Precuing the target location in visual searching by a chimpanzee (*Pan troglodytes*): Effects of precue validity

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Abstract: A chimpanzee (*Pan troglodytes*) performed a visual search task using a modified matching-to-sample procedure in which a sample stimulus was followed by the search display, which contained one stimulus identical to the sample (target) and several uniform stimuli different from the sample (distractors). On cued trials, while the subject was observing the sample, a white square (precue) appeared at the location where the target was to be presented (valid trials), or elsewhere (invalid trials). The validity of the precue (correspondence between the cued and the target locations) was changed from 0% to 100% across conditions. Cost-benefit analyses were performed on the difference between valid and noncued trials (benefit) and between invalid and noncued trials (cost). Under the high-validity conditions, the response times were shorter when the cued location corresponded to the target location than when the precue did not appear. When the cued location did not correspond to the target location, on the other hand, the subject took longer to select the target than on noncued trials. When the validity of the precue was relatively low, however, cost of the invalid trials disappeared, while benefit of the valid trials remained. These results confirmed the two-process (automatic and attentional) theory of priming in human information processing; the advance information had the same effects on a chimpanzee’s visual search performance as on humans’.

Key words: attention, precuing, visual search, cost-benefit analysis, chimpanzee.

In a speeded response task including the detection or identification of stimuli, human performance is better when valid information about a forthcoming event is provided relative than when false or no information is given (Johnston & Dark, 1986; Kinchla, 1992; Neely & Keefe, 1989; Schacter, Delaney, & Merikle, 1990). Valid information can be divided into two types. One is manipulation of the frequency, probability, or repetition of certain stimuli and responses (Pang, Merkel, Egeth, & Olton, 1992). This implicit information improves performance by encouraging the subject’s expectation of such specific stimuli or responses. For example, LaBerge and Tweedy (1964) investigated the effects of stimulus probability on human choice reaction time. Subjects were instructed to press one button in the presence of a green rectangle, and to press the other button in the presence of a red or blue rectangle. The probability of green trials was kept at 40% of total trials, whereas the probability of red and blue trials was changed from 50% vs. 10% to 10% vs. 50%. The results showed that the choice
reaction time was shorter on trials with the relatively higher probability stimulus than with lower probability stimulus.

Manipulating the repetition or frequency of a stimulus can also improve or worsen animal performance. This has been observed in pigeons during a visual search for a target or target-distractor combination (D. S. Blough, 1992, 1993; P. M. Blough, 1989, 1991, 1992). Pigeons' search performance can also be influenced by the reinforcement probability (D. S. Blough, 1989, 1992). Performance of rats during a choice reaction time task is also affected by manipulating the stimulus frequency (Pang et al., 1992). Tomonaga (1993c) also found facilitation and inhibition in chimpanzee visual searches by repeating the target location.

Another type of advance information can be provided by explicitly presenting a “priming” cue to the subjects before the onset of a trial. Priming is a well known technique frequently used in studies of human attention and memory (Beller, 1971; Farah, 1989; Neely, 1977; Posner & Snyder, 1975). For example, Posner and Snyder (1975) investigated same-different judgments of letter pairs by human subjects. Letter pairs were preceded by either a neutral cue, or a letter of the alphabet. The letter primes were either the same as the subsequent letter pair (valid cue) or different from them (invalid cue), and preceded the letter pair in half the “same” trials. Half the subjects were tested under a high-validity condition, in which the letter prime corresponded to the subsequent letter pair on 80% of the letter-prime trials, while the rest of the subjects were tested under a low-validity condition, in which the letter prime corresponded to the letter pair on 20% of trials. The other half of the “same” trials featured the neutral cue, which contained no advance information. To determine the facilitatory and inhibitory effects of the letter prime, Posner and Snyder used a cost-benefit analysis, in which the difference in accuracy or reaction time between the neutral and valid trials indicated the benefits of priming, and the difference between neutral and invalid trials was identified as the costs of priming. The results showed that both benefits and costs were observed in the high-validity condition, whereas only benefits were observed in the low-validity condition.

The effects of primes (or precues) on subsequent task performance have been explored in the study of identity or semantic priming in the lexical decision task (Jacoby, 1983; Neely, 1977), and the precuing of forthcoming target location in visual search (LaBerge, 1983; Posner, 1980; Posner & Cohen, 1984). In animals, such explicit precuing has also been shown to affect performance (P. M. Blough, 1989; Bowman, Brown, Kertzman, Schwarz, & Robinson, 1993; Shimp & Friedrich, 1993).

In human cognitive psychology, the effects of advance information have been discussed within an “attentional” framework (Johnston & Dark, 1986; Kinchla, 1992). Recently, neurophysiological (e.g., Boussaoud & Weiss, 1993; Bowman et al., 1993; Harter & Aine, 1984; Hillyard & Kutas, 1983) and neuropsychological (e.g., Posner, Walker, Friedrich, & Rafal, 1984) studies of attention have contributed to the models of attention (Parasuraman & Davies, 1984). Although primates have most often been the subjects in neurophysiological studies of attention (Boussaoud & Weiss, 1993; Bowman et al., 1993), there have been few behavioral studies of attention using primates (cf. Bowman et al., 1993). The human cognitive system is a product of evolution and has some phylogenetic continuity with that of other primates (Matsuzawa, 1991). To evaluate the validity of the models of attention based on human experimental studies and animal neurophysiological studies, and to mediate between these two areas, psychological (or behavioral) experiments with animals will need to be done.

The present experiment investigated the effects of precuing on visual search by a chimpanzee. One chimpanzee performed a modified version of the matching-to-sample task (Tomonaga, 1993a, 1993c), in which a sample stimulus was followed by the search display containing one target, which was the same as the sample, and several identical distractors that differed from the sample. A precue about the location of the forthcoming target was briefly presented while the subject was observing the
sample. Search response times were used in a cost-benefit analysis to examine the effects of the valid and invalid cues on the chimpanzee’s visual search performance. By manipulating the precue validity, I examined the changes of benefits and costs between the high- and low-validity conditions.

Method

Subject
An 11-year-old female chimpanzee (Pan troglodytes), named Chloe, served as subject. She had previously been trained on various tasks using a conditional discrimination procedure such as matching-to-sample tasks (Fujita & Matsuzawa, 1989; Tomonaga, 1993b; Tomonaga & Matsuzawa, 1992; Tomonaga, Matsuzawa, Fujita, & Yamamoto, 1991; Tomonaga, Matsuzawa, & Matano, 1991). In particular, she had been trained on a visual search task using a modified version of the matching-to-sample task (Tomonaga, 1993a, 1993c). After the previous experiment on visual search tasks (Tomonaga, 1993c), Chloe was immediately shifted to the present experiment. She lived in a cage (6.2 m wide × 2.0 m high × 1.8 m deep) with a sun room (6.2 m × 2.0 m × 2.2 m) together with two other young chimpanzees. She maintained her free-feeding weight without deprivation during the present experiment. Chloe used her left hand for responding and right hand for picking up rewards. Care and use of the chimpanzee followed the guidelines of the Primate Research Institute, Kyoto University.

Apparatus
The subject was tested in an experimental compartment for chimpanzees (2.4 m × 2.0 m × 1.8 m). This compartment had a 14-inch cathode-ray-tube display with an optical touch panel (Minato Electronics Model TD-100) on one side wall. This display was divided into 12 imaginary areas (four columns and three rows) for the presentation of the computer-graphic stimuli (see Figure 1). A response was defined as touching the screen. Response time was defined as the time from the onset of the search display to the subject’s response, and was measured with a programmable timer (CONTEC Model TIR-6-[98]). A universal feeder delivered a variety of foods as reward to a tray installed to the right of the display. All experimental events were controlled by a personal computer (NEC Model PC-9801F2).

Stimuli
Figure 1 shows the six line drawings (approximately 3.5 cm × 3.5 cm) selected from the list by Snodgrass and Vanderwart (1980). In a previous experiment (Tomonaga, 1993a), these stimuli had been divided into two perceptual categories (camel-cow-dog/barn-church-stove) by the same chimpanzee as in the present experiment. All targets and distractors were thus always selected from the same perceptual category (e.g., camel target and cow distractors). The precue stimulus was a white, meshed rectangle (3.5 cm × 3.5 cm).

Procedure
A multiple-alternative matching-to-sample procedure (Tomonaga, 1993a, 1993c) was employed with a slight modification for presenting the
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Chloe showed highly accurate and stable performance – more than 99% correct in each condition. Mean response times on correct trials for each trial type (except for target-only trials) and each target location are shown in Figure 3. Mean response times for target-only trials were 0.50 s for the 20% validity condition, 0.49 s for the 80% validity condition, 0.53 s for the 100% validity condition, and 0.48 s for the 0% validity condition.

Two points should be noted with regard to Figure 3. First, the mean response times on noncued (that is, control) trials were stable
Figure 2. Schematic diagram of the four types of trials used in the present experiment.
across validity conditions. Mean response times for noncued trials were 0.81 s for the 20% validity condition, 0.82 s for the 80%, 0.86 s for the 100%, and 0.80 s for the 0% condition. Second, there were significant differences in response times between target locations. Targets appearing on the right supported faster response times than on the left. In addition, targets appearing on the bottom row supported faster response times than on the top row. These findings were statistically confirmed by a three-way analysis of variance [row (2 [top and bottom]) x column (4) x validity condition (4)] of the mean response times for the noncued trials (averaged across session blocks). The results revealed significant main effects for row, $F(1, 9) = 112.95, p < .01$, and column, $F(3, 9) = 154.57, p < .01$, but no significant effect for validity condition, $F(3, 9) = 3.59, p > .05$. The interactions between row and the other factors were also significant: row x column, $F(3, 9) = 4.74, p < .05$, row x validity condition, $F(3, 9) = 4.16, p < .05$. The interaction between column and validity condition was not significant, $F(9, 9) = 1.36, p > .05$.

A difference in response times among stimulus locations has frequently been observed in tasks in which subjects are required to point, touch, or peck the stimulus (D. S. Blough, 1979; Tomonaga, 1993c, 1994). In the present experiment, the subject was required to touch the sample, presented in the third column of the middle row, before touching the comparison stimulus (see Figure 2). Because of the difference in distance between the starting point (sample stimulus) and the goal of the manual movement (target stimulus), the left-side locations caused slower response times than the right-side locations.

There were also differences in response times between trial types for each condition. Separate three-way (session block [2] x target location [10] x type of trial [3, without target-only trials]) analyses of variance were performed on the response-time data for each validity condition.

For the 20% validity condition, all the main effects were significant: session block, $F(1, 18) = 17.64, p < .01$, target location, $F(9, 18) = 123.98, p < .01$, and trial type, $F(2, 18) = 8.87, p < .01$. The interactions between target location and the other factors were also significant: target location x trial type, $F(18, 18) = 2.41, p < .05$, target location x session block, $F(9, 18) = 2.75, p < .05$. There was no significant interaction between trial type and session block, $F(2, 18) = 1.07, p > .05$.

For the 80% condition, the analysis of variance showed significant main effects for target location, $F(9, 18) = 49.24, p < .01$, and trial type, $F(2, 18) = 55.15, p < .01$, but no significant effect for session block, $F(1, 18) = 0.93, p > .05$.
Figure 3. Mean response times in correct trials for each trial type (except for target-only trials) as functions of target locations and the precue validity conditions.
There were no significant interactions between factors, target location × trial type, $F(18, 18) = 1.58$, target location × session block, $F(9, 18) = 0.66$, and trial type × session block, $F(2, 18) = 2.33$, all $p$ values $>.05$.

For the 100% condition, analysis of variance revealed significant effects for session block, $F(1, 9) = 21.04$, $p < .01$, target location, $F(9, 9) = 73.59$, $p < .01$, and trial type, $F(1, 9) = 118.54$, $p < .01$. The interaction between trial type and session block was significant, $F(1, 9) = 8.71$, $p < .05$, but the other interactions were not significant: target location × trial type, $F(9, 9) = 2.04$, target location × session block, $F(9, 9) = 1.15$, both $p > .05$.

Finally, for the 0% validity condition, the effects for session block, $F(1, 9) = 18.37$, $p < .01$, and target location, $F(9, 9) = 88.73$, $p < .01$, were significant, but effect for trial type was not, $F(1, 9) = 3.86$, $p > .05$. There were no significant interactions among factors: target location × trial type, $F(9, 9) = 1.52$, target location × session block, $F(9, 9) = 1.27$, and trial type × session block, $F(1, 9) = 0.03$, all $p$ values $>.05$.

Cost-benefit analyses
Figure 4 shows the costs and benefits in terms of response times for each validity condition. Costs are shown in the downward direction and benefits in the upward direction in this figure. For the 20% and 80% validity conditions, both costs and benefits are shown, while only benefit is shown for the 100% condition and only cost for the 0% condition. To examine the effects of the precue validity on the costs and benefits, Tukey’s HSD tests were conducted in addition to the results of main effect for trial type in the separate analyses of variance for validity conditions 20% and 80%. Only benefit was significant ($p < .05$) for the 20% condition, while both cost and benefit were significant ($p < .05$) for the 80% condition. The results of main effect for trial type in the separate analyses of variance for the 100% and 0% conditions confirmed that benefit was significant for the 100% condition, but cost was not significant for the 0% condition.

Discussion
In the present experiment, I found two types of processing of advance information by the chimpanzee. When the precue was valid, the subject’s performance was significantly better than when the precue was absent, irrespective of the precue validity. In contrast to valid trials, the inhibitory effects of the precue on the invalid trials depended on the validity condition. This inhibition was observed only when the precue validity was high (validity condition 80%). Posner and Snyder (1975) classified signal processing into two types: automatic and attentional. This dichotomy frequently appears in many theories of perception, attention, and information processing (e.g., Schneider &
In Posner and Snyder’s priming model, a stimulus input automatically activates the memory pathway regarding the physical form (or perhaps location) and semantic properties of the stimulus (e.g., Neely, 1977; Rosch, 1975). In humans, although the processing of these automatically activated properties takes time, it occurs without attention. Furthermore, this automatic activation never causes inhibitory diffusions to other pathways, so that it results in facilitation without inhibition. In the other mode, the subject “attends” to the signal. Since these attentional processing resources are considered to be limited (Norman & Bobrow, 1975), the processing (or activation) of the attended signal is facilitated, but the processing of unattended signals is inhibited. Posner and Snyder proposed three independent variables to control the processing modes: (1) instruction, (2) probability of correspondence between the precue and the target, and (3) the precue-search-display interval (or stimulus-onset asynchrony, SOA). They proposed that automatic processing dominated when the cue validity was low, or SOA was short, while attentional processing was dominant when the validity was high or SOA was long. The present results from the chimpanzee seem to be consistent with Posner and Snyder’s results from humans. As such, it seems reasonable to conclude that for the chimpanzee, much like humans, there is a shift to a more attentional form of processing as the precue validity increases.

One of the differences in the design of the present experiment and Posner and Snyder’s was the type of information of the precue. In the present experiment, the precue contained information about the target location but not about the target identity, as in Posner and Snyder’s studies. Precuing the target location is also frequently studied in humans (Eriksen & Yeh, 1985; Jonides, 1980, 1981; Müller & Rabbitt, 1989; Posner, 1980; Posner & Cohen, 1984; see also Farah, 1989; Johnston & Dark, 1986; Kinchla, 1992). To study such selective spatial attention, two different cuing techniques are employed (Cheal & Lyon, 1991; Jonides, 1981; Müller & Rabbitt, 1989; Yantis & Jonides, 1984, 1990). One is called central cuing, in which symbolic or arbitrary cues (such as arrows) are presented at the subject’s fixation point (e.g., Posner, 1980). The other is called peripheral cuing, in which cues such as a flash are presented in the peripheral visual field (e.g., Posner & Cohen, 1984).

Studies of spatial attention in humans reveal that the control of attention to peripheral cues occurs faster and more strongly than does the control of attention to central cues. For example, Müller and Rabbitt (1989) examined differential effects of peripheral and central cues in human subjects in their second experiment. In their procedure, the sample stimulus (a T-shaped form) was followed by the precue before the brief presentation of the search display containing one T-shaped form (target) and three crosses (distractors) presented around the fixation point. Subjects were required to report the target location and a same-different judgment between the sample and the target. Müller and Rabbitt changed the precue-search-display interval from 0.6 s to 1.2 s and presented both peripheral (flash) and central (arrow) cues together. When the two cues predicted different locations and the target was presented at the location precued by the peripheral flash, the subjects showed higher accuracy of same-different judgments at the shorter precue-display interval than at the longer interval. On the contrary, when the target was presented at the location precued by the central cue, accuracy was higher for the longer precue-display interval than for the shorter interval. These results indicate that human spatial attention involves two different mechanisms: one automatic or reflexive, and the other controlled or voluntary. When the precue-display interval is short, automatic processing (or reflexive orienting) tends to dominate, while attentional or controlled processing (or voluntary orienting) dominates when the interval is long. These different mechanisms seem highly analogous to the priming effects described by Posner and Snyder (1975).

In the present experiment, since the precue was peripheral, it may also have caused reflexive orienting in the chimpanzee. However, one
should be careful in linking the chimpanzee’s performance with human visual orienting experiments, for two reasons. As Posner and Snyder (1975) demonstrated, the processing mode of the precue strongly depends on its validity, as well as the precue-display interval. In the study of Müller and Rabbitt (1989) and many others, cue validity was held at 50%; there are few experiments to examine the effects of cue validity by manipulating its value (cf. Eriksen & Yeh, 1985; Jonides, 1980). For example, Jonides (1980) manipulated the cue validity from 70% through 50% to 30% using a central cuing technique. His results, however, were incompatible with Posner and Snyder’s (1975) and those of the present experiment. He observed that both cost and benefit decreased as the validity of the precue decreased, especially in the 30% condition, in which neither were statistically significant. Although cost and benefit also decreased when the validity was low in Posner and Snyder’s (1975) and my experiment, the benefit was still significant even in the low-validity condition in both studies. It also seems less possible to compare the results of Jonides (1980) and of my experiment because of the substantial procedural differences, such as cuing types and precue-display interval. We need to examine further the effects of the validity of the precue on visual orienting in both humans and other animals (see Bowman et al., 1993; Shimp & Friedrich, 1993).

The second point concerns the problem of eye movements. In the present experiment, I could not monitor or control the subject’s eye movements precisely. Therefore it is impossible to determine whether the subject moved her eyes to the precue while responding to the sample. Humans are capable of directing attention to a specific area without eye movements to that area (James, 1890; Kinchla, 1992; Posner, 1980), but are unable to move the eyes to the area without a shift in attention (Remington, 1980). We should distinguish overt and covert visual orienting (Posner, 1980). An abrupt onset of a peripheral visual stimulus causes reflexive movement of the eyes to that location (Remington, 1980). It is unclear to what degree eye movements contributed to the present results. To control and record eye movements in primates, researchers frequently use a restraining chair (e.g., Bowman et al., 1993). However, it is physically (and ethically) impossible to restrain chimpanzees. An alternative is to control (but not record) the eye movements of the unrestrained subject. Recently, Hopkins and his colleagues developed a convenient method to control the eye movement of a primate subject by using a task with a joystick (Hopkins, Morris, & Savage-Rumbaugh, 1991; Hopkins, Washburn, & Rumbaugh, 1990; Richardson, Washburn, Hopkings, Savage-Rumbaugh, & Rumbaugh, 1990; Wilde, Vauglair, & Fagot, 1994). The subject can move the cursor on the screen by manipulating the joystick. A possible modification of this joystick method may enable us to develop a task to examine the relationship between eye movement and attention shift in chimpanzees (cf. Washburn, 1993).

In conclusion, the present experiment clearly demonstrated the facilitatory and inhibitory effects of a precue of a forthcoming target location on a chimpanzee’s visual search performance. Furthermore, the inhibitory effects depended on the validity of the precue. These results seem to provide evidence for automatic and attentional processing in the chimpanzee. Finally, it should be noted again that such kinds of behavioral studies in nonhuman primates as the present experiment will give much more information to us in evaluating the physiological, computational, developmental, and evolutionary validity of the psychological models of perception and cognition, and mediating between human cognitive psychology and primate neurophysiology.

References


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