

Serially Presented Stimuli May Be Processed Simultaneously: Evidence From Study on the Attentional Blink *

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Abstract Whether serially presented stimuli can be processed simultaneously or sequentially are tested by adopting a simplified AB paradigm. It was found that, when two stimuli (Target and Probe, T & P for short respectively) were serially presented without distracter between them, their pattern of RT matched the prediction of the Parallel Model exactly (Experiment 1). However, when T was immediately followed by a backward mask (in other words, T & P were interrupted by a distracter), T & P's pattern of RT accorded with the Serial Model (Experiment 2). These patterns of results indicated that serially presented stimuli which have no distracter between them can be processed simultaneously. And this kind of parallel mechanism may be extremely capacity-limited and possibly deals with only two objects simultaneously. Moreover, it can be interrupted by long interval between two targets.

Key words parallel model, serial model, attention blink.

1 Introduction

Whether serially presented stimuli can be processed simultaneously or sequentially is an unresolved mystery in the psychological research on the mechanism of attention which still befuddles psychologists now. However, the emergence of RSVP Paradigm (Rapid Serial Visual Presentation) made it possible to have an insight on the dynamic course of processing serially presented stimuli.

Studies on Attention Blink^[1~3], fascinate many researchers. When observer pop-out the first target (Target, T for short) accurately which is embedded in the stream of stimuli at speed of 10 items per second, subject can not detect or identify the second target (probe, P for short) which followed the first target within 500 ms. This impairment of detection of the second target was first discovered by Broadbent^[2], and labeled Attention Blink (AB for short) by Raymond^[3]. Moreover, many researchers discovered that AB effect disappear when T and P have no backward masks.^[1, 4, 5]

To explain all these findings of the AB effect, researchers developed two categories of theory of attention to reveal the time course of attentive process. One is the Serial Model including the

Two-stage model^[6] and Central Interference Theory^[7~9]. These serial models share the same assumption that human subjects can not recognize two objects simultaneously, in other words, the capacity of a phase in central process is extremely limited so that it can deal with one stimulus at most. Sharply contrast to the serial models, the Retrieval Competition theory belongs to the Parallel Model.

Chun and Potter used the dichotomy of this problem by dividing process of stimuli into two stages. One is the peripheral processing stage which can be performed with other mental operations synchronously, while the other is the central stage that must be performed in sequence. The attentional blink results from obstruction in the central stage of the second target.

Based on the two stage model, Pierre Jolicoeur and Dell Acqua developed the Central Interference Theory^[7~9] of the Attention Blink, which divided processing of stimulus more specifically, the first phase refers to sensual and perceptual encoding which is followed by the central mechanism such as Short-term Consolidation^[10], mental rotation, and response selection, et al. AB is due to the decay or the substitution of the Probe before the central processing mechanism is disengaged

from the process of Target (Figure 1).

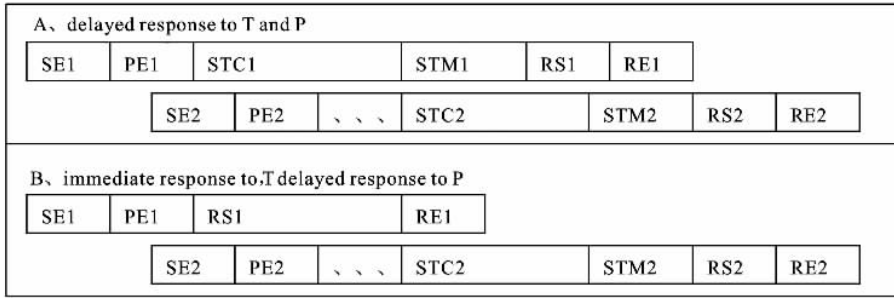


Figure 1 The illustration of the Central Interference theory. SE refer to sensory encode, PE refer to perceptual encode, STC refer to short term consolidation, RS referred to response selection.

There are some strong evidences which contradict these serial models. Using the typical AB paradigm, Shapiro et al. report the visual cocktail effect that the observer's own name can survive the Attention Blink^[11]. Even the names of other persons' can survive the AB if the distracters are made up of normal word but not of names. These results suggested that the strictly serial model can not explain what has been found by Shapiro et al., and may be not perfect, because observers would not be able to report their own names in the course of AB if the central mechanism can only process one stimulus at one time and refuse the entries of another stimulus.

In addition, Luck et al. found a surprising result that "word meaning can be accessed but not reported in the attentional blink"^[12]. In this study, the researcher use N400 as a sensitive index of semantic-mismatch detection, and there is no significant reduction in N400 amplitude in the attentional dwell time although the observers can not report the probe as a semantic-mismatch, with the context word presented at the beginning of the trial. This result indicated the word meaning can be accessed unconsciously although they may not be reported consciously. Moreover, Shapiro et al., adopting a three target AB paradigm, reported the consistent result with Luck's^[13]. They showed that when participants were unable to report Probe, nevertheless, this stimulus do prime third target (presented after the blink) as indicated by better performance of third target when P and third target were related, compared to when they were unrelated. The outcomes above demonstrates that the Probe (presented in the AB) reach a high level of processing, even though it is not reportable.

Another experimental fact, which dispute the strictly serial model, is that a large body of experiments show that T+1 item plays a special role and

probe can survive the AB when it is presented at the location T+1^[14]. Lots of researchers explain this phenomenon as following: the probe, together with the target, enter the presumed central stage simultaneously because of the probe's approximation to the target. This punctured the story of serial models which derived from Feature Integration Theory (FIT for short), although there are a number of contrary results in some studies.

Under FIT's assumption of a serial, self-terminating search, the time for each covert deployment of attention can be estimated from the slope of the function of RT vs. set size because the slope is linearly related to the additional cost of each added item in the display. Estimates of 20-60ms are fairly standard^[17]. Is this an estimate of the time required to process each item in visual search? No credible mechanism of object recognition works that fast^[15, 16], even the overt deployment of eye is much slower: 100-200ms per saccade^[20]. Therefore, although the FIT accounts well for the experimental results in the visual search, an alternative theory-mixed theory may match the facts more accurately than FIT. For example, the carwash model, which was proposed by Wolfe, assumed that a capacity-limited stage can deal with several stimuli at a time, although these stimuli may not enter the stage simultaneously^[15]. In specific, it would cost nearly 20ms-60ms for spatial-attention to select one salient item (or a group of items) and transfer it(or them) to the stage in visual search, but every items would stay at this stage for several hundred millisecond, thus there would be several items in the stage at the same time.

All the evidence mentioned above suggest that the Probe (presented in the AB) reaches a high

level of processing though it can not be reported. They cast doubt on the serial model. But they are insufficient to demonstrate whether serially presented stimuli can be processed simultaneously or sequentially. Thus we hope to test the forenamed question by studying P's influence on the T's processing. The basic logic of our research is that RT of T would not decrease as the interval between T and P prolong if they can be only processed serially. On the contrary, RT of T would decrease sharply as the interval between T and P prolong if they can be processed simultaneously.

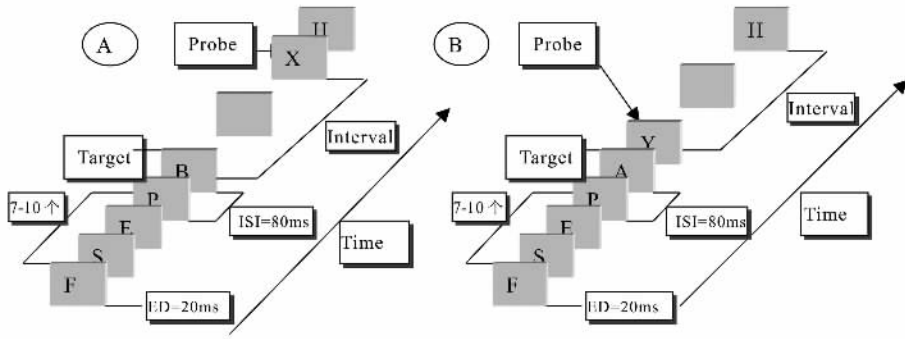


Figure 2 The illustration of the mode A(the inter mode) and mode B(non-inter mode).

Figure 2A refer to the inter mode, Figure 2B refer to the non-inter mode

Why do we set the mode B (non-inter mode)?

Under such a condition, the interval between T and P is stable across all the trials. Then as the interval between P and P+1 item increases, the peripheral process of P becomes easier, but its central stage will not be influenced. Thus the variation in RT of T should be attributed to the change in P's peripheral process. Therefore, we can compare the inter mode with the non-inter mode. If the inter mode and the non-inter mode have significant difference, the interference between central processing of two targets would be proved to exist.

According to two types of models, the RT pattern of two display modes can be predicted respectively. Based on the Central Interference Theory, the response of T is prior to the response of P, P can not enter the central mechanism and its further process would be suspended when T engaged the central mechanism, thus T's process would not be interrupted or delayed by P. As a consequence, in the both modes, the RT of T should be constant or decline slightly as the interval increases, moreover, the RT of P should decline significantly as the interval prolong. The approximate illustration will be demonstrated in Fig-

Based on the basic logic above, we hope to conduct a systematic study on this issue by using the simplified RSVP Paradigm. Two modes of display will be applied in the following experiments. In the mode A (inter mode), T will be immediately followed by blank screen for variable duration and then P will be present after it. In the mode B (non-inter mode), T and P will be present sequentially without distracters or blank screen between them. Speeded response of T and P are required in both modes. The details in these display modes are illustrated in following figure 2.

ure 3A.

According to the parallel models, however, different RT patterns would be predicted. Although the response to T is prior to the response to P, T would be interfered or delayed by the process engaged by P because T and P are processed simultaneously. In the non-inter mode, this interference declines slightly as the interval after P prolongs, thus RT of T should decline accordingly. While in the inter mode, the interference declines greatly as interval between T and P increase, thus the RT of T should decline significantly. The approximate illustration will be demonstrated in Figure3B.

Considering the special role of the P, we design two experiments to test whether attentive process is parallel or serial under RSVP Paradigm by using the method mentioned above.

2 Experiment 1

2.1 Method

2.1.1 Participants and equipments 20 undergraduates of China Agricultural University, whose age vary from 20 to 22, participated in the experiment, 14 of them are male. All the participants have normal vision or corrected to normal vision.

They have no experience in a similar experiment.

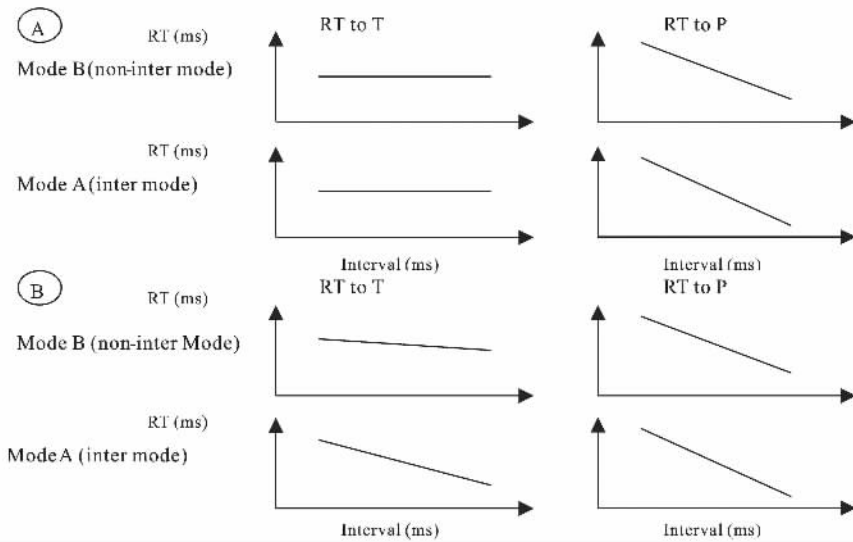


Figure 3 The prediction of the RT patterns according to different theories. Figure 3A refers to the prediction based on serial model, Figure 3B refers to the prediction based on parallel model.

The stimuli are displayed on a 15 inch CRT screen, 100Hz refresh rate, a standard keyboard is used for response. All the procedures are programmed by E-Prime.

2.1.2 Materials All the items including targets and distracters are chosen from the alphabet randomly. The T is present from the 7th item to 10th item randomly. Half of T is the letter A and another half is the letter B. The P is either the letter X or the letter Y with equal chance. In the inter mode, the T and P are separated by a blank screen with varied duration. A backward mask follows P immediately (Fig2A). While in the non-inter mode, the P appears shortly after the T and a blank screen is displayed after P (Fig2B).

All the items are presented at the center of the screen. The size of letters is 16mm×11mm. The color of the letters is black and the color of the background is silver. The exposure duration(ED) of items is 20ms and the inter stimuli interval (ISI) is 80ms. All the subjects are required to view the screen at approximately 60cm.

2.1.3 Experiment Design There are two within-subjects variables including display modes (inter mode and the non-inter mode respectively) and SOA (100ms,200ms,300ms,600ms and 900ms respectively). The experiment contain 16 sessions, each has 20 trials. The trials of the two display modes are equal. The sequence of 16 sessions is decided randomly. Subjects have a short rest for 1min every 64 trials.

2.1.4 Tasks and Procedures Participants are re-

quired to focus on the RSVP stream at the center of the screen. They should press the key "F" to A and press key "J" to B as soon as possible. If X or Y emerges, they should press key "D" to X and press "K" to Y. Speeded responses to two targets are demanded in the experiment. But participants were asked to give priority to the response to the T. They were demanded to make sure that the accuracy of the response to T should be more than 90 percent and that of P should be more than 80 percent. To balance difference between four combinations of T and P, they take place at equal chance.

Participants have to exercise before the formal experiment. The procedure and task in exercise are almost the same as the formal experiment with something different from the formal test sessions. Firstly, the exercises only contain one session including 40 trials and provide subjects with feedback (no feedback in formal experiment). When subjects can accomplish the task by achieving the criteria of accuracy (T: more than 90 percent, P: more than 80 percent), the exercises stops. If not, subjects have to exercise again until they pass it.

2.2 Results

2.2.1 The RT and Accuracy of two targets are listed in Table1

2.2.2 Analysis of the RT of T and P Five subjects were deleted because they failed to achieve the criteria of accuracy during their exercise. The RT of the correct response to T and the RT of the correct response to P when T is reported correctly enter the further statistical analysis. We adopted

these procedures because we want to ensure that subjects gave priority to T and only the correct response would be included.

The repeated measure ANOVA with display mode and SOA factors reveal the following effects on the RT of T. The main effect of display mode is significant, $F(1,14)=18.247, p=0.001$; the main

effect of SOA is also significant, $F(4,56)=13.713, p=0.000$. However, the interaction between two factors is insignificant, $F(4,56)=1.438, p=0.233$. This pattern of results matches the prediction of parallel model exactly (Figure 4A).

Table 1 the RT and Accuracy of T and P

condition	SOA	100ms	200ms	300ms	600ms	900ms
Mode A (inter mode)	Accuracy of T	0.95	0.95	0.94	0.94	0.93
	Accuracy of P	0.89	0.91	0.91	0.90	0.84
	RT of T (ms)	615±82	590±62	581±72	564±54	565±80
	RT of P (ms)	777±97	685±102	617±73	539±52	532±49
Mode B (non-inter mode)	Accuracy of T	0.93	0.95	0.94	0.93	0.94
	Accuracy of P	0.92	0.96	0.95	0.95	0.96
	RT of T (ms)	634±91	639±87	621±75	605±68	610±62
	RT of P (ms)	761±81	758±74	742±72	725±60	725±55

The repeated measure ANOVA with display mode and SOA factors reveals following effects on the RT of P. The main effect of display mode is significant, $F(1,14)=180.716, p=0.000$; the main effect of SOA is also significant, $F(4,56)=66.807, p=0.000$; Moreover, the interaction be-

tween the two factors is significant, $F(4,56)=32.483, p=0.000$. This pattern of results indicates that the declination of the RT of P in the inter mode is much larger than that in the non-inter mode (Figure 4B).

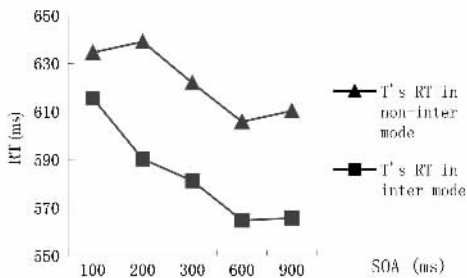


Figure 4A Illustration of RT of T

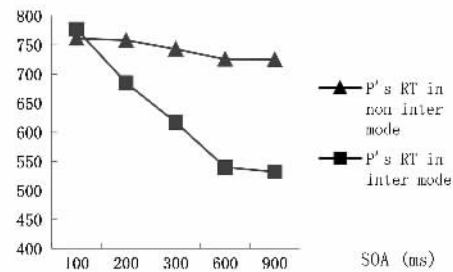


Figure 4B Illustration of RT of P

2.2.3 Analysis of the accuracy of T and P The repeated measure ANOVA with display mode and SOA factors reveals the following effects on the accuracy of T. The main effect of display mode is insignificant, $F(1,14)=0.072, p=0.793$; the main effect of SOA is also insignificant, $F(4,56)=0.802, p=0.529$. Moreover, the interaction between two factors is also insignificant, $F(4,56)=0.384, p=0.819$. (Figure 5).

The repeated measure ANOVA with display mode and SOA factors reveals the following effects on the accuracy of P. The main effect of display mode is significant, $F(1,14)=25.897, p=0.000$; the main effect of SOA is insignificant, $F(4,56)=1.769, p=0.148$. But, the interaction between the two factors is significant, $F(4,56)=5.809, p=0.001$. This indicates that accuracy of P in The

non-inter mode is higher than that in the inter mode (Figure 5).

2.3 Discussion The pattern of RT in this experiment matches the parallel model exactly, except of one point. According to the prediction of parallel model, the RT of P would decline in non-inter mode as greatly as inter mode. However, the results contradict this assumption. The significant interactive effect on the RT of P between the display mode and the SOA indicates that the process of T impedes the process of P much more greatly than the inference between the process of P and P+1 (the backward mask of P). This also accounts for the existence of the difference between the RT of T in two modes.

In conclusion, the results above support the parallel model. In another word, the central mech-

anism can at least process two stimuli simultaneously. As the lag between T and P become longer (as SOA increase in the inter mode), the interference between the two processes reduces sharply.

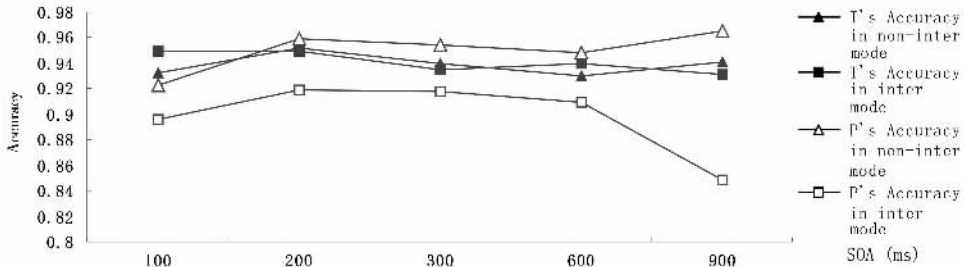


Figure 5 Accuracy of T and P

Since some researchers proposed that T and P can be processed simultaneously, according to the existing results which indicate that the T+1 item can survive AB. Therefore, the parallel pattern of RT may be due to the lack of interruption of distracters. In the next experiment, we want to eliminate the doubts on whether a distracter between two targets can destroy the parallel mechanism by adding a backward mask immediately after T.

3 Experiment 2

3.1 Method

The basic parameters in the experiment 2 are as same as that in the first experiment except for three aspects. The first difference in design is that T is immediately followed by a randomly-selected letter. In the inter mode, the T+1 (the item immediately following T) and P are separated by a blank screen with varied duration. A backward mask follows P immediately just as in the inter mode of the experiment 1. While in the non-inter mode, the P appears shortly after the T+1 and a blank screen is displayed after P.

In the second place, five different SOA (200ms, 300ms, 400ms, 500ms and 700ms) were chosen for this experiment since it was found that RT of T and P are stable as interval varies from

Moreover the interference becomes smaller when one of two parallel processes becomes easier (as the SOA between P and P+1 increase in the non-inter mode).

600ms to 900ms in the first experiment. We adjusted the range of SOA factor in order to exam the hypothesis more delicately.

Thirdly, we set ED=30ms and ISI=70ms in order to cut down the difficulty of the tasks. Some of previous studies in our lab proved that, as ED is prolonged, magnitude of Attention Blink would decline without accompanying decline in RT of T^[19].

19 undergraduates from China Agricultural University, whose age varied from 20 to 22, participated the experiment, 16 of them are male. All the participants have normal vision or corrected to normal vision. They have no experience in similar experiments.

The stimuli were displayed on the 15 inch CRT screens, standard keyboards were used for response. All the procedures were programmed by E-Prime.

3.2 Results

3.2.1 The RT and Accuracy of two targets are list in Table2

3.2.2 Analysis of the RT of T and P Five subjects were deleted because they failed to achieve the criteria of accuracy in training sessions. The method adopted to analyze the data was as same as that in Experiment 1.

Table 2 the RT and Accuracy of T and P

condition	SOA	200ms	300ms	400ms	500ms	700ms
Mode A (inter mode)	Accuracy of T	0.96	0.96	0.95	0.97	0.95
	Accuracy of P	0.90	0.93	0.91	0.90	0.86
	RT of T (ms)	585±121	583±118	590±116	596±123	600±140
	RT of P (ms)	706±102	631±96	569±73	532±84	517±69
Mode B (non-inter mode)	Accuracy of T	0.94	0.96	0.97	0.98	0.96
	Accuracy of P	0.93	0.95	0.96	0.94	0.94
	RT of T (ms)	582±116	579±105	580±97	573±93	577±87
	RT of P (ms)	651±116	637±96	635±91	624±85	623±80

The repeated measure ANOVA with display mode and SOA factors reveals following effects on the RT of T. The main effect of display mode was insignificant, $F(1,13)=0.941, p=0.350$; the main effect of SOA was also insignificant, $F(4,52)=0.309, p=0.871$. Moreover, the interaction between two factors was also insignificant, $F(4,52)=1.444, p=0.233$. This pattern of results matches the prediction of serial model exactly and is contrary to the result of the first experiment (Fig-

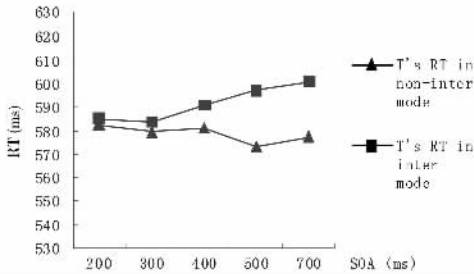


Figure 6A Illustration of T's RT

ure 6).

The repeated measure ANOVA with display mode and SOA factors reveal following effects on the RT of P. The main effect of display mode is significant, $F(1,13)=13.433, p=0.001$; the main effect of SOA is also significant, $F(4,52)=52.489, p=0.000$; Moreover, the interaction between two factors is significant, $F(4,52)=48.587, p=0.000$. (Figure 6)

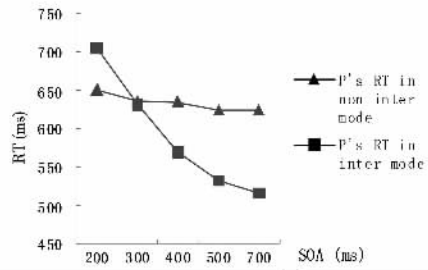


Figure 6B Illustration of T's RT

3.2.3 Analysis of the accuracy of T and P The repeated measure ANOVA with display mode and SOA factors revealed the following effects on the accuracy of T. The main effect of display mode was insignificant, $F(1,13)=0.107, p=0.749$; the main effect of SOA was also insignificant, $F(4,52)=2.395, p=0.062$. Moreover, the interaction between two factors was also insignificant, $F(4,56)=2.117, p=0.092$. (Figure 7)

The repeated measure ANOVA with display

mode and SOA factors revealed the following effects on the accuracy of P. The main effect of display mode was significant, $F(1,13)=9.095, p=0.010$; the main effect of SOA was insignificant, $F(4,52)=2.039, p=0.102$. In addition, the interaction between two factors was insignificant, $F(4,52)=1.539, p=0.205$. This replicates the result of first experiment which indicates that accuracy of P in Non-inter mode is higher than that in inter mode. (Figure 7)

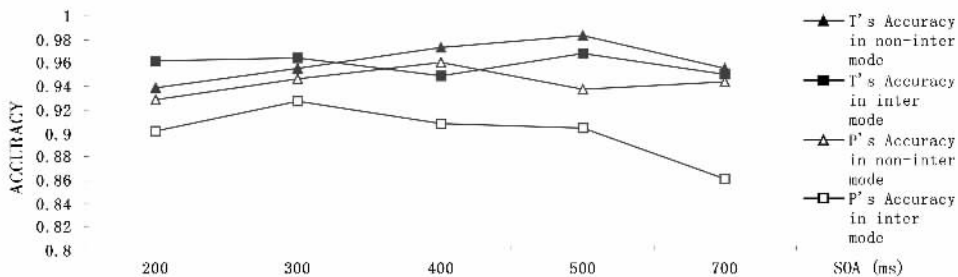


Figure 7 Accuracy of T and P

3.3 Discussion

In the two modes of this experiment, the RT of response to T remained constant with the prediction of the serial model perfectly. On the contrary, the RT pattern replicated the results of the first experiment. The results of Experiment 2 demonstrate that the process of T can not be interfered by the following process of P. In other words, the central mechanism may be only able to

deal with one stimulus at a certain moment when two sequentially presented targets are interrupted by a distracter.

Combining these results with the results in the first experiment, we conclude that the mechanism of objects recognition can be operated in parallel way. It is the distracter between two sequentially presented targets that spoil the parallel mechanism, thus producing the results like the prediction

of serial model.

4 General Discussion

In the first experiment, the pattern of RT gave a hand to the parallel model. In specific, the central mechanism processed two sequentially presented stimuli simultaneously. As the lag between T and P became longer in the inter mode (as SOA increases in the inter mode), the interference between two processes reduced greatly. What is more, in the non-inter mode, the interference became smaller when one of two parallel processes became easier too (as the SOA between P and P+1 increases in the non-inter mode).

However, when T and P were interrupted by a distracter in the second experiment, it is interesting to see the RT of T remaining invariable as the SOA changed in both modes. This result seems to support serial models for the reason that the process of T can not be delayed by the following process.

Combining the results of both experiments, we can draw a conclusion that human subjects can process two sequentially presented stimuli in RSVP stream simultaneously. In other words, parallel processing in the central mechanism of objects recognition do exist. But why did the results in the second experiment match the prediction of serial models? It may be the T+1 that disrupts the parallel processing mechanism. In specific, T+1 may have entered the central mechanism instead of P. The fixed SOA between T and T+1 in the second experiment leads to constant interference between T and T+1. Therefore the RT of T is constant in the second experiment, which exactly matches the serial model.

Some researchers may argue that the result of the first experiment can be explained by serial model too. For example, T and P are processed alternately. Although the process of T and P seem to be parallel in the whole, they are still processed in sequence from the micro-perspective. In other words, the processing system is a time-sharing system. Admittedly, such an explanation can account for the result in the non-inter mode in the first experiment because the slope of T's function of RT vs. SOA is similar to that of P's in the non-inter mode. But it can not explain why the slope of T's function of RT vs. SOA is much smaller than that of P's in the inter mode. In fact, the result in the inter mode contradicts the prediction of the explanation above.

There may be some controversies in the expla-

nation of the results. Some one may argue that it is not the central mechanism but the peripheral process that operates simultaneously just as the two-stage model or Central Interference theory assumed. But this account is insufficient to explain why RT of T in the inter mode of the second experiment is constant. As we know, T+1 (the backward mask immediately after T) is at least suppose to be processed to the extent that it can be dismissed as a distracter. Meanwhile, T+1 is not as sufficiently processed as targets. In other words, the process of T+1 includes at least peripheral processing but lacks some phase of central processing (the detail explanation is listed in the next paragraph). If the deduction in the RT of T in the non-inter mode of the first experiment is due to the deduction of interference between the peripheral process of P and the central process of T, a similar deduction in the RT of T in the inter mode of the second experiment is supposed to be observed. But results make such an assumption impossible.

In both experiments, the significant interactive effect on the RT of P between display mode and SOA factors indicate that the process of T impedes the process of P much more seriously than the process of P+1 (the backward mask of P) interferes with the process of P. Therefore, we can infer that distracters were not as sufficiently processed as targets. This is opposite with the assumption of Retrieval Competition theory which hold that T and P and their respective backward masks are recognized although subjects can not report them.

Previous studies point out that P can survive Attention Blink when it immediately follows T. Researchers postulate that T and P enter the central mechanism simultaneously because of extremely short lag between them. This intuition is supported by this study. However, it is not only the short lag between them but also the lack of distracter between them that results in the parallel processing. When SOA equaled to 200ms or 300ms in the inter mode of the first experiment, RT of T kept on declining which reveal the characteristic of parallel processing. However, the RT of T in the inter mode of the second experiment indicates the feature of serial process when the SOA equals to 200ms or 300ms. In fact, the SOA between T and P under the conditions above in the first experiment is as same as that in the second experiment. The different results may be due mainly to the T+1, not the short lag.

According to the analysis above, the theories for Attentional Blink have to be revised in order to accommodate our findings. When there is no distracter between T and P and the lag between them is short, they can be processed simultaneously. Although less attention is allocated to P, P can survive the Attentional Blink. However, if there is a distracter between two sequentially presented targets, it will spoil the parallel mechanism and delay the central process of P, thus producing the typical Attentional Blink.

In both experiments, accuracy of T is constantly higher than 90 percent and its RT is shorter than that of P. All these results demonstrate that subjects gave priority to T as they were required. The fact that the accuracy of P in the non-inter mode is much higher than that of P in the inter mode suggests that parallel processing is more efficient than serial processing. In the non-inter mode, T and P are always processed simultaneously. However, parallel mechanism will be disrupted when lag between T and P is too long (maybe 700ms or 800ms). This may be an account for the significant decline of the accuracy of P at long lag in the inter mode. Under such a condition, subjects had to switch from parallel processing mode to serial processing mode, thus producing the decline in accuracy.

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序列呈现的刺激可以被并行的加工:来自注意瞬脱研究的证据

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摘 要 采用 RSVP 范式验证了两个序列呈现的刺激可以被并行加工的假设。实验一发现:在两个目标刺激(Target 和 Probe, 以下简称 T 和 P)间无干扰刺激时, T 的反应时随着 T、P 之间的间隔显著减小, 其模式符合并行加工模型的预测。而实验二发现:当 T 和 P 之间有干扰刺激(即 T 后呈现后续掩蔽)时, T 的反应时并不随着 T、P 的间隔而减小, 其模式符合序列加工模型的预测。由此可推论, 只要两个序列呈现的刺激之间没有干扰刺激, 可以对它们进行并行的注意加工, 但是会受到两个刺激之间的时间间隔的影响。

关键词 并行加工模型, 序列加工模型, 注意瞬脱。

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