SELECTIVE PREPARATION AND TIME UNCERTAINTY*

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Discrete two-choice reaction time experiments were performed under two time-uncertainty conditions provided by constant foreperiods of either 5.0 or 0.5 sec. The problem was how to know whether selective preparation may be maintained over time or whether it is a short-term process. Selective preparation of one of the two stimuli was induced through monetary incentive in Experiment 1 and through frequency unbalance in Experiment 4, it was assessed through prediction in Experiments 3 and 4. With all three manipulations the effects of selective preparation and of time uncertainty were found to combine additively. Those results support the idea that selective preparation can be maintained over time. On the other hand, the improvement in reaction time due to a reduction of time uncertainty is achieved by a short-term preparatory adjustment which is not stimulus-specific.

It has often been assumed that in choice reaction situations, fast responding depends on a state of selective preparation which is specific of one particular stimulus. Evidence favoring this assumption was provided by three separate experimental procedures, each of which demonstrated the possibility of trading-off speed between alternatives. (1) The best known procedure has been to manipulate frequency of occurrence: reaction time (RT) to more frequent stimuli tends to be shorter (Fitts et al. 1963; Hawkins and Underhill 1971). (2) Using a pay-off matrix which emphasized speed on one particular stimulus, LaBerge et al. (1967) had their Ss react about 100 msec faster to the

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emphasized stimulus than to the other ones. (3) When the $S$ is asked before each trial to predict the stimulus to be presented, RTs to correctly predicted stimuli are faster than to uncorrectly predicted ones (Bernstein and Reese 1965; Geller and Pits 1970; Hinrichs 1970).

One question which has received rather scant attention is whether selective preparation can be maintained over time or whether it is a necessarily short-term process. One way to answer the question, which has been proposed by Bertelson and Barzeele (1965), is to examine if the size of the selective preparation effect is influenced by foreperiod (FP) manipulations. If selective preparation is short-term, its effect on RT will be reduced when the moment of occurrence of the stimulus is made less predictable. Bertelson and Barzeele measured RTs to two stimuli with presentation probabilities 0.20 and 0.80 with constant FPs of 0.5 sec in one condition and 5.0 sec in the other. The effect of presentation probability was about twice as large (73 msec against 39 msec) with the short as with the long FP. They concluded that selective preparation is at least partially short-term.

The original purpose of the present study was to extend Bertelson and Barzeele's finding to situations where selective preparation is either induced by the incentive method or assessed through predictions. A two-choice task involving manual responses to shapes, similar to the task of Bertelson and Barzeele, was run under two time-uncertainty conditions: one with a short constant FP of 0.5 sec, giving low time uncertainty, the other with a long constant FP of 5.0 sec, giving high time uncertainty. $S$s were induced to privilege speed on one stimulus through monetary incentive in Experiment 1, through frequency unbalance in Experiment 4. In Experiments 2 and 3 no particular stimulus was stressed, but $S$s predicted on each trial which particular stimulus they expected to occur.

General method

Stimuli and apparatus

The stimuli were the digits 0 and 1 presented via a Nixie numerical indicator (Adzam 1020) which was rotated 90° from its normal position. In that position, the stimuli appeared as a horizontal bar and a horizontal ellipse. The Nixie was inserted into a vertical panel, at eye level, approximately 80 cm from where the $S$ was sitting. A neon pea lamp, placed 2.5 cm above the Nixie, was used to deliver warning signals. The response keys consisted of two flexible strips of
steel resting on microswitches. They were placed in a near-vertical plane, 10 cm apart, behind an inclined board. The S rested his hands and forearms on the board with the tips of the index fingers in contact with the keys.

The stimulus to be presented on each trial and the length of the FP were selected by hand by the E, who also controlled the start of each trial. RTs were measured to the nearest msec on a decade timer and recorded manually by E. The E was separated from the S by a vertical panel. All noisy parts of the equipment were placed in another room.

Procedure

In Experiments 1, 2 and 4 each trial started with a 1 sec illumination of the warning lamp. The offset was followed after a FP of either 0.5 or 5.0 sec by the appearance of the stimulus, which stayed on until one of the keys was pressed. Ss were given one practice and two 45 min experimental sessions on successive days. Half the Ss were instructed to press the left key for the bar and the right key for the ellipse. The other half was given the opposite stimulus-response assignment.

During the practice session, the bar and the ellipse occurred with equal frequencies. Half the runs involved a constant FP of 0.5 sec and the other half a FP of 5.0 sec. Ss were instructed to react as fast as possible but to avoid errors. Each fast reaction compared with an arbitrary criterion was rewarded by 0.5 Belgian francs (BF, approximately 1 dollarcent). A slow correct reaction was neither rewarded nor penalized and an error cost two fast reactions. After each correct response, S was verbally informed whether he had been fast or slow. After an incorrect response, he was only informed that an error had been made. The mean RT of the practice session was used as an individual criterion with which performance during the two experimental sessions was to be compared. In each experiment, the experimental manipulation was introduced at the beginning of the second session.

Subjects

Different groups of Ss were used in the four experiments. All were students, naive regarding RT experiments, who volunteered to participate. They were paid a fixed hourly rate, plus a bonus depending on speed and accuracy, as indicated in the procedure section.

Experiment 1

This experiment dealt with the incentive manipulation. A fast correct reaction was rewarded more for one stimulus than for the other one.

Method

Ten Ss, six male and four female, aged 19–26 years, participated in one practice and two experimental sessions. At each experimental session, they were given 16 runs of 20 trials each, eight with the 0.5 sec FP and eight with the 5.0 sec one, in alternating order. The two stimuli occurred in random order, with equal relative frequencies. Ss were told that the two stimuli
were equally likely but that one stimulus had a high value (HV) and the other a low value (LV).
A fast correct RT was rewarded by 1 BF if it occurred in response to the HV stimulus and by
only 0.10 BF if it was a response to the LV stimulus. For both HV and LV stimuli, a slow
correct RT was neither rewarded nor penalized and an error cost 1 BF. Ss were instructed about
the stimulus-incentive assignment at the beginning of each run. On each experimental session,
two possible stimulus-incentive associations were each used in eight runs of trials, four with
the 0.5 sec FP and four with the 5.0 sec one.

Results

Table 1 shows the mean correct RTs, for each condition, together with the percentage of
errors.

Table 1
Mean reaction time in msec (RT) and percentage of errors (E) in Experiment 1.

<table>
<thead>
<tr>
<th>Incentive</th>
<th>Low value</th>
<th>High value</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>E</td>
<td>RT</td>
</tr>
<tr>
<td>Foreperiod</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0 sec</td>
<td>413</td>
<td>4.8</td>
<td>359</td>
</tr>
<tr>
<td>0.5 sec</td>
<td>372</td>
<td>3.7</td>
<td>318</td>
</tr>
</tbody>
</table>

Both the FP effect and the incentive effect are in the expected direction: the RTs are faster
with the short FP than with the long one, and they are faster for the HV than for the LV
stimulus. On the other hand, there is no trace of an interaction: the incentive manipulation
produced exactly the same 54 msec mean effect both with high and low time uncertainty. A
4-way mixed model analysis of variance, with Ss, FP, incentive and sessions as factors, was
carried out. The FP effect was found significant at p < 0.01, F(1,9) = 48.8, and the incentive
effect at the same level, F(1,9) = 37.4. The FP x incentive interaction was not significant (F <
1.0).

Discussion

One aspect of these results is that they confirm LaBerge’s et al. finding that monetary
pay-offs can produce a bias in reaction speed.

Regarding the main objective of the study, it seems that the incentive effect does not
combine with time uncertainty in the way that relative frequency effects have been found to
combine in Bertelson and Barzele’s experiment.

Experiment 2

In this experiment, the S predicted, at the beginning of each trial, which stimulus would be
presented. The comparison of interest was between RTs to stimuli the occurrence of which had
been predicted and to those that had not been predicted.
Method

12 Ss, six male and six female, 20–30 years old, participated in three sessions, one practice and two experimental ones.

At the beginning of each trial E called verbally for a prediction of the stimulus to be presented. S answered by saying 'ellipse' or 'bar'. The warning signal was set on approximately 1 sec after S's prediction, and was, as in the other experiments, followed by presentation of the stimulus after either a 0.5 or a 5.0 sec FP.

Six runs of 40 trials, three under each FP condition, were given on each session, in alternating order. The two stimuli occurred with equal frequencies and fast correct reactions were rewarded in the same way (0.5 BF) whatever the stimulus.

Results

Table 2 shows mean RTs, averaged over sessions and Ss, for each condition, together with percentage of errors.

Table 2
Mean reaction time in msec (RT) and percentage of errors (E) in Experiment 2.

<table>
<thead>
<tr>
<th>Prediction outcome</th>
<th>Incorrect</th>
<th>Correct</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>E</td>
<td>RT</td>
</tr>
<tr>
<td>Foreperiod</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0 sec</td>
<td>409</td>
<td>4.0</td>
<td>376</td>
</tr>
<tr>
<td>0.5 sec</td>
<td>377</td>
<td>3.0</td>
<td>332</td>
</tr>
</tbody>
</table>

The RT to predicted stimuli is faster than to non-predicted ones. The effect is slightly smaller with the long 5.0 sec FP (33 msec) than with the short 0.5 sec one (45 msec). Analysis of variance showed that both the FP effect, $F(1,11) = 47.8, p < 0.01$, and the prediction effect $F(1,11) = 47.3, p < 0.01$, are significant. Their interaction falls just short of the 0.05 level, $F(1,11) = 4.38, p = 0.064$.

Discussion

At first sight, the result would seem to go in the general direction of Bertelson and Barzele's conclusion: the effect on RT of selective preparation, as indexed by verbal prediction, is reduced when time uncertainty increases. The reduction, however, is established at a dubious significance level only. Moreover, another explanation for the observed interaction is available. Since the prediction was always given just before the warning signal, the increase of the FP from 0.5 to 5.0 sec is accompanied by an equal increase in the prediction–stimulus interval. After the present experiment had been run, Geller and Whitman (1972) showed that the prediction effect is reduced when the prediction-stimulus interval is increased. In their opinion this result was due to a fading memory trace of the prediction. An alternative interpretation is that the probability that the S shifts his preparation to the non-predicted stimulus
increases as time goes by. The reduction in the prediction effect with increasing time uncertainty might thus be due to the fact that time uncertainty was, in the present experiment, confounded with the duration of the prediction-stimulus interval. Consequently, another experiment was run where the possibility of such confounding was eliminated.

Experiment 3

The objective of this experiment was to test the influence of time uncertainty on the prediction effect in a situation where time uncertainty was varied without affecting the prediction-stimulus interval. The main comparison was between two conditions where this interval was kept at a constant duration, while the warning signal occurred either 0.5 or 5.0 sec before the stimulus. A third condition, similar to the low time uncertainty condition of Experiment 2, with a shorter prediction-stimulus interval and a 0.5 sec FP, was introduced to provide a non-biased test of the hypothesis of an effect of the prediction-stimulus interval as such.

Method

12 Ss participated in four sessions each, one practice and three experimental ones. A second neon lamp was added to the display. It was lit at the start of each trial for 0.5 sec. Its meaning was that the S had to make his prediction. It will be called the prediction signal. The duration of both the warning signal and the prediction signal was reduced to 0.5 sec. 3 conditions were studied which varied by the duration of the prediction signal-warning signal interval and of the warning signal-stimulus interval (the FP). These two intervals lasted respectively 2.5 and 5.0 sec in Condition 1, 7.0 and 0.5 sec in Condition 2, and 3.0 and 0.5 sec in Condition 3. Conditions 1 and 2 thus have the same prediction signal-stimulus interval (7.5 sec) but different FPs. Condition 3 has the same short FP as Condition 2 but a shorter prediction signal-stimulus interval of 3.5 sec, giving a general timing similar to the 0.5 sec FP condition of Experiment 2.

Results and discussion

As can be seen in table 3, comparison of the results for Conditions 2 and 3 confirms the hypothesis formulated in the discussion of Experiment 2, i.e., that lengthening the prediction-

<table>
<thead>
<tr>
<th>Prediction outcome</th>
<th>Incorrect</th>
<th>Correct</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT E</td>
<td>RT E</td>
<td>RT E</td>
</tr>
<tr>
<td>Foreperiod</td>
<td>Prediction interval</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition 1</td>
<td>5.0 sec</td>
<td>7.5 sec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>409 1.3</td>
<td>368 1.1</td>
<td>41 0.2</td>
</tr>
<tr>
<td>Condition 2</td>
<td>0.5 sec</td>
<td>7.5 sec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>368 1.6</td>
<td>327 0.7</td>
<td>41 0.9</td>
</tr>
<tr>
<td>Condition 3</td>
<td>0.5 sec</td>
<td>3.5 sec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>370 1.7</td>
<td>318 0.8</td>
<td>52 0.9</td>
</tr>
</tbody>
</table>
stimulus interval might in itself reduce the difference between RTs to correctly and incorrectly predicted stimuli. This effect was probably responsible for the interaction, observed in Experiment 2, between warning condition and prediction outcome.

When the prediction-stimulus interval is held constant as in Conditions 1 and 2 the modification of FP does not influence the effect of prediction outcome any longer. The conclusion is thus that selective preparation, as indexed by verbal predictions, combines additively with time uncertainty.

Experiment 4

With both the incentive and the prediction manipulations, the effects of selective preparation appear to combine additively with those of time uncertainty. To make these results consistent with the interaction found by Bertelson and Barzele in the case of relative frequency, one would have to assume that the different procedures reach preparatory processes with different temporal properties. Before accepting that unparsimonly conclusion, it was felt worthwhile to run a new study of the influence of time uncertainty on the effect of frequency unbalance, under conditions similar to those of the previous three experiments.

Method

Twelve male Ss, 19–28 years old, participated in three sessions, one practice and two experimental ones. At each experimental session, four runs of 64 trials were given. Two runs comprised 75% ellipses and 25% bars, in random order, and the two other runs 25% ellipses and 75% bars. The two relative frequency arrangements were alternated from run to run. On each session, each S did two successive runs under one FP, and the two other runs with the other FP. The order of FPs was balanced across Ss and sessions. The Ss were informed verbally before each run about the duration of the FP and the relative frequency of the two stimuli.

Table 4
Mean reaction time in msec (RT) and percentage of errors (E) in Experiment 4.

<table>
<thead>
<tr>
<th>Foreperiod</th>
<th>0.25</th>
<th>0.75</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>E</td>
<td>RT</td>
</tr>
<tr>
<td>5.0 sec</td>
<td>434</td>
<td>5.7</td>
<td>382</td>
</tr>
<tr>
<td>0.5 sec</td>
<td>400</td>
<td>4.9</td>
<td>343</td>
</tr>
</tbody>
</table>

Results

As can be seen in table 4, RT is already affected by both FP duration and stimulus relative frequency. By variance analysis these effects are both significant beyond $p = 0.01$, $F(1,11) = 47.3$ and 59.4. The effect of relative frequency is just a little larger with the short FP (58 msec) than with the long one (52 msec) and the corresponding interaction is non-significant, $F(1,11) = 1.16$. 
Discussion

Bertelson and Barzeele's interaction between FP duration and relative frequency has clearly not been replicated.

There is no ready explanation for the discrepancy. There are small differences of procedure between the two studies but they are unlikely sources of major differences in the results; these differences are, e.g., the fact that in the present experiment the inter-trial period was left to vary somewhat from trial to trial (around a mean value of about 4 sec), whereas Bertelson and Barzeele used a fixed 10 sec response-warning signal interval; also, that they used a slightly more extreme frequency unbalance (0.20–0.80 instead of 0.25–0.75 as here); or that their response keys, which were attached to the arms of the S's chair, were wider apart.

A more serious possibility is that the same frequency bias applied throughout Bertelson and Barzeele's experiment. As a consequence, relative frequency was confounded with amount of practice received on the particular S–R pair. To test for a possible role of that particular feature, six fresh Ss were run for three sessions under a procedure identical to that of Experiment 4, except for the fact that, throughout the two experimental sessions, the bar, associated with the right response, occurred on 75% of the trials, and the ellipse, associated with the left response, on the remaining 25%. As can be seen in Table 5, there is no overall influence of time uncertainty on the effect of frequency of occurrence.

For the time being, the only available explanation is that Bertelson and Barzeele's result was due to chance fluctuations.

Table 5
Mean reaction time in msec (RT) and percentage of errors (E) in the replication of Bertelson and Barzeele's experiment.

<table>
<thead>
<tr>
<th>Stimulus frequency</th>
<th>0.25</th>
<th>0.75</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>E</td>
<td>RT</td>
</tr>
<tr>
<td>Foreperiod</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0 sec</td>
<td>412</td>
<td>5.2</td>
<td>376</td>
</tr>
<tr>
<td>0.5 sec</td>
<td>374</td>
<td>3.5</td>
<td>340</td>
</tr>
</tbody>
</table>

General discussion

With regard to the problem of main interest, the present study shows that the ability to be selectively prepared for one particular stimulus in a two-choice task is not impaired by increasing time uncertainty. The effect of foreperiod duration and of selective preparation reached a significant level with all three manipulations studied here, while no interaction between the two factors was found. In terms of Sternberg's (1969) additive factor method, additivity between two independent variables may be interpreted as indicating that two separate, non-overlapping stages of information processing are involved in the situation.
One of these stages is affected by uncertainty regarding the time of occurrence of the stimulus. The effect is a short term non-selective preparatory process which leads to fast responding if its optimal level is synchronized with stimulus onset, whatever the nature of the stimulus. As can be seen in tables 1 to 5, reduction in time uncertainty decreases RT without increasing the error rate. Short term preparation may thus not be attributed to a change in speed-accuracy tradeoff.

The second stage is affected by a selective preparatory process which can be maintained over time. It leads to fast responding if the stimulus the $S$ is prepared for is actually presented, whatever its time of occurrence. Selective preparation does not necessarily last as long as the longest interval considered here, 5.0 sec. But, contrary to temporal preparation, it lasts long enough to avoid any problem of synchronization with stimulus onset within this interval.

The fact that the three ways of inducing selective preparation which have been used yield the same combination rule with time uncertainty does not preclude that either the same process or different processes with the same temporal properties may account for selective preparation. The reduction in RT to the prepared signal is always obtained at the cost of an increase in the error rate to the unprepared one. Selective preparation seems to be the result of a change in the speed-accuracy tradeoff. However the extent to which this is true is not the same with the three manipulations. Although the 54 msec incentive effect, the 41 msec prediction effect (Experiment 3, Conditions 1 and 2) and the 55 msec relative frequency effect are very close together, the difference in error rate between the prepared and unprepared signals is much greater, 4.55%, with the relative frequency manipulation than with the incentive and the prediction manipulations (only 1.5% and 0.6% respectively). Using the latency operating characteristic analysis, defined as the trade-off between RT and discrimination accuracy, Lappin and Disch (1972) and Harm and Lappin (1973) have shown that the stimulus frequency effect in two-choice tasks may be entirely accounted for by a shift in the subject's decision criterion without any reference to an increase in the speed of perceptual processing. An error rate of 25% was tolerated in those studies. Further studies are needed to know whether the conclusion may account for the present results where the error rate is much lower and where selective effects are obtained without large increases in the error rate with at least two manipulations.

There is evidence from other RT studies in which time uncertainty
and stimulus categorization demands were covaried which is consistent with the present finding. Alegria and Bertelson (1970) have shown that increasing the number of choices from two to eight leads to the same increase in RT with either of the two FPs of 0.5 and 5.0 sec. A similar result was obtained by Broadbent and Gregory (1965) using two and four choice. Posner and Boies (1971) have studied the combination of temporal and selective preparation in letter-matching tasks. In one condition they varied the FP separating a warning signal from simultaneous presentation of the two letters to be compared. In another condition, the first letter arrived 500 msec after a warning signal, so with roughly minimal time uncertainty, and was followed after different inter-stimuli-intervals by presentation of the second letter. Both manipulations were found to affect RT significantly. In a third condition, the first letter arrived with high time uncertainty, thus providing both time and event information. The main finding was that the reduction in RT obtained for a given interval in the last condition was nearly the sum of those obtained in the two other conditions. This not only confirms that selective and temporal preparation are separate processes, but it also shows that they can be carried out in parallel without interference.

References