different PIs within regular series and within irregular series made for statistically significant differences in RT. It may be seen in Table 1 that with 3 and 156 *df*, the *F* ratios associated with PIs were 59.54 and 4.36, for regular and irregular series, respectively ($p < .01$).

It may be seen in Fig. 1 that RTs of irregular series were slower than the RTs of regular series. This difference was statistically significant across the four PI conditions as determined by a separate analysis of variance comparing the two types of series. The *F* ratio was 52.78 which with 1 and 53 *df*, $p < .01$. Thus, RT was found related to PI duration within each type of series, and to the regularity vs. irregularity of the series.

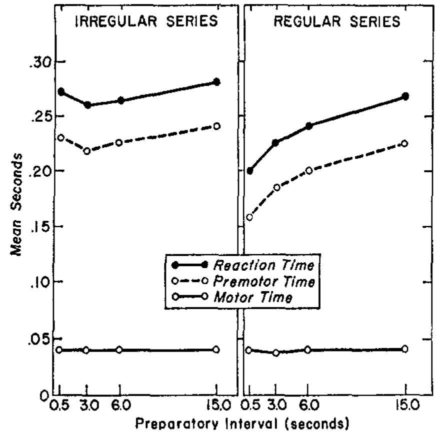

FIG. 1. Mean simple auditory RT of 54 *S*s, and the premotor and motor time components of RT, as functions of 4 preparatory intervals within a regular series and within an irregular series.

Motor time.—A contrasting role of PI and of type of series may be seen in Fig. 1 with the motor component of RT. Mean MT was essentially a constant, independent of PI or type of series. The range of mean MT was from .038 sec. (3.0 sec. PI of regular series) to .042 (15.0 sec. PI, also of regular series). This contrasting role of MT was confirmed by the same type of analyses of variances as were carried out on the total RT data. It may be seen in Table 1 that a statistically significant effect of PI on MT was not found ($p > .05$). The separate variance analysis comparing MTs between regular and irregular series indicated no statistically significant difference ($F < 1.0$, $p > .05$). Thus, the experimental conditions which provide for differences in set, (PI and type of series) did not have a reliable effect on motor speed.[2]

[2] These results of MT were complicated and made less clear by variance analyses

TABLE 1

ANALYSES OF VARIANCES OF RTs, MTs, AND PMTs OF REGULAR AND IRREGULAR SERIES

Source	*df*	RT		MT		PMT	
		Reg.	Irreg.	Reg.	Irreg.	Reg.	Irreg.
Prep. Interval (PI)	3	59.54**	4.36**	2.00	.06	75.14**	4.30**
Ss	53	8.83**	7.82**	11.80**	20.08**	9.01**	5.23**
Sex Groups × PI	3	.80	1.98	1.81	.81	.40	1.39
Error: Pooled *Ss* × PI[a] (Mean Square)	156	(.76)	(.82)	(.08)	(.05)	(.57)	(.91)
Sex Groups	1	1.13	.02	.38	.68	2.15	.20
Error: *Ss* in Sex Groups[a] (Mean Square)	52	(6.75)	(6.53)	(.91)	(1.03)	(5.03)	(4.85)
Total	215						

[a] Mean squares were divided by 1000 and rounded for the purpose of this table. RTs, PMTs, and MTs were in msec.
** $p < .01$.

Premotor time.—Reference to Fig. 1 indicates that the RT and PMT functions were very nearly parallel. The corresponding variance analyses for PMT were also similar to those of RT. Table 1 shows that *F* ratios associated with PIs and with individual differences were highly statistically significant in both regular and irregular series ($p < .01$). The PMTs were statistically longer for the irregular series than for the regular series, as seen in a separate analysis of variance, F (1, 53) = 74.49, $p < .01$.

which were carried out on each sex group separately. While the results with irregular series of each sex group, and with regular series of women *Ss* were similar to those of results seen in Table 1, the MT results with regular series of male *Ss* were not. The mean differences in MT due to the four regular PIs were very small, but the associated F (3, 99) = 3.60, $p < .05$. The trend was of slightly longer MTs with longer PIs. Paradoxically, there was a statistically nonsignificant trend in the opposite direction for female *Ss*. These data, however, did not make for a significant sex interaction with PI, as may be seen in Table 1. The meaningfulness of the statistical tests involving separate sex groups are not only unclear, but they probably are not important. The levels of significance related to PI differences were low and the range of the mean MTs was so small that an appreciable relation to PI and type of series was not possible. It would be more meaningful, perhaps, to be impressed with the small error term (*Ss* × PIs) than with the variation associated with regular PIs of male *Ss*.

Intercorrelations.—Pearson product-moment correlations (r) were computed between the two components of RT. That is, the median PMTs and median MTs of *Ss* were correlated for each PI of regular and irregular series. Table 2 indicates the independence of the two RT components. The eight coefficients of correlation between MT and PMT were near zero, ranging from −.10 to .24, with a mean r (by z' transformation) of .14, $p > .05$.

Since RT = PMT + MT, and since PMT and MT were uncorrelated, the contribution to the variance of RT by each of the two components was a direct function of the relative size of their variances. The ratios of the variance of PMT to that of MT ranged from 4.08 with the 0.5-sec. regular PI, to 9.41 with this same short PI in irregular series. Each of these *F* ratios (53,53) was statistically significant, $p < .01$.

The variance of PMT was clearly larger than that of MT, and thus it followed that PMT and not MT, was the major contributor to the variance of RT. As may be seen in Table 2,

TABLE 2

CORRELATIONS AMONG RT AND COMPONENTS OF RT IN RELATION TO THE PREPARATORY INTERVAL OF IRREGULAR AND REGULAR SERIES

Correlates	Preparatory Interval (Sec.)							
	Irregular				Regular			
	0.5	3.0	6.0	15.0	0.5	3.0	6.0	15.0
PMT-RT	92[a]	87	91	93	88	92	92	96
MT-RT	21	50	48	34	51	45	55	42
MT-PMT	−10	10	18	05	09	24	20	18

[a] All product-moment correlation coefficients multiplied by 100.

the part-whole correlations between PMT and RT were very high ranging from .87 to .96 with a mean (by z' transformation) of .92, $p < .01$. The eight correlation coefficients between MT and RT ranged from .21 to .55 with a mean (by z' transformation) of .44. The mean and six of the eight MT-RT correlations in Table 2 were statistically significant, $p < .01$.

Product-moment coefficients of correlation were also computed within *S*s. The approximately 40 measures of RT, PMT, and MT were intercorrelated within each *S* of a randomly selected subsample of 9 men and 5 women for regular series, and an equal *N* for irregular series. Thus, three coefficients of correlation were available on each of 28 *S*s.

The intra-*S* correlations were similar to the inter-*S* correlations in that the two components of RT were uncorrelated, the variances of PMT were larger than those of MT, and thus, PMT and RT were very highly correlated, and MT and RT were correlated, but poorly.

Specifically, the 28 ratios of the variances of PMT to MT ranged from 0.80 with the regular series of one *S*, to 81.61 with the regular series of another *S*. Only 1 of the 28 ratios was less than 1.00; the mean and median of the ratios of variances were 15.24 and 8.50, respectively. Of the 28 ratios, i.e., *F* tests (approximately 39,39), 25 were statistically significant, $p < .01$, indicating larger variances of PMT as compared to MT.

Overall, the two components of RT were uncorrelated within *S*s. However, there were individual differences in this regard. Five of the 28 coefficients of correlation between MT and PMT were statistically significant, but two of the 5 were negative, i.e., increased MT was associated with decreased PMT. In fact, 13 of 28 coefficients were negative. The overall mean r was .16, and not statistically significant ($p > .05$).

The 28 coefficients of correlation between MT and RT ranged from −.05 to .77, with 8 of them being significant at the .05 level, and 7 at the .01 level. The mean r (by z' transformation) was .34, $p < .05$. The range of the 28 coefficients of correlation between PMT and RT was .80 to .99, with 21 of the coefficients being above .90. The mean r (by z' transformation) was .95, and highly statistically significant, $p < .01$.

DISCUSSION

Anticipatory set is manipulated experimentally by variation both of PI duration and of the context of the PI (of which regularity and irregularity of series is the most common). It is clear, therefore, that the value of an investigation to determine the "locus" of set rests, in part, upon the choice and extensity of these experimental variables. Weiss' study (1965), upon which the present one was based, was understandably limited in the extensity of the variables which relate to set. His data included the analysis of RT, not only in relation to set, but in relation to shock motivation, and age of *S*. His RT data were based on PIs of the limited range, 1, 2, 3, and 4 sec. of only an irregular series.

It was considered important in the present study to extend the range of PI duration from 0.5 to 15.0 in both regular and irregular series. The reason for this was seen in the data of a previous study (Botwinick & Brinley, 1962). In that study, a PI of 0.5 sec. played a different role in RT set than other, longer PIs in the series. In addition, the regular and irregular series appeared to require different RT sets or different RT abilities with this same short PI of 0.5 sec.

The uniqueness of RT with long PIs of 6.0 and 15.0 sec. was not demonstrated (Botwinick & Brinley, 1962). However, the PI range was extended to these durations in the present study because 6.0- and 15.0-sec. PIs tend to make for very slow RTs and, therefore, presumably, poor sets. The RTs with 15.0-sec. PIs are of similar slowness both in the regular and in the irregular series, although RTs with shorter PIs are very different in the two types of series.

The conclusion in this study that RT is comprised of two components, one related to PI and one not, describes remarkably well the data of a very recent study by Hohle (1965). Hohle performed a mathematical analysis of two assumed components of RT, one distributed normally, and one distributed exponentially. He found the former RT component to be in functional relation to PI, and not the latter. Hohle did not label his components, but, instead, was content to conclude that variation in RT was due to variation in the normally distributed component. This component and the premotor one of the present study seem to bear close conceptual resemblance.

It was very clear in the present data that the premotor component of RT, and RT itself were measures of the same aspect of the set phenomenon and whatever else was involved. The correlations between these two measures were so high, that prediction of one from the other, either between or within *S*s, may be made with very little error. It was also clear that the two components of RT were unrelated, and that the motor component did not have any appreciable relation to PI.

Davis (1940) argued for the importance of peripheral contributions to RT set. He found higher amplitudes of muscle action potentials during PIs when RTs were quicker. Weiss (1965) suggested that since MT did not vary with PI while RT did, Davis' higher amplitudes may have been reflections of an increased central state of set. This consideration, plus the fact that PMT and RT shared so much of the common variance in the present study, indicate that set is a function of premotoric processes, rather than motoric ones.

There is still a distinction to be made in "locus" between premotoric and central processes. Premotoric includes peripheral sensory phenomena such as receptor organs and afferent pathways. While it does not appear to be likely that the "locus" of set is in the precentral periphery, it must be ruled out by experiment, not by assumption, nor by what seems to be a logical inference. For example, RT depends upon stimulus intensity such that RT is long when the stimulus is weak (Woodworth & Schlosberg, 1954, p. 16–27). Is it possible that set and attention variables underlie this relation, and that the periphery may be a partial explanation or antecedent of these states? The most precise and conservative conclusion at this time may be that RT set is a premotoric process, and probably a central one.

REFERENCES

Botwinick, J., & Brinley, J. F. An analysis of set in relation to reaction time. *J. exp. Psychol.*, 1962, **63**, 568–574.

Breitwiesser, J. V. Attention and movement in reaction time. *Arch. Psychol.*, 1911 (Whole No. 18).

Davis, R. C. Set and muscular tension. *Indiana U. Publ., Sci. Ser.*, 1940, No. 10.

Drazin, D. H. Effects of foreperiod, foreperiod variability, and probability of stimulus occurrence on simple reaction time. *J. exp. Psychol.*, 1961, **62**, 43–50.

Freeman, G. L. The optimal locus of anticipatory tensions in muscular work. *J. exp. Psychol.*, 1937, **21**, 554–564.

Freeman, G. L. The optimal muscular tensions for various performances. *Amer. J. Psychol.*, 1938, **51**, 146–150.

Freeman, G. L., & Kendall, W. E. The effect upon reaction time of muscular tension induced at various intervals. *J. exp. Psychol.*, 1940, **27**, 136–148.

Gibson, J. J. A critical review of the concept of set in contemporary experimental psychology. *Psychol. Bull.*, 1941, **38**, 781–817.

Hermelin, B. M., & Venables, P. H. Reaction time and alpha blocking in normal and severely subnormal subjects. *J. exp. Psychol.*, 1964, **67**, 365–372.

Hohle, R. H. Inferred components of reaction times as functions of foreperiod duration. *J. exp. Psychol.*, 1965, **69**, 382–386.

Karlin, L. Reaction time as a function of foreperiod duration and variability. *J. exp. Psychol.*, 1959, **58**, 185–191.

Klemmer, E. T. Time uncertainty in simple reaction time. *J. exp. Psychol.*, 1956, **51**, 179–184.

Lansing, R. W., Schwartz, E., & Lindsley, D. B. Reaction time and EEG activation under alerted and nonalerted conditions. *J. exp. Psychol.*, 1959, **58**, 1–7.

Mowrer, O. H. Preparatory set (expectancy)-some methods of measurement. *Psychol. Monogr.*, 1940, **52**(2, Whole No. 233).

Mowrer, O. H., Rayman, N. W., & Bliss, E. L. Preparatory set (expectancy)-an experimental demonstration of its "central" locus. *J. exp. Psychol.*, 1940, **26**, 357–372.

Weiss, A. D. The locus of reaction time change with set, motivation, and age. *J. Gerontol.*, 1965, **20**, 60–64.

Woodworth, R. S., & Schlosberg, H. *Experimental psychology.* New York: Holt, 1954.

(Early publication received June 28, 1965)