BRIEF-STIMULUS PRESENTATIONS ON MULTIFORM TANDEM SCHEDULES

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Three experiments examined the influence of a brief stimulus (a light) on the behavior of food-deprived rats whose lever pressing on tandem schedules comprising components of different schedule types resulted in food presentation. In Experiment 1, either a tandem variable-ratio variable-interval or a tandem variable-interval variable-ratio schedule was used. The variable-interval requirement in the tandem variable-ratio variable-interval schedule was yoked to the time taken to complete the variable-ratio component in the tandem variable-interval variable-ratio schedule, and the length of the variable-interval component in the latter schedule was yoked to the variable-ratio component in the former schedule. If a brief stimulus occurred following completion of the first component, then behavior was differentiated in the two components; subjects responded more quickly in the variable-ratio than in the variable-interval component. If the stimulus was removed, then response rate was determined by the nature of the final component. Similar results were obtained in Experiments 2 and 3 with the use of a three-component tandem variable-ratio variable-interval variable-ratio schedule or tandem variable-interval variable-ratio variable-interval schedule. Thus, a brief stimulus that was not explicitly paired with reinforcement engendered behavior typical of the component schedule preceding its presentation.

Key words: brief stimulus, tandem schedule, multiform schedule, conditioned reinforcement, discrimination, marking, lever press, rat

The presentation of a brief, salient stimulus following the completion of a component schedule during exposure to a second-order schedule of reinforcement may engender performance characteristic of that component (see Marr, 1979, for a review). For example, if a subject is required to complete four fixed-interval (FI) 60-s schedules before primary reinforcement is delivered (i.e., if a second-order fixed-ratio [FR] 4 [FI 60-s] schedule is in force), then, in the absence of a stimulus change accompanying the completion of each FI 60-s component, performance will resemble that produced on an FI 240-s schedule. However, if a brief stimulus is presented on completion of each component schedule, then performance will resemble that produced by four individual FI 60-s schedules (cf. Neuringer & Chung, 1967).

A number of theories regarding the effect of such brief stimuli have been put forth. Keller (1966) suggested that the brief stimulus

may acquire conditioned reinforcing powers and, consequently, may support the pattern of behavior typical of the schedule it follows. Although it has been shown that brief stimuli do not need to be paired with reinforcement to produce such effects (e.g., Squires, Norborg, & Fantino, 1975), this demonstration only argues against the conditioned reinforcement theory of brief-stimulus action if it is accepted that a secondary reinforcer is generated only by contiguous pairing with a primary reinforcer (e.g., Hull, 1943). Contemporary accounts of the action of conditioned reinforcement suggest that previously neutral stimuli acquire reinforcing effectiveness to the extent that they signal a reduction in time to the delivery of primary reinforcement (e.g., Fantino, 1981). Schaal and Branch (1988, 1990) have documented that a stimulus does not need to be temporally contiguous to reinforcement to acquire a secondary reinforcing function. Therefore, even a procedure in which the brief stimulus is not presented following completion of the terminal component, and, hence, is never presented along with primary reinforcement, may endow the brief stimulus with conditioned reinforcing efficacy. Contingencies that use variable-interval (VI) or variable-ratio (VR) schedules may be especially susceptible to this effect, because the stimulus might sometimes occur in close temporal proximity to reinforce-

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ment if the last component has a small interval or response requirement.

An alternative view of brief-stimulus effects is that they serve as discriminative stimuli, signaling the operation of the individual components of a second-order schedule and allowing the subject to perform appropriately (e.g., Squires et al., 1975). A number of mechanisms regarding how brief stimuli come to serve as discriminative stimuli have been suggested; these include generalization between primary reinforcement and brief stimuli (see Squires et al., 1975) and the "marking hypothesis" (Lieberman, Davidson, & Thomas, 1985). Unfortunately, there is little evidence that enables us to discriminate between these theories.

Despite the wide-ranging nature of theorizing regarding this issue, the conditions under which the effects of brief stimuli have been studied have been limited. Most studies have been conducted on second-order contingencies in which all the components are of the same schedule type (but see Williams & Royalty, 1990). Further, the vast majority of such studies have been conducted using interval rather than ratio schedules. Given the generality of the explanation provided by the aforementioned theories and the possible importance of these studies to the development of theory, this limited variation of schedule type is unfortunate.

It is possible to arrange a schedule such that the component schedules are different (e.g., VI and VR schedules). Such a schedule can be referred to as *multiform*. The present experiments attempted to explore the effects of a brief stimulus on performance during exposure to a schedule in which the components were different (e.g., VR and VI schedules). If brief stimuli engender performance typical of the component schedules on which they are presented, then (irrespective of the mechanisms responsible for the effect) this effect should be noted with multiform contingencies as well as with the previously investigated second-order contingencies.

EXPERIMENT 1

The first experiment arranged a contingency in which subjects had to complete one schedule in order to gain access to a second schedule (i.e., a tandem schedule). Completion of the second schedule produced reinforce-

ment. For one group of subjects, the first schedule was a VR and the second a VI. For a second group of subjects, the first schedule was a VI and the second a VR. In the absence of a brief stimulus upon completion of the first schedule, performance might be expected to be essentially uniform across the entire contingency and resemble that engendered by the second component of the contingency (see, e.g., Peele, Casey, & Silberberg, 1984; Reed & Hall, 1989). Should a brief stimulus presented at the end of the first schedule be effective, then performance in the component schedules should differ and resemble that engendered by the appropriate simple VR and VI schedules. That is, response rate should be higher in the VR component than in the VI component of the contingency (cf. Zuriff, 1970). Thus, for the tandem VI VR schedule, rates of response in the VI component should be higher without the brief stimulus than with the brief stimulus, because performance without the stimulus would be determined by the final VR schedule. For subjects receiving the VR VI schedule, response rates should be lower in the initial VR component without, rather than with, the brief stimulus, because performance will be determined by the terminal VI schedule component.

METHOD

Subjects

Six male DA rats, naive with respect to lever pressing and the visual stimulus to be used in the present study, served as subjects. The rats were 6 to 7 months old at the start of the study, had free-feeding body weights ranging from 250 to 295 g, and were maintained at 80% of these weights throughout the study. The animals were housed singly, and had free access to water in the home cage.

Apparatus

Six identical conditioning chambers (Campden Instruments Ltd.) were employed. Each chamber was housed in a light- and sound-attenuating case, and was ventilated by an extractor fan that also provided a 65-dB(A) background masking noise. The chamber had two retractable levers, but only one was used in the study. Located between the levers was a recessed tray, covered by a clear, hinged Perspex flap, into which a reinforcer (one 45-mg

food pellet) could be delivered. A light (24 W) was centrally located on the ceiling of the chamber, and could be used to provide the brief stimulus. Apart from the brief stimulus, the chamber was not illuminated during this experiment.

Procedure

The subjects were magazine trained during two 40-min sessions of a variable-time (VT) 60-s schedule. During the first session, the flap covering the magazine tray was taped open to allow easy access to the pellets. For the second session, the flap was lowered to its standard resting position. The rats were then trained to lever press by inserting a lever and reinforcing every response (a CRF schedule). Two sessions of CRF were given; each lasted until the subject had earned 75 reinforcements. The animals were then divided into three pairs; the 2 subjects in each pair were matched in terms of speed of acquisition of the lever-press response.

One subject from each pair was trained on a tandem VR VI schedule, and the other subject was trained on a tandem VI VR schedule. Both subjects in each pair served as the master animal for one component of the tandem schedule. A yoking procedure was designed to match reinforcement frequency, and the frequency of brief-stimulus presentation, for both types of tandem schedule. The subject receiving the tandem VR VI schedule acted as master for the subject receiving the VI VR schedules during the first component. The time taken to complete the initial VR schedule became the interval criterion set up for the 2nd animal. The first response by the yoked subject following completion of the VR schedule by the master subject satisfied the interval criterion. For the second component, the master and yoked subject roles were reversed so that the time taken to complete the VR component by the subject experiencing the tandem VI VR schedule set up the interval schedule criterion for the subject performing on the tandem VR VI schedule. The first response by the yoked subject after the master subject had completed the VR component satisfied the interval. One aspect of this procedure is worth brief comment. If the master VR subject completed the requirement in, for example, 20 s, this subject would then enter the next component (the VI component). The subject responding on the

yoked VI schedule may have been responding more slowly and, therefore, may not have satisfied the interval requirement until a further 10 s had elapsed. At this point, the latter subject became the master (VR) subject. In this scenario, the actual yoked interval for the rat that began the sequence on the VR schedule commences after that rat had been responding for 10 s following completion of the VR schedule. Responses during these "dead" periods were counted as responses during the yoked VI schedule for that subject.

During Phase 1, a 2-s flash provided by the overhead light followed completion of the first component, and reinforcement (but no flash of light) followed completion of the second component. For both animals in each pair, the schedule requirements were made progressively more severe, and the same VR schedule parameters were used for both subjects. The schedule parameters were as follows: for sessions 1 through 4, VR 5 (range, 1 to 9); Sessions 5 and 6, VR 10 (range, 1 to 19); Sessions 7 through 10, VR 15 (range, 1 to 29); Sessions 11 through 14, VR 20 (range, 1 to 39); Sessions 15 through 18, VR 25 (range, 1 to 49); and Sessions 19 through 80, VR 30 (range, 1 to 59).

During Phase 2, the VR schedule parameter remained unaltered from its terminal Phase 1 value, but the 2-s flash of light that followed completion of the first schedule component was removed. Reinforcement followed completion of the second schedule component. This phase lasted for 40 sessions.

During Phase 3, subjects still responded on a schedule with a VR 30 component, but they again received a flash of light following completion of the first component and reinforcement following completion of the second component, as described for Phase 1. Phase 3 lasted for 60 sessions.

Each session of the three critical experimental phases lasted until the subject had earned 30 reinforcers.

RESULTS AND DISCUSSION

The mean response rates for the three pairs of subjects, for each component of the second-order schedule averaged over the last six sessions of each phase, are displayed in Figure 1. During Phase 1, subjects with the VI VR schedule (left graphs) had a higher rate for the VR (second) component than for the initial VI

Fig. 1. Results from Experiment 1. Mean response rates over the last six sessions of each phase for each component; error bars show the range (hatched bars = VR component; open bars = VI component) for all subjects. Left graphs: subjects receiving the tandem VI VR schedule; right graphs: subjects experiencing the tandem VR VI schedule. Phases 1 and 3: with brief-stimulus presentations; Phase 2: without brief-stimulus presentations.

component. Although a difference remained in this direction after the stimulus had been removed in Phase 2, the difference in rate of response between the components was substantially reduced, largely due to an increase in response rate during the VI component. On return to the baseline conditions in Phase 3, the difference in rate between the components again became larger, although this difference was not necessarily identical to that established in Phase 1.

For the subjects experiencing the VR VI schedule (right graphs), these data reveal that subjects responded at a higher rate in the VR than in the VI component of the schedule in Phase 1 when there was a brief stimulus. This difference was exhibited by all subjects. When the brief stimulus was withdrawn during Phase 2, this difference was reversed in 2 of the 3 subjects; subjects responded faster in the VI component than during the VR component.

With the reintroduction of the brief stimulus in Phase 3, all subjects came to respond at a higher rate in the VR than the VI component.

These data demonstrate that a brief stimulus inserted following the initial component of a tandem schedule (in fact, generating a primed chained schedule; see Ferster & Skinner, 1957) can markedly alter performance in the individual components of such a schedule compared to that performance observed when no stimulus is presented. With this stimulus, response rates in the VR component of a tandem VR VI schedule were higher than in the absence of the stimulus. In contrast, when a brief stimulus was presented following the VI component of a random VI VR schedule, response rates were lower in the VI component than in the absence of the stimulus. These results, therefore, are consistent with the findings for second-order schedules in which the components are of the same schedule type. That

is, a brief stimulus serves to alter performance in line with the expectation of performance should that component have terminated in primary reinforcement: Response rates on the VR schedule are expected to be greater than those on the VI schedule.

EXPERIMENT 2

This series of experiments was designed to establish whether a brief stimulus could engender behavior characteristic of the component schedules of a tandem contingency, even when the component schedules are of a different type. Although Experiment 1 demonstrated that on a tandem VR VI or a tandem VI VR schedule, a stimulus following the initial component could differentiate performance on the two component schedules, it did not demonstrate that this brief stimulus could control behavior on two different schedules. It is possible that the stimulus controlled behavior for only one of the two schedules (either prospectively or retrospectively). Experiment 2 attempted to establish whether a brief stimulus could simultaneously control behavior on two different schedules. To this end, subjects were trained on a three-component schedule, either a tandem VR VI VR or a tandem VI VR VI schedule. A brief stimulus was presented following the first two components but not after the third. Thus, the same brief stimulus was presented following both a VR and a VI schedule (and preceding both a VR and a VI schedule). If the brief stimulus engendered performance characteristic of the individual component schedules that it separated, then the stimulus would need to control two different behavioral patterns.

METHOD

Subjects and Apparatus

Six experimentally naive male DA rats served as subjects. The subjects were 4 to 5 months old at the start of the study, had free-feeding weights ranging from 260 to 310 g, and were maintained as described in Experiment 1. The apparatus was that used in Experiment 1.

Procedure

Subjects were magazine and lever-press trained as described in Experiment 1. As in Experiment 1, the subjects were divided into

three pairs, matched for speed of acquisition of the lever-press response. Each subject in all the pairs served as the master for some part of the contingency. The yoking was conducted as described in Experiment 1, with the time taken to complete the VR components generating the interval for the VI components of the schedule. The subject that experienced the tandem VR VI VR schedule was the master for the first and third components, and the subject that received the tandem VI VR VI schedule was the master for the second component.

In Phase 1, the VR schedule parameters were gradually made more severe. The schedule parameters were increased as follows: Sessions 1 through 3, VR 5; Sessions 4 through 9, VR 10; Sessions 10 through 15, VR 15; Sessions 16 through 21, VR 20; Sessions 22 through 27, VR 25; and Sessions 28 through 80, VR 30. For all subjects, a 2-s flash of light was presented only following completion of the first and second components; reinforcement alone followed completion of the final component.

During Phase 2, subjects continued to respond with the VR parameters experienced at the end of Phase 1 training, but the brief stimulus was not presented following the first two components. Reinforcement followed the completion of the final component. This phase lasted 40 sessions.

For Phase 3, subjects experienced the same VR schedule parameters as they had in Phase 2, but the brief stimulus was reintroduced following the first and second components of the schedule, as described for Phase 1. Phase 3 lasted 60 sessions.

All sessions during the critical treatment phases lasted until the subject had obtained 30 reinforcers.

RESULTS AND DISCUSSION

Figure 2 displays the mean response rate for each subject, over each component, averaged over the last six sessions during each phase. Inspection of these data from the tandem VR VI VR subjects (left graphs) reveals that during Phase 1, response rates in the initial VR components were slightly higher than in the VI component. Rates were substantially higher in the terminal VR component than in either of the other components. During Phase 2, the overall response rates increased. There

Fig. 2. Results from Experiment 2. Mean response rates over the last six sessions of each phase for each component; error bars show the range (hatched bars = VR component; open bars = VI component) for all subjects. Left graphs: subjects receiving the tandem VR VI VR schedule; right graphs: subjects experiencing the tandem VI VR VI schedule. Phases 1 and 3: with brief-stimulus presentations; Phase 2: without brief-stimulus presentations.

was no consistent effect on response rate during the initial VR schedule relative to Phase 1, but the rate increased markedly for the VI component of the schedule. On the reintroduction of the brief stimulus in Phase 3, the pattern of behavior observed in Phase 1 was restored, although the Phase 3 rates were not necessarily equal to the rates emitted in Phase 1. Rates were highest in the terminal VR component, and were higher for all subjects in the initial VR component compared with the VI component. Rates in the VI component were reduced compared to those of Phase 2.

Inspection of these data for the subjects responding on the tandem VI VR VI schedule (Figure 2, right graphs) show that Subjects R49 and R51 responded at a higher rate during the VR component than in either the initial or terminal VI components during Phase 1. When the brief stimulus was omitted during Phase 2, a different pattern emerged. Subject

R49 displayed an increasing response rate over the three components so that rates declined from their Phase 1 levels in the VR component, but the terminal VI component now displayed the highest response rate. The other 2 subjects responded at similar rates in the initial two components and at a higher rate in the final component. For all 3 subjects, response rate during the VR component was reduced in Phase 2. On the reintroduction of the brief stimulus during Phase 3, the pattern observed in Phase 1 baseline proved to be difficult to reestablish, and only Subject R49 displayed a pattern of results that was similar to that in Phase 1. Response rates were generally low in the first VI component, high in the VR component, and slightly higher still in the terminal VI component. Rates in the VR component were increased relative to those of Phase 2.

On the whole, these results demonstrate that with a three-link tandem schedule, a brief

stimulus can engender performance on the individual components similar to that which might be expected if primary reinforcement followed each schedule. When the brief stimulus was present, the VR schedules tended to produce higher rates of response than the VI schedules did. However, when the stimulus was omitted, performance appeared to be determined both by the position of the component in relation to primary reinforcement and the nature of the component receiving primary reinforcement: If behavior in a VR component received reinforcement, then response rates were high during VI components in the absence of a brief stimulus compared to when a brief stimulus signaled the schedules; when lever pressing in the VI schedule was reinforced, then response rates in the VR schedule in the absence of a signal were lower than when a brief stimulus signaled the operation of that schedule. This pattern of results was achieved despite presentation of the brief stimulus being contingent upon the operation of two different schedules. It is not immediately clear, however, how the same stimulus promoted two quite different patterns of behavior. One possibility is that the stimulus occurring after the first component and the stimulus occurring after the second component of the schedule, although sharing the same physical characteristics, differ in their ordinal relationship to the previous reinforcer. It could be that this information (i.e., ordinal position since the last reinforcer) operates to allow the same physical stimulus to control different patterns of behavior.

EXPERIMENT 3

The effect of a brief-stimulus presentation on a multiform tandem schedule has not received a great deal of attention, if any at all. Hence, before commenting on the likely source of the stimulus control over behavior, it would be prudent to explore further the effects of brief-stimulus presentations on this type of schedule. In the previous experiments reported here, subjects were initially trained with the brief stimulus present, and the effect of the removal of the stimulus was studied. In an attempt to replicate systematically the results obtained from Experiment 2 and thereby extend the generality of the findings, Experiment 3 trained subjects on the same schedules as in

Experiment 2. However, the three-link tandem schedule with no brief-stimulus presentations was presented first, and then the effect of the addition of the brief stimulus was studied.

METHOD

Subjects and Apparatus

Six experimentally naive male DA rats served as subjects. The subjects were 3 to 4 months old at the start of the study, had free-feeding weights ranging from 210 to 225 g, and were maintained as described in Experiment 1. The apparatus was that used in Experiment 1.

Procedure

Subjects were trained exactly as described in Experiment 2, except that there were no brief-stimulus presentations in Phases 1 and 3; the brief-stimulus presentations were made in Phase 2. Phase 1 lasted 80 sessions, Phase 2 lasted 80 sessions, and Phase 3 continued for 60 sessions. Each session in all three phases lasted until the subject had earned 30 reinforcers.

RESULTS AND DISCUSSION

Figure 3 displays the mean response rate for each subject, over each component, averaged over the last six sessions of training of each phase. Inspection of these data from the subjects experiencing the tandem VR VI VR schedule (left graphs) reveals that, during Phase 1, response rates in the three components were generally similar. At the end of Phase 2 training, the overall rates of response had decreased from their Phase 1 levels. The pattern of response rates in the three components was also altered. Response rates were now higher in the initial and the terminal VR components than in the VI component for all 3 subjects. In Phase 3, the pattern of behavior observed in Phase 2 was abolished. Two of the subjects now demonstrated an increasing level of responding over the three components, and the other subject (R54) demonstrated no systematic effect of component on responding.

The data from the subjects experiencing the tandem VI VR VI schedule (right graphs) revealed that each of the subjects displayed a different pattern of response rates across the three components of the tandem schedule. Sub-

Fig. 3. Results from Experiment 3. Mean response rates over the last six sessions of each phase for each component; error bars show the range (hatched bars = VR component; open bars = VI component) for all subjects. Left graphs: subjects receiving the tandem VR VI VR schedule; right graphs: subjects experiencing the tandem VI VR VI schedule. Phases 1 and 3: without brief-stimulus presentations; Phase 2: with brief-stimulus presentations.

ject R55 responded faster in the two VI components than during the VR component, Subject R56 responded faster in successive components, and Subject R57 responded slightly faster in the VR component compared to the VI components. These baseline patterns were not reestablished, even after extensive training, in Phase 3. In this latter phase, subjects all tended to display an increasing rate of response across the three components. In Phase 2, 2 of the subjects (R55 and R56) responded at a higher rate in the VR component than in the two VI components, and the other subject responded faster in the terminal VI component than in the other two components.

On the whole, these results corroborate what was apparent from inspection of the results in Experiment 2: Response rates in the absence of a brief stimulus are determined by the proximity to reinforcement and the nature of the terminal schedule component. Thus, response

rates were higher in the terminal, compared to the initial, components of the tandem schedule, and were higher for the subjects responding on the VR VI VR schedule than for those responding on the VI VR VI schedule. Further, when the brief stimulus was presented after completion of the component schedules, it usually led to response rates typical of the schedule on which the stimulus was presented. Thus, for the tandem VI VR VI schedule, VR components followed by a brief stimulus tended to produce a higher response rate than did the VI components on that schedule. For the tandem VR VI VR schedule with the stimulus, rates during the VI component tended to be lower than those in the VR components.

GENERAL DISCUSSION

The present experiments extended the range of contingencies over which brief-stimulus ef-

fects have been studied. In these experiments, a brief stimulus presented after each component of a multiform tandem schedule (except the final component) maintained performance characteristic of that which would be expected if each of the components were followed by primary reinforcement: Response rates were generally higher in the VR component than in the VI component of the tandem contingency. In the absence of brief-stimulus presentations, response rates were determined largely by the nature of the final component and by the proximity to reinforcement. These effects were noted with both two- and three-link tandem schedules. That a stimulus with the same physical characteristics could differentially control performance on two different schedules suggests that a characteristic of the stimulus (such as ordinal position since reinforcement) was responsible for the discriminative control exerted by the stimulus. However, on the basis of the present data, it would be unwise to speculate further regarding the responsible mechanism.

Although the major aim of these experiments was to document the effect of presenting a brief stimulus on a tandem schedule in which the components are different schedule types, the results also have some relevance regarding the function of a stimulus presentation. When the data from all three experiments are considered together, the pattern of results suggests that response rate produced in a particular component does not depend only on the presence or absence of a brief stimulus, the schedule type, and the proximity to primary reinforcement, but also appears to depend on which schedule is experienced next in the tandem contingency.

In Experiment 1, rats responding on the tandem VI VR schedule showed a rate decrease in the VI component on the addition of the brief stimulus, whereas rats responding on the tandem VR VI schedule showed an increase in VR response rate with the addition of the stimulus. Similarly, in both Experiments 2 and 3, the tandem VR VI VR subjects showed a decrease in rate in the VI component following the addition of the brief stimulus, and the subjects responding in the tandem VI VR VI schedule showed an increase in VR rate on addition of the stimulus (although this effect was less pronounced in Experiment 3). These results replicate those from Experiment 1, and

suggest that when reinforcement is relatively temporally proximate (at least, only one link away) the presentation of a brief stimulus serves to promote schedule-appropriate behavior.

However, the effect of the addition of the stimulus on response rate in the initial component of the three-link tandem schedules in Experiments 2 and 3 is less easy to accommodate into the description given above. For subjects responding on the tandem VR VI VR schedule, the addition of the brief stimulus had less pronounced effects on behavior, but if anything tended to reduce levels of responding in the initial VR component. For subjects responding on the tandem VI VR VI schedule, rates either tended to increase in the initial VI schedule (Experiment 2) or showed little reliable effect (Experiment 3).

Schaal and Branch (1988, 1990) have noted that although there need not be absolute temporal contiguity between a stimulus and reinforcement for the stimulus to acquire conditioned reinforcing properties (see also Fantino, 1981), there is a temporal limit on the acquisition of conditioned reinforcing properties (the same may be true of marking stimuli; see Reed, Mitchell, & Nokes, 1994).¹ More speculatively, it may be the case that the effectiveness of the stimulus in maintaining schedule-appropriate behavior may also be determined by the type of schedule that follows its presentation. Data from Experiment 2 and 3 bear on this issue. The response-rate increase in the initial VI components following addition of the brief stimulus and the lack of consistent effects on rate in the initial VR components are compatible with the suggestion that reaching the VR schedule was reinforcing, but reaching the VI schedule was not.

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