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Preparing for perception and action (II): Automatic and effortful processes in response cueing

Jos J. Adam
University of Maastricht, The Netherlands

Bernhard Hommel
University of Leiden, The Netherlands

Carlo Umiltà
University of Padua, Italy

In this paper we tested the automatic-effortful processing assumption of the Grouping Model. According to the Grouping Model, left–right cues are pull cues and inner–outer cues are push cues, evoking exogenous and endogenous control, respectively. In a series of four experiments we manipulated the characteristics of the cues: Onset vs. no-onset cues, spatial vs. symbolic cues, valid vs. invalid cues. The results consistently showed a dissociation between left–right and inner–outer cues. Together, the present findings provide converging evidence for the notion that left–right cues induce a fast, automatic selection of the cued responses, whereas inner–outer cues need slower, effortful processes to establish a selective preparatory set.

Forewarning people about upcoming events and impending actions generally improves performance. The preparatory processes underlying this performance enhancement have been studied in precuing paradigms, with precues providing advance information about some (or all) aspects of the upcoming stimulus and its associated response. In the so-called response-cueing paradigm developed by Miller (1982)—who adapted Rosenbaum's (1980, 1983) movement precueing technique—spatial cues provide information about which fingers to use for responding. In particular, participants are forewarned about the location of an upcoming response or, more precisely, about a particular subset of possible

Please address all correspondence to: Jos J. Adam, Department of Movement Sciences, Maastricht University, PO Box 616, 6200 MD Maastricht, The Netherlands.
Email: jos.adam@bw.unimaas.nl

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responses. Typically, horizontally defined stimuli are reacted to by spatially compatible discrete key-press responses with the index and middle fingers of the two hands. The visual display usually consists of three horizontal rows of symbols, representing warning, cue, and target stimulus, respectively (see Figure 1). The warning stimulus consists of four plus signs, indicating the four possible stimulus–response locations. The cue, which follows after a fixed delay, consists of two plus signs, indicating a subset of possible stimulus–response locations. After a certain preparation interval, which may vary between 100 ms and 3 s, the target stimulus is presented, a single plus sign that indicates the location of the required response.

The functional significance of the precue is that it logically transforms the original four-choice reaction task into a two-choice reaction task. Four precue or preparation conditions can be distinguished. In the *left–right* condition, the precue occupies the two left-most or two right-most positions. In the *inner–outer* condition, the precue occupies the two inner or two outer positions. In the *alternating* condition, the precue signal occupies the outside left and inside right position, or the inside left and outside right position. A control condition may also be included: the *uncued* condition. Here the ''precue'' contains four plus signs, so that no selective preparation is possible. This condition is a necessary control condition because it leaves the basic, four-choice task unaltered. Since two-choice responses normally yield shorter reaction times (RTs) than four-choice responses (Hick, 1952; Hyman, 1953), cue effectiveness is inferred from

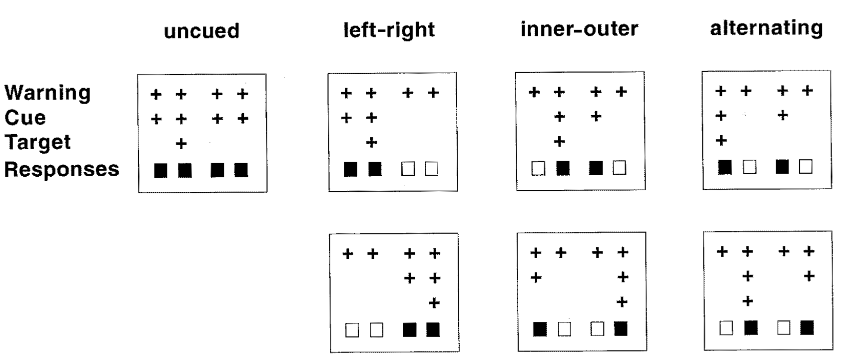

Figure 1. A schematic representation of the response-cueing task as developed by Miller (1982). The stimulus display consists of a warning signal (row 1), a cue signal (row 2), and a target signal (row 3). First the warning signal is presented. After a delay of 750 ms, the cue signal appears below the warning signal. Then, after a variable delay (the preparation interval), the target signal (a single ''+'' sign) appears below the cue signal. The participant's task was to respond as quickly as possible to the position of the target signal by pressing the appropriate response key. The black squares indicate the possible responses indicated by the cue, and thus reflect the number and type of prepared responses. Note that in all conditions only one response was actually required, namely the finger key-press response indicated by the single target stimulus.

a significant RT advantage for the two-choice cue conditions (i.e., left–right, inner–outer, and alternating) over the control, four-choice (uncued) condition.

A robust finding from the response-cueing task is the left–right advantage: RTs are shorter for the left–right condition than for the inner–outer and alternating conditions (see, for reviews, Adam, Hommel, & Umiltà, 2003; Reeve & Proctor, 1990). Importantly, this phenomenon is only observed with short preparation intervals (i.e., shorter than 1500 ms) but not with longer preparation intervals, where all cue conditions show comparable RTs.

THE GROUPING MODEL

A recent account of the left–right advantage is the Grouping Model (Adam, Hommel, & Umiltà, 2003). As shown in Figure 2, the Grouping Model assumes that cues and other visual stimuli are coded in a visual buffer while response codes are maintained in a motor buffer (Adam, Hommel, & Umiltà, 2003). The buffers are thought to interact, so that the results of stimulus coding can affect response processing and the results of response coding can affect stimulus processing. The major idea of the model is that the individual elements of multistimulus displays and multiresponse arrays are not processed independently but are preattentively organized according to low-level grouping factors that may depend on stimulus-driven factors (e.g., Gestalt principles) and on response-related factors (e.g., interresponse tendencies).

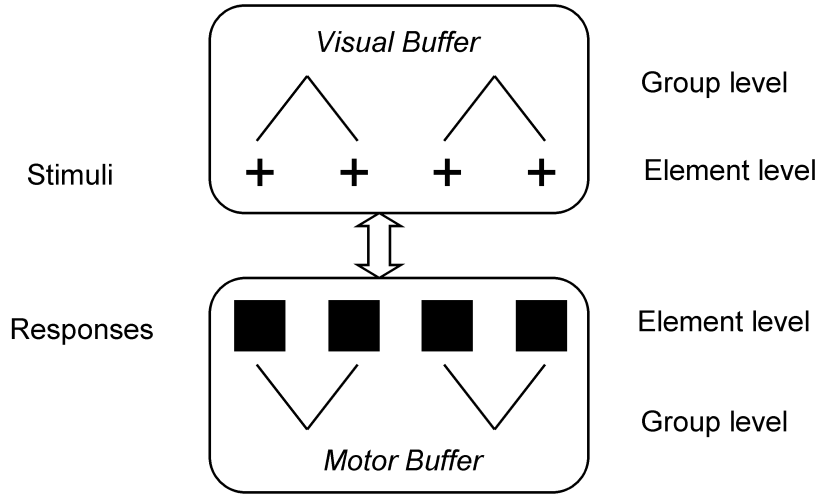

Figure 2. Sketch of the representational assumptions of the Grouping Model showing the default or bottom-up organizations in visual and motor buffers for the standard precuing task (Miller, 1982) with the hands placed adjacent.

In particular, horizontally extended rows of stimuli are likely to be organized with respect to a viewer-based, egocentric and a scene-based, allocentric frame of reference (which in the standard precueing paradigm are perfectly confounded, so that we can ignore this distinction for the moment). Left–right cues are the easiest to code in such frames of references, as they provide the sensory, bottom-up material for building a ''left'' or ''right'' visual group by sharing the relative position with respect to the midpoint of the reference frame and by obeying to the Gestalt law of proximity (we will address in the General Discussion why proximity alone is insufficient). Not so the other types of precues, neither inner–outer and alternating positions offer an obvious, Gestalt-based organization of the stimulus array.

Now consider the cognitive representation of the response alternatives or the effectors they imply. Responses are coded within an action-based frame of reference (e.g., Lippa, 1996; Tipper, Lortie, & Baylis, 1992). For this frame, the location and the anatomical identity of the effectors are important coding factors (e.g., Adam, Hommel, & Umiltà, 2003; Hommel, 1993; Riggio, Gawryszewski, & Umiltà, 1986). In particular, there is strong evidence that responses with effectors (fingers) belonging to the left or right hand are organized into left and right spatial groups, respectively (Adam, Hommel, & Umiltà, 2003, Exp. 5; Hommel, 1996; Miller, 1985; Nicoletti & Umiltà, 1984). If we accept that stimulus and response events are cognitively organized according to these considerations, we can assume that the cues and the actions they cue strongly match in the case of left–right cues: A ''left'' stimulus group indicates a ''left'' response group and a ''right'' stimulus group indicates a ''right'' response group. Assuming that the organized representations in visual and motor buffers interact with each other (Hommel, Müsseler, Aschersleben, & Prinz, 2001), we can thus predict that left–right cues directly activate the responses they indicate, which is a very simple, direct, and fast way to prepare the precued responses—preparation is *bottom-up* driven, so to speak (see Figure 3a).

In contrast, inner–outer and alternating cues would activate elements belonging to two different groups, the left and the right group, in both the stimulus and response dimensions. Hence, in this situation, code activation at the grouping level does not unequivocally identify the two cued elements; additional, top-down processing is needed to ''create'' a subgroup. Accordingly, whereas left–right cues would allow a fast, automatic *selection* of a distinctly, preattentively defined subgroup, other two-element cues would require an additional, time-consuming process to *create* such a subgroup. Of course, this would be necessary for both the stimulus set and the response set (see Figure 3b).

Similarly, if visual and motor groups do not match, then too a slow, effortful *top-down* process is needed to break up the spontaneous groups and to create better matched, finely tuned subgroups. In the latter case, selection and preparation of the cued subset of responses is delayed in time because it draws upon

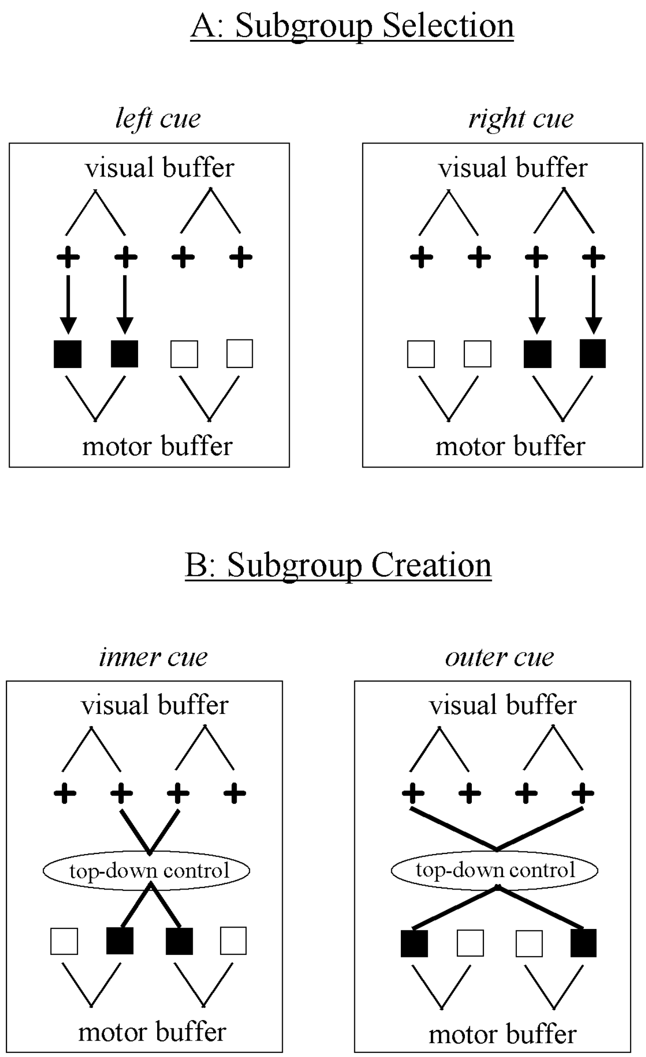

Figure 3. Sketch of the processing assumptions of the Grouping Model showing (a) subgroup selection or the bottom-up, exogenous control mode, versus (b) subgroup creation or the top-down, endogenous control mode.

central resources. Importantly, group mismatches may result from stimulus or response manipulations. Indeed, the benefit associated with left–right cues for a given left–right grouped set of responses decreases and can even disappear by decreasing the distance between the two inner positions which strengthens the grouping of the two inner positions and weakens the grouping of the two leftmost and two rightmost elements (Adam, 1994; Adam, Hommel, & Umiltà, 2003, Exp. 2; Reeve, Proctor, Weeks, & Dornier, 1992). Likewise, a given set of left–right cues shows an advantage for responses carried out with two fingers of each hand (where hand identity supports left–right grouping) but not for responses carried out with four fingers of one hand (where hand identity does not support left–right grouping; Adam, Hommel, & Umiltà, 2003, Exp. 3; Proctor & Reeve, 1986, Exp. 2). In sum, according to the Grouping Model, if the cue indicates a strong, good subgroup of stimuli that corresponds closely with a strong and similar grouping of responses, then a fast, automatic selection (activation) of cued responses occurs. If, on the other hand, the cue indicates stimuli belonging to different subgroups, or if there is a mismatch between the grouping of stimuli and the grouping of responses, then a slower, effortful process is needed to create good, finely tuned subgroups.

The Grouping Model's automatic-effortful processing distinction is consistent with several modern dual-route conceptions of response selection (e.g., Frith & Done, 1986; Kornblum, Hasbroucq, & Osman, 1990; Tagliabue, Zorzi, Umiltà, & Bassignani, 2000). According to these views, response selection can occur via (a) a slow, indirect, translation route that applies a translation rule and draws upon central resources, and/or (b) a direct, automatic response-activation route that exploits natural and coherent stimulus–response associations. The Grouping Model endorses this notion by distinguishing between fast, automatic subgroup selection and slow, controlled subgroup creation.

EVIDENCE FOR THE AUTOMATIC-EFFORTFUL PROCESSING DISTINCTION

Three lines of evidence corroborate the automatic-effortful processing distinction of the Grouping Model. First, left–right precueing benefits start to accrue extremely quickly with significant gains during the first 100 ms of preparation time (e.g., Adam, 1994). Inner–outer and alternating cues, on the other hand, need longer preparation intervals (i.e., 250 ms and more) to start producing preparation benefits (e.g., Adam, Hommel, & Umiltà, 2003; Reeve & Proctor, 1984).

Second, older age does not affect the RT benefits associated with the left–right cue, but does reduce—and in a rather dramatic way—the efficiency of the inner–outer and alternating cues (Adam et al., 1998). Assuming that advancing age is accompanied by a reduction in central resources (e.g., Allen, Groth, Weber, & Madden, 1993; Salthouse, 1988), while leaving automatic processes intact (e.g., Hasher & Zacks, 1979; Hoyer & Plude, 1980), this outcome accords with the notion that left–right cues prompt the fast, automatic selection of subgroups, while the inner–outer cues require slower, effortful processes to create a subgroup.

Finally, supportive evidence for the automatic-effortful notion comes from a study that employed *tactual* stimuli (Adam, Keyson, & Paas, 1997). In contrast to the visual precueing task, where precues visually specify a subset of potential finger responses, the tactual precueing task specifies a subset of finger responses vibrotactually, and hence more directly. According to the Grouping Model, this manipulation should eliminate the left–right advantage, because *all* precues specify the cued responses directly and automatically, thereby eliminating any potential differences in subgroup making. Consistent with this prediction, the results showed that with the vibrotactual cues the left–right advantage disappeared. In fact, there was a striking and significant advantage (27 ms) for the inner–outer cues over the left–right cues. This latter phenomenon probably reflects the Kornblum effect, the phenomenon that between-hands choices are faster than within-hand choices (e.g., Alain, Buckolz, & Taktak, 1993; Hasbroucq, Mouret, Seal, & Akamatsu, 1995; Kornblum, 1965).

In sum, the above findings provide preliminary, but still somewhat indirect, support for the distinction between two qualitatively different processes mediating response-cueing effects: Automatic subgroup selection and effortful subgroup creation. The goal of the present study was to provide more direct, converging evidence.

TWO CLASSES OF CUES

Cueing research distinguishes between two classes of cues (Logan, 1995), variously called *endogenous* versus *exogenous* cues (Posner, 1980), *central* versus *peripheral* cues (Jonides, 1980), and *push* versus *pull* cues (Kahneman, Treisman, & Gibbs, 1992). The first kind of cue is thought to require some sort of *top-down* processing or cognitive interpretation in order to be effective. In contrast, the second kind of cue is thought to exert *bottom-up* control by attracting attention automatically. Thus, push cues work slowly, draw upon central resources, and are often effective only when they are valid (for some exceptions see Hommel, Pratt, Colzato, & Godijn, 2001). Pull cues, on the other hand, work fast, are utilized despite resource limitations, and are effective whether or not they are valid (e.g., Jonides, 1980; Müller & Rabbitt, 1989; Yantis & Jonides, 1990). Left–right, inner–outer, and alternating cues also fall into two categories; they are either unilateral or bilateral cues. That is, they contain elements either on one side of fixation (in case of the left–right cues) or on both sides of fixation (in case of inner–outer and alternating cues). Importantly, when two stimuli are presented simultaneously on either side of fixation, attention is either maintained at fixation or perhaps allocated in parallel to the two stimulus locations. Either way, bilateral cues might prevent fast, lateral shifts of attention, whereas unilateral cues automatically attract attention to their position (e.g., Briand & Klein, 1987). Hence, according to the Grouping Model, the standard left–right cues are pull cues, which are considered to induce automatic, bottom-up, exogenous control, whereas inner–outer and alternating cues are push cues, needing endogenous control to select the cued elements; presumably, this is a slower, top-down, effortful process.

PURPOSE OF STUDY

The Grouping Model of response-cueing effects has two major tenets. First, it assigns a critical role to grouping operations in the input and output buffer that define the basic units of selection. Second, it assigns a critical role to the mode of selection by distinguishing between fast, automatic subgroup selection and slow, effortful subgroup creation. In a previous paper, we have provided evidence in support of the former, grouping assumption (see Adam, Hommel, & Umiltà, 2003). In this paper, using converging operations, we aimed to provide additional evidence in support of the latter assumption, that is, the notion of automatic versus effortful processing.

In the first two experiments, we manipulated the physical characteristics of the cues. According to the Grouping Model, the left–right advantage with short preparation intervals occurs because left–right cues are exogenous (or pull) cues that allow response preparation to proceed via the direct, automatic route, whereas inner–outer cues are endogenous (or push) cues that need the indirect, effortful, top-down route. Thus, in order to observe a left–right advantage, the left–right cue should be an exogenous or pull cue. The first two experiments were designed to violate this requirement by using *no-onset cues* (i.e., removing rather than presenting stimuli; Experiment 1) and *central cues* (i.e., letters that provide advance information; Experiment 2). Note that both these manipulations were thought to transform the standard (i.e., onset, peripheral) exogenous left–right cues into endogenous cues, and hence the left–right advantage should disappear.

The last two experiments were designed to examine the automatic versus effortful processing notion of the Grouping Model even more directly by using cues that were not informative (that is, the cues were only valid in 50% of the trials). Experiment 3 was designed to test whether left–right cues are really processed as automatically as the model assumes, and whether they are processed *more* automatically than the other types of cues. To do so, we made use of the frequent finding that truly ''automatic'' cues produce inhibition of return (IOR; see below) while less automatic cues do not. According to our model, this implies that left–right cues should produce IOR while other types of cues do not—a prediction that Experiment 3 will evaluate. Finally, Experiment 4 served to link the outcome of Experiment 3 back to the response side. If the Grouping Model would be correct in assuming that left–right cues are able to activate a corresponding left or right response group automatically, we should be able to confirm two predictions: First, performance should reflect a particular benefit from left–right cues even if these cues are uninformative, but, second, this benefit should only occur to the degree that the response set affords or suggests a grouping of effectors that matches the organization of the precues. We tested the latter prediction by comparing the standard two-hands set, which we know affords left–right grouping, with a one-hand response set, that at least strongly reduces left–right grouping (Adam, Hommel, & Umiltà, 2003).

EXPERIMENT 1: ONSET VERSUS NO-ONSET CUES

In the first experiment, we contrasted the effects of onset and no-onset cues on the left–right advantage for short (100 ms) and long (1000 ms) preparation intervals. With onset cues, we used the standard cueing procedure by presenting two plus signs in two of four possible (empty) locations. With no-onset cues, the cue signal initially consisted of four plus signs, occupying all four possible stimulus positions. Then, this four-element signal was modified by removing two plus signs. Note that the two *remaining* plus signs (and thus not the two disappearing ones) provided the valid cue information by indicating the two possible stimulus–response positions. This is important because disappearing cue elements automatically attract attention to their (past) position, whereas remaining elements do not (e.g., Miller, 1989; Pratt & Hirshhorn, 2003; Riggio, Bello, & Umiltà, 1998; Riggio, Scaramuzza, & Umiltà, 2000).

If, as the Grouping Model assumes, (short-duration) onset left–right cues in the standard response-cueing task act as pull cues and onset inner–outer cues as push cues, then the usual left–right advantage should emerge. However, with no-onset cues there should be no left–right advantage because the remaining left–right cue elements do not automatically attract attention to their position; that is, they are push cues, requiring slow, effortful processes to produce a precueing benefit. In fact, if the no-onset left–right cues would cause an automatic shift of attention to the side of the *disappearing* cue elements, one would rather expect a disadvantage or RT cost for the left–right preparation condition. This is so because attention then would need to be reoriented away from the wrongly cued side to the opposite (correct) side.

With the longer preparation interval of 1000 ms, one would expect a much smaller—or even no—effect of cue type (onset versus no-onset) on precueing efficiency because, regardless of cueing procedure, there should be sufficient time to engage the slower, effortful endogenous control mode.

Method

Participants. Thirty students, ten male and twenty female, with a mean age of 19.7 years (range 18–23), participated. In this, and all further experiments, participants were students from Maastricht University, were paid a small amount of money, and were naive as to the purpose of the experiment. All of them had normal or corrected-to-normal vision.

Apparatus and stimuli. Stimuli were presented on a standard video display monitor controlled by an IBM-Pentium computer. Responses were made by pressing one of four keys (''Z'', ''X'', ''.'', and ''/'') of the keyboard (the two leftmost and two rightmost keys on the bottom row of the keyboard). Viewing distance was held constant at about 50 cm. The computer was housed in a normally lit room, and was used to control the presentations of the stimulus displays and to record response latencies and accuracies. Stimuli were plus (''+'') signs and presented in the standard character set of the computer; one single plus sign was approximately 2.6 mm wide and 3.0 mm high. The two leftmost and two rightmost plus signs were separated by one blank space covering 3 mm; the two inner positions were separated by two blank spaces covering 6 mm. The stimulus display consisted of a warning signal, a cue signal, and a target signal, with the entire display centred on the viewing monitor. The warning signal was a row of four plus signs. After a delay of 750 ms, the cue signal appeared immediately below the warning signal. With onset cues, the precue occupied the two leftmost or two rightmost stimulus positions (i.e., the left–right preparation condition), the two inner or two outer stimulus positions (i.e., the inner–outer preparation condition), or all four stimulus positions (i.e., the uncued condition). After a variable (preparation) interval (i.e., 100 or 1000 ms) the target signal (one single plus sign) appeared immediately below the cue row, in a position always indicated by the cue. With no-onset cues, the cue signal initially consisted of four plus signs, occupying all four stimulus positions for 750 ms. Then, depending on the preparation condition, this four-element signal was modified by removing (turning of) two plus signs: In the left–right preparation condition, the two leftmost or two rightmost plus signs were removed; in the inner–outer preparation condition the two inner or two outer plus signs were removed. The remaining two plus signs indicated the two possible stimulus positions. In the uncued preparation condition, no plus signs were removed. Then, after a variable preparation interval (i.e., 100 or 1000 ms) the target signal (one single plus sign) appeared immediately below the cue row, in a position always indicated by the cue. The participant's task was to respond as quickly as possible to the position in which the target signal occurred by pressing the appropriate response key.

Procedure. There were two cue types: Onset and no-onset cues. Participants were randomly assigned to one of these two cue types, so that half the participants ($n = 15$) performed with the onset cues, and the other half ($n = 15$) with the no-onset cues. All participants received a series of 120 trials for each of the two preparation intervals (100 and 1000 ms). Within a block of 120 trials there were 40 trials for the uncued condition (10 for each of the four stimulus conditions), 40 trials for the left–right condition (10 for each of the four stimulus positions), and 40 trials for the inner–outer condition (also 10 for each of the four stimulus positions). The order of these preparation conditions within a block of 120 trials was random. Order of preparation interval was counterbalanced. Twenty-five practice trials preceded each block of 120 test trials. Participants were informed regarding the nature of the task and were explicitly told to take advantage of the cue. They were instructed to react as quickly as possible to the target stimulus by pressing the correct response key. Error feedback was provided on individual trials.

Analysis. RTs below 150 ms or in excess of 1250 ms were considered outliers and were excluded from data analyses; 0.16% of the trials were removed using this criterion. Mean correct RTs and proportions of errors were calculated for each participant as a function of preparation condition and preparation interval. An ANOVA was performed on mean RTs and percentage errors with cue type (onset and no-onset) as between-subject variable, and with preparation condition (uncued, left–right, and inner–outer), preparation interval (100 and 1000 ms) as within-subject variables. Whenever appropriate, in this and all further experiments, the tests were adjusted for heterogeneity of variance and covariances using the Huynh-Feldt corrected significance values. Post-hoc analyses concerning main effects were carried out using Tukey's honestly significant difference (hsd) procedure. Interaction effects were analysed by tests on simple main effects or by transforming the factorial design into a set of smaller factorials.

Results

Reaction time. The main effects of preparation interval, $F(1, 28) = 46.98$, $p < .001$, and preparation condition, $F(2, 56) = 27.12$, $p < .001$, were significant. The main effect of cue type was not significant, $F(1, 28) < 1$, $p > .4$. Importantly, however, there was a significant Preparation interval × Preparation condition × Cue type interaction, $F(2, 56) = 26.31$, $p < .001$. This interaction is graphically depicted in Figure 4.

To understand the exact nature of this three-way interaction, we conducted separate ANOVAs for the 100 and 1000 ms preparation intervals. These ANOVAs included one within-subject factor (preparation condition) and one between-subject factor (type of cue).

For the 100 ms preparation interval, the ANOVA yielded the expected Preparation condition × Cue type interaction, $F(2, 56) = 38.38$, $p < .001$, shown in Figure 4a. This interaction indicated that the *onset* left–right precue generated a small though significant RT benefit, whereas the *no-onset* left–right precue generated a significant cost (relative to their respective uncued conditions; benefit 17 ms; cost 50 ms; both *p*s < .001). Inner–outer precues, on the other hand, were not affected by type of cue ($p > .5$), and, moreover, did not produce benefits relative to the respective control (i.e., uncued) condition.

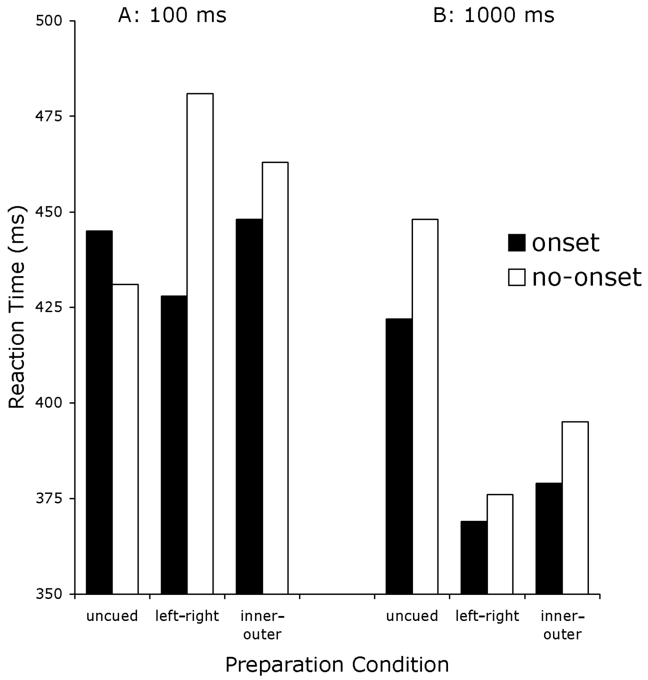

Figure 4. Mean reaction time as a function of preparation condition and cue type (onset vs. no-onset) for (a) the short (100 ms) and (b) the long (1000 ms) preparation interval in Experiment 1.

For the 1000 ms preparation interval, the ANOVA yielded only a main effect of preparation condition, $F(2, 56) = 90.05$, $p < .001$. This main effect indicated significant differences between all three preparation conditions (*M*s = 435, 372, and 387 ms for uncued, left–right, and inner–outer preparation conditions, respectively), reflecting the usual pattern of differential precueing benefits. Importantly, this effect occurred independent of cue type, as all effects including the factor cue type were nonsignificant (all *p*s > .1) (see Figure 4b).

Errors. Mean error rates as a function of type of cue, preparation condition, and preparation interval are presented in Table 1. There was a significant main effect of preparation interval, $F(1, 28) = 4.69$, $p < .05$, indicating fewer errors for the long than for the short preparation interval (*M*s = 2.6% and 3.4%, respectively). Also, there was a main effect of preparation condition, $F(2, 56) = 14.2$, $p < .001$, indicating more errors for the inner–outer than for both the left–right and uncued conditions (*M*s = 4.8%, 2.3%, and 2.0%, respectively). Cue type did not affect the number of errors, $F(1, 28) < 1$, $p > .4$).

TABLE 1
Error rates (%) as a function of type of cue, preparation condition, and preparation interval in Experiment 1

Preparation interval (ms)	*Type of cue*					
	Onset			*No-onset*		
	Uncued	*Left–right*	*Inner–outer*	*Uncued*	*Left–right*	*Inner–outer*
100	2.5	2.7	4.5	1.0	3.5	6.5
1000	2.5	1.3	2.8	2.0	1.7	5.5

Discussion

The critical finding was that, with the short preparation interval of 100 ms, cue type interacted with preparation condition. This interaction indicated that cue type (onset vs. no-onset) modulated preparation efficiency of the left–right cue but not that of the inner–outer cue. Consequently, there was a left–right advantage with onset cues that disappeared, in fact reversed, with no-onset cues. This key finding reveals a clear dissociation between left–right and inner–outer cue conditions. In particular, it is consistent with idea that onset left–right cues exert exogenous control (they are pull cues), whereas onset inner–outer cues exert endogenous control (they are push cues). As expected, there was no effect of cue type with the longer preparation interval of 1000 ms, which confirms that with sufficient time available, endogenous control takes over exogenous control, thereby eliminating or abating bottom-up effects.

EXPERIMENT 2: PERIPHERAL VERSUS CENTRAL CUES

According to the Grouping Model, (onset, peripheral) left–right cues are pull cues, evoking fast, bottom-up, exogenous control. Inner–outer cues, on the other hand, are push cues, needing slow, top-down, endogenous control. In this view, the left–right advantage critically depends on the exogenous control characteristics of the left–right cue. In this experiment, we contrasted the effects of the standard, peripheral cues (that usually generate the left–right advantage) with those of central cues. Since central cues need the endogenous control mode regardless of preparation condition (left–right vs. inner–outer cue), we expected the left–right advantage to disappear with central cues. In fact, because of the Kornblum effect, we expected an advantage for the inner–outer over the left–right preparation condition, especially with longer preparation intervals that allow sufficient time to create good two-element subgroups. In order to trace the time course of the expected left–right advantage with peripheral cues and the inner–outer advantage with central cues, we used five preparation intervals: 60, 250, 500, 1000, and 2000 ms.

Method

Participants. Ten new students, nine male and one female, with a mean age of 23.1 years (range 21–28), participated in this experiment.

Apparatus and stimuli. Responses were made by pressing one of four keys (''V'', ''B'', ''N'', and ''M'') of the keyboard (adjacent keys located in the middle of the bottom row of the keyboard). We used two types of cue: Peripheral and central cues. *Peripheral* cues consisted of plus signs either in all four positions indicated by the warning signal (uncued condition) or in only two of the four possible positions (the left–right and inner–outer conditions). *Central* cues were letters of 3 mm width and 5 mm height that appeared in the centre of the cue row. The letter ''N'' (from the Dutch word ''neutraal'', which means ''neutral'') represented the uncued condition; ''L'' and ''R'' the left- and right-cues (from the Dutch words ''links'' and ''rechts'', which mean ''left'' and ''right'', respectively); ''C'' and ''B'' the inner- and outer-cues (from the Dutch words ''centraal'' and ''buiten'', which mean ''centre'' and ''outer'', respectively). After a variable preparation interval, the target signal (a single plus sign) appeared immediately below the cue row, always in the position indicated by the cue.

Procedure. Participants participated in two sessions, each lasting about 45 minutes, on separate days. In each session, participants received a series of 100 trials for each of the five preparation intervals (60, 250, 500, 1000, and 2000 ms) with either the peripheral or central cue. Within a block of 100 trials there were 20 trials for the uncued condition (5 for each of the four stimulus positions), 40 trials for the left–right condition (10 for each of the four stimulus positions), and 40 trials for the inner–outer condition (also 10 for each of the four stimulus positions). The order of these preparation conditions within a block of 100 trials was random. Order of type of cue (peripheral or central) between sessions was counterbalanced. Order of preparation interval within a session was randomized. Twenty-five practice trials preceded each block of 100 test trials.

Analysis. Using the outlier criteria of Experiment 1, we removed 0.18% of the trials from analysis. Mean correct RTs and proportions of errors were calculated for each participant as a function of type of cue, preparation condition, and preparation interval. An analysis of variance (ANOVA) was performed on mean RTs and percentage errors with type of cue (peripheral and central), preparation condition (uncued, left–right, and inner–outer), and preparation interval (60, 250, 500, 1000, and 2000) as within-subject variables.

Results

Reaction time. There were significant main effects for preparation condition, $F(2, 18) = 41.27$, $p < .001$, and preparation interval, $F(4, 36) = 13.15$, $p < .001$. These main effects indicated shorter RTs for the left–right and inner–outer conditions than for the uncued condition (*M*s = 420, 419 and 465 ms, respectively), and a U-shape RT curve as a function of preparation interval (*M*s = 471, 439, 423, 407, and 433 ms, respectively). These main effects, however, were qualified by several interactions.

The significant Cue type × Preparation condition interaction, $F(2, 18) = 13.78$, $p < .001$, indicated that, with the peripheral cue, RTs were significantly ($p < .05$) shorter for the left–right than for the inner–outer condition (406 vs. 418 ms, respectively), whereas with the central cue RTs were significantly ($p < .05$) shorter for the inner–outer condition than for the left–right condition (420 vs. 433 ms, respectively). In other words, the usual advantage for the left–right condition with the peripheral cue reversed to an advantage for the inner–outer condition with the central cue. Furthermore, this interaction revealed that type of cue (peripheral vs. central) affected the left–right condition but not the inner–outer condition (see Figure 5a).

This differential pattern of cueing effects for peripheral and central cues varied as a function of preparation interval, $F(8, 72) = 2.57$, $p < .05$ (see Figure 6).With the peripheral cues, the left–right advantage emerged only for the shorter preparation intervals (i.e., up to 500 ms), while with the central cue, the inner–outer advantage emerged with longer preparation intervals.

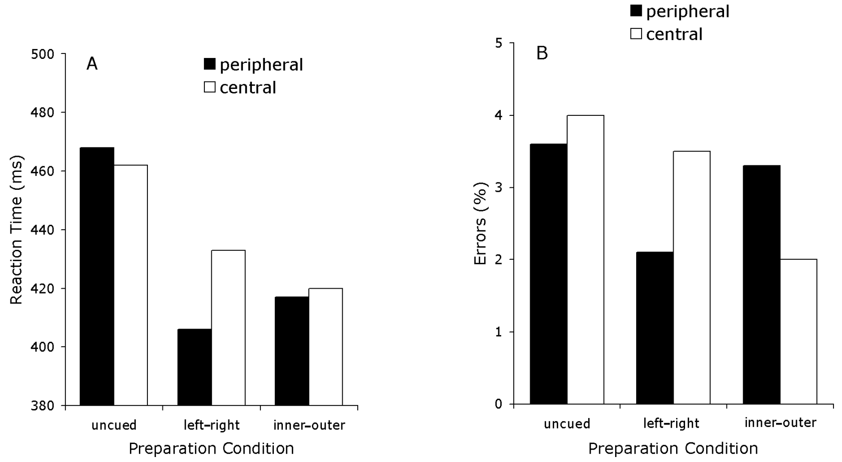

Figure 5. (a) Mean reaction time and (b) percentage errors as a function of preparation condition and cue type (peripheral vs. central) in Experiment 2.

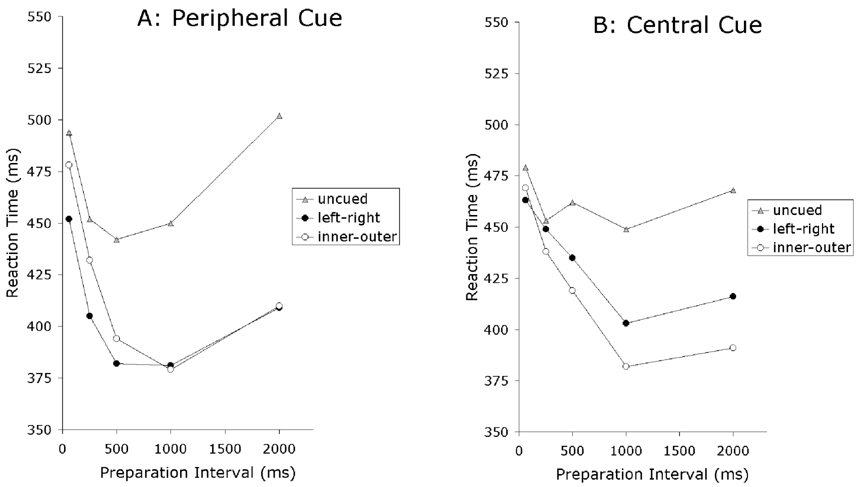

Figure 6. Mean reaction time as a function of preparation condition and preparation interval for (a) the peripheral cue and (b) the central cue in Experiment 2.

Errors. Mean error rates as a function of type of cue, preparation condition, and preparation interval are presented in Table 2.There was a main effect of preparation interval, $F(4, 36) = 4.26$, $p < .01$, indicating that the two longest preparation intervals generated fewer errors than the shorter intervals (i.e., 3.6, 3.9, 3.4, 2.5, and 1.9% of errors for preparation intervals of 60, 250, 500, 1000, and 2000 ms, respectively). Also, the near-significant Type of cue × Preparation condition interaction, $F(2, 18) = 3.33$, $p = .059$, indicated that the peripheral cues produced fewer errors in the left–right condition than in the

TABLE 2
Error rates (%) as a function of type of cue, preparation condition, and preparation interval in Experiment 2

Preparation interval (ms)	*Type of cue*					
	Peripheral			*Central*		
	Uncued	*Left–right*	*Inner–outer*	*Uncued*	*Left–right*	*Inner–outer*
60	4.5	3.3	4.8	2.0	4.0	3.0
250	4.0	1.8	4.3	7.0	4.0	2.5
500	3.5	2.3	3.3	4.5	4.5	2.5
1000	4.0	0.8	2.8	4.5	2.3	0.8
2000	2.0	2.5	1.5	2.0	2.5	1.0

inner–outer condition, but that the central cues produced fewer errors in the inner–outer condition than in the left–right condition (see Figure 5b).

Discussion

The results confirm our expectation that peripheral and central cues generate a qualitatively different pattern of response-cueing effects. Whereas peripheral cues produced the usual advantage for the left–right condition (confined to short preparation intervals), the central cues produced an advantage for the inner–outer condition (confined to longer preparation intervals). Moreover, the results showed that cue type affected the left–right preparation condition but not the inner–outer preparation condition. These outcomes indicate that a *conditio sine qua non* for the left–right advantage is an (onset) spatial, peripheral left–right cue.

The advantage of the inner–outer preparation condition with central cues can be attributed to the Kornblum effect—the phenomenon that between-hands choices are faster than within-hand choices.

EXPERIMENT 3: UNINFORMATIVE CUES AND INHIBITION OF RETURN

In the final two experiments, the cues indicated with a probability of only 50% where the target stimulus (and the corresponding response) would occur. Thus, the cue was not informative as to the location of the upcoming stimulus.

When cues are uninformative, exogenous (pull) cues, but not endogenous (push) cues, can generate IOR (e.g., Wright & Richard, 2000). IOR is the phenomenon that response times for targets at previously cued locations are longer than those for targets at previously uncued locations (for a review, see Klein, 2000). Usually this happens when there is a relatively long interval between onset of the cue and onset of the target stimulus. Thus, while short (i.e., 200 ms and shorter) stimulus–onset asynchronies (SOA) between cue and target typically produce facilitation (that is, faster responses to cued than to uncued targets), SOAs of about 300 ms and longer typically produce inhibition (that is, slower responses to cued than to uncued targets). Posner, Rafal, Choate, and Vaughan (1985) referred to this latter inhibitory effect as IOR, suggesting that it reflects a tendency to bias attention away from a previously explored location.

In the present experiment, we examined the ability of left–right and inner–outer cues to generate IOR (using the standard onset, spatial cueing paradigm). If, as the Grouping Model assumes, left–right cues are pull cues and inner–outer cues are push cues, then left–right cues should be able to generate IOR, while inner–outer cues do not.

Method

Participants. Eighteen students, nine male and nine female, with a mean age of 21.8 years (range 18–25), participated.

Apparatus and procedure. Figure 7 shows the sequence of events for each trial. At the beginning of each trial, a warning signal consisting of a central fixation point (which remained visible throughout the trial) and four peripheral ‘‘+’’ signs (two to the left and two to the right) were presented for 500 ms. Then, after a blank period of 500 ms, in which only the central fixation point was visible, the cue signal was presented for 100 ms. The cues indicated with a probability of 50% that the target stimulus would occur in one of the two locations indicated by the cue. After an SOA of 500 ms, the target stimulus was presented. The target stimulus remained on the screen until a response was made. Participants were instructed to remain fixated on the central fixation point throughout the trial and to make a simple key-press response as soon as they detected the target by pressing the ‘‘B’’ key of the keyboard with the index finger of the preferred hand. The fixation point was presented midway between the two centre stimulus positions.

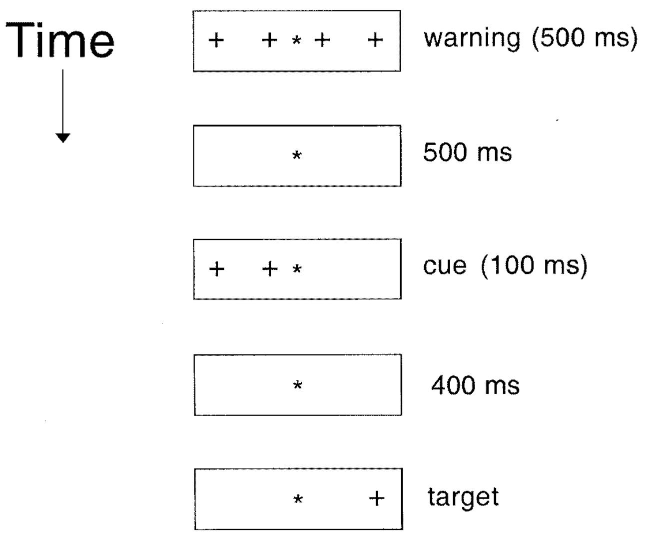

Figure 7. The timing of the trial sequence in Experiment 3. The precues indicated with a probability of 50% that the target stimulus would occur in one of the two locations indicated by the precue. The precue was visible for 100 ms. After a stimulus onset asynchrony (SOA) of 500 ms, the target stimulus was presented. The response was a simple detection response.

Design. Participants received a series of 160 experimental trials. Within a block of test trials there were 40 trials for the left–right cue, 40 trials for the inner–outer cue, and 40 trials for the uncued condition. Also, there were 40 catch trials. The order of conditions within a block of trials was random. Twenty-five practice trials preceded the test trials. Within a series of test trials, a short break occurred halfway. An intertrial interval of 1 s separated the response in a trial from the start of the next trial.

Analysis. Responses on catch trials were rare (0.83%). RTs below 100 ms (0.32%) or in excess of 750 ms (0.60%) were discarded as anticipations and misses, respectively. Mean RTs were calculated for each participant as a function of preparation condition and cue type. An analysis of variance (ANOVA) was performed on mean RTs with preparation condition (left–right or inner–outer) and cue type (valid or invalid) as within-participant variables.

Results

The main effect of cue type, $F(1, 17) = 38.37$, $p < .001$, revealed the presence of IOR because RTs were longer for valid than for invalid trials (*M*s = 326 and 311 ms, respectively). Importantly, however, this main effect was qualified by a significant Cue type × Preparation condition interaction, $F(1, 17) = 12.01$, $p < .001$. This interaction indicated a substantial IOR effect of 28 ms for the left–right cue ($p < .001$), but no effect of cue type for the inner–outer cue ($p > .6$) (see Figure 8). Mean reaction time for the uncued condition was 325 ms.

Discussion

The results revealed a robust IOR effect for the left–right cue but not the inner–outer cue. This outcome supports the notion that left–right cues are exogenous or pull cues, whereas inner–outer cues are endogenous or push cues.

EXPERIMENT 4: UNINFORMATIVE CUES AND AUTOMATIC RESPONSE ACTIVATION

In the previous experiment, using uninformative cues, participants made a simple detection response. The results showed IOR, but only for left–right cues, indicating that only these cues act as exogenous cues, able to attract attention automatically. In the present experiment, we combined the uninformative cueing procedure with the standard response-cueing paradigm that typically employs a four-fingers response set. This was done to examine the extent to which automatic effects of uninformative cues would spread into the response-selection system. In particular, we examined the ability of uninformative left–right and uninformative inner–outer cues to cause automatic response activation effects (e.g., Eimer, 1995; Kornblum et al., 1990). According to our notion that left–

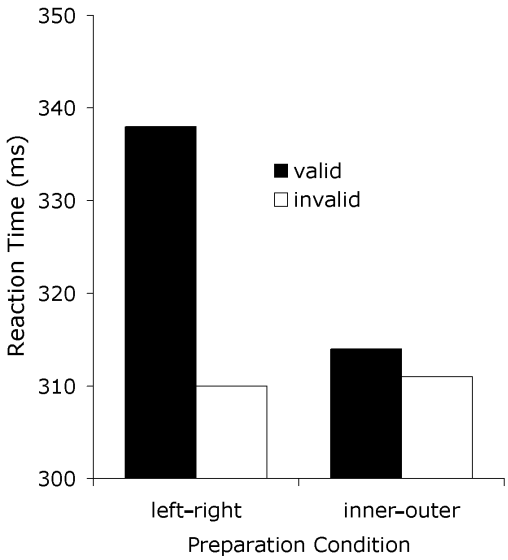

Figure 8. Mean reaction time as a function of preparation condition and cue type (valid vs. invalid) in Experiment 3 (simple detection response).

right cues are pull cues and inner–outer cues push cues, we expected an effect of cue type (valid vs. invalid) only for left–right (pull) cues. Moreover, according to the Grouping Model, left–right cues are especially effective when they can exploit the anatomical left–right (hand) distinction. Hence, we expected a larger effect of cue type (valid vs. invalid) with the standard two-hands response set compared to a one-hand response set, which we used as a neutral (i.e., spontaneously ungrouped) control on the response side.

Method

Participants. Thirty-two students, sixteen male and sixteen female, with a mean age of 20.3 years (range 18–25), participated.

Apparatus and stimuli. The apparatus and stimuli were identical to those of Experiment 1, with one exception. Cue probability was lowered to 50% so that cues were not informative as to the location of the upcoming stimulus.

Procedure. There were two response sets: The standard two-hands response set (index and middle fingers of both hands), and a one-hand response set. In the latter condition, the fingers of the left hand were used. Participants were randomly assigned to one of these two response sets, so that half the participants (n = 16) performed with the one-hand response set, and the other half with the two-hand response set. With the two-hand response set, responses were made by pressing one of the ‘‘Z’’, ‘‘X’’, ‘‘.’’, and ‘‘/’’ keys of the keyboard (the two leftmost and two rightmost keys on the bottom row of the keyboard). With the one-hand response set, responses were made by pressing one of the ‘‘V’’, ‘‘B’’, ‘‘N’’, and ‘‘M’’ keys of the keyboard (adjacent keys located in the middle of the bottom row of the keyboard). All participants received a series of 120 trials for each of two SOAs or preparation intervals (100 and 1000 ms). Within a block of 120 trials there were 40 trials for the uncued condition, 40 trials for the left–right preparation condition, and 40 trials for the inner–outer preparation condition. As mentioned before, the cues indicated with a probability of 50% that the target stimulus would occur in one of the two locations indicated by the cue. The order of the preparation conditions within a block of 120 trials was random. Order of preparation interval was counterbalanced. Twenty-five practice trials preceded each block of 120 test trials.

Analysis. RTs below 150 ms or in excess of 1000 ms were considered outliers and were excluded from data analyses; 0.37% of the trials were removed using this criterion. Mean correct RTs and proportions of errors were calculated for each participant as a function of cue type, preparation condition, and preparation interval. An ANOVA was performed on mean RTs and percentage errors with response set (one-hand or two-hands) as between-subject variable, and with preparation condition (left–right or inner–outer), cue type (valid or invalid), and preparation interval (100 or 1000 ms) as within-subject variables.

Results

Reaction time. The significant main effect of cue type, $F(1, 30) = 99.55$, $p <$ .001, indicated faster responses for valid than for invalid cues (*M*s = 451 and 484 ms, respectively). The significant main effect of preparation interval, $F(1, 30) =$ 12.40, $p < .001$, indicated faster responses for the long than for the short preparation interval (*M*s = 461 and 475 ms, respectively). The significant main effect of preparation condition, $F(1, 30) = 4.94$, $p < .05$, indicated faster responses for the inner–outer cue than for the left–right cue (*M*s = 464 and 471 ms, respectively). The main effect of response set, $F(1, 30) = 3.33$, $p = .078$, approached significance, with faster responses for the two-hands than for the one-hand response set (*M*s = 451 and 484 ms, respectively). Importantly, however, these main effects were qualified by several significant interactions.

The Cue type $\times$ Preparation interval interaction, $F(1, 30) = 12.25$, $p < .001$, indicated that the RT advantage for valid cues (compared to invalid cues) was greater for the short than for the long preparation interval (45 and 21 ms, respectively). The Response set $\times$ Preparation interval interaction, $F(1, 30) =$ 7.75, $p < .01$, indicated that only the two-hands response set generated faster responses with the long than with the short preparation interval (*M*s = 439 and

464 ms, respectively; $p < .01$); the one-hand response set generated similar RTs with the two intervals (*M*s = 483 and 485 ms, respectively; $p > .4$).

Importantly, the Cue type × Preparation condition interaction, $F(1, 30) = 37.89$, $p < .001$, indicated that the left–right condition showed a substantial RT advantage (53 ms; $p < .001$) for valid over invalid cues, whereas inner–outer cues showed a small, nonsignificant advantage ($p > .05$). Moreover, this two-way interaction between cue type and preparation condition was further qualified by a significant three-way interaction involving the factor response set, $F(1, 30) = 5.01$, $p < .05$. This interaction indicated that the facilitative effect of the (valid) left–right cues was greater for the two-hands response set than for the one-hand response set (63 vs. 43 ms, respectively) (see Figure 9). Mean RT in the uncued preparation condition was 438 ms and 469 ms for the two-hands and one-hand response set, respectively.

Errors. Mean error rates as a function of response set, type of cue, preparation condition, and preparation interval are presented in Table 3. There was no main effect of response set, $F(1, 30) < 1$, $p > .8$. However, as with RT, there was a significant Cue type × Preparation condition × Response set interaction, $F(1, 30) = 10.20$, $p < .001$. This interaction is depicted in Figure 8. It indicated that, with the two-hands response set, valid cues (relative to invalid

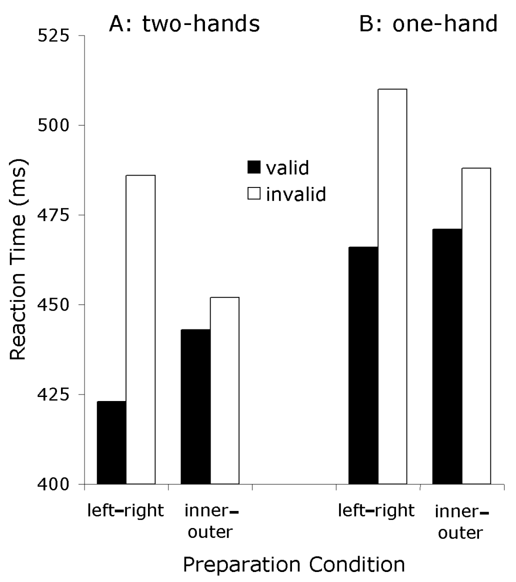

Figure 9. Mean reaction time as a function of preparation condition and cue type (valid vs. invalid) for (a) the two-hands response set and (b) the one-hand response set in Experiment 4 (four-choice key-press response).

TABLE 3
Error rates (%) as a function of type of cue, preparation condition, and preparation interval for the two-hands and the one-hand response set in Experiment 4

Preparation interval (ms)	*Type of cue*			
	Valid		*Invalid*	
	Left–right	*Inner–outer*	*Left–right*	*Inner–outer*
Two-hands response set				
100	2.8	5.6	6.6	2.2
1000	0.3	5.0	7.5	1.9
One-hand response set				
100	3.8	4.7	5.0	4.1
1000	5.3	3.4	4.4	2.5

cues) improved performance in the left–right preparation condition, but hampered performance in the inner–outer preparation condition (see Figure 10a). With the one-hand response set, however, there was no effect of cue type nor of preparation condition (see Figure 10b). Mean error rate in the uncued preparation condition was 2.90% and 2.89% for the two-hands and one-hand response set, respectively.

Discussion

Conforming to our expectations, RTs of valid left–right cues were substantially shorter than those of invalid left–right cues, and this effect was greater for the two-hands response set than for the one-hand response set. This outcome appears to indicate that left–right cues prompted a robust process of automatic response activation. For inner–outer cues this process was absent.

GENERAL DISCUSSION

The advantage for left–right cues in the response-cueing paradigm is a robust phenomenon. According to our Grouping Model (Adam, Hommel, & Umiltà, 2003), these cues are particularly effective in reducing RT because they activate unambiguous representational groups, that is, potent, distinct chunks of information that allow fast, automatic activation of responses that are cognitively organized (grouped) in the same way. In contrast, bilateral cues indicate stimuli and responses belonging to poorly defined subgroups needing slower, effortful processes to select and activate the cued responses. In other words, according to the Grouping Model, left–right cues are pull cues, inducing automatic, bottom-

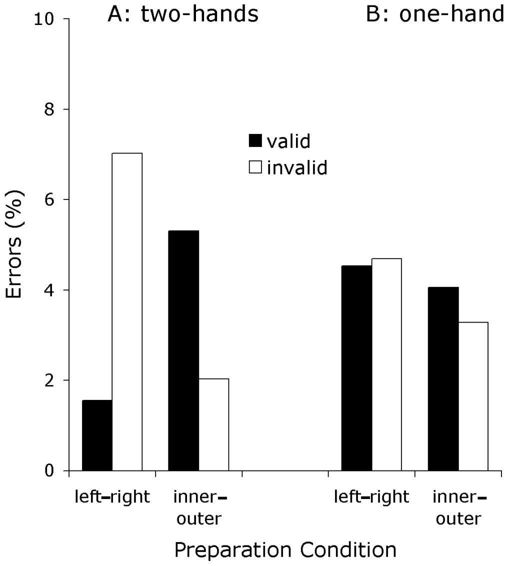

Figure 10. Mean error rate (%) as a function of preparation condition and cue type (valid vs. invalid) for (a) the two-hands response set and (b) the one-hand response set in Experiment 4.

up, exogenous control, whereas inner–outer cues are push cues, needing slower, endogenous control to select the responses indicated by the cue.

In an attempt to provide direct evidence for this contention, we manipulated the characteristics of the cues. In Experiment 1, we found that onset but not no-onset cues generated the left–right advantage. In Experiment 2, we demonstrated that peripheral but not central cues generated the left–right advantage. In Experiment 3, using uninformative cues, we observed that left–right but not inner–outer cues generated the phenomenon of inhibition of return. In Experiment 4, again using uninformative cues, we established that left–right cues but not inner–outer cues generated automatic response activation effects. Thus, the consistent finding was that the left–right cue, but not the inner–outer cue, was sensitive to the experimental manipulations. Together, these results reveal a strong dissociation between left–right and inner–outer cues, providing direct, converging evidence for the notion that left–right cues act as pull cues and inner–outer cues as push cues. This conclusion supports the assumption of the Grouping Model that, in the spatial response-cueing task, left–right cues induce a fast, automatic, bottom-up selection of the cued responses, whereas inner–outer cues need slower, effortful, top-down processes to establish a selective preparatory set.

Discounting an alternative interpretation of the left–right advantage

An alternative interpretation of the left–right advantage is the ''spatial proximity'' hypothesis. Often, the plus signs are in closer spatial proximity for the left–right cue condition than for the inner–outer cue condition. One may thus advance a spatial proximity hypothesis, according to which preparation for two stimulus positions is more efficient the closer together they are, e.g., due to an advantage in sharing attention across nearby positions (Miller, 1982). Among other things, such a spatial proximity hypothesis would predict shorter RTs for the inner cue condition than for the outer cue condition, because the precued locations are in closer proximity in the former situation than in the latter. However, the present results, as well as results from many other studies, contradict this prediction by showing either very similar RTs for both conditions or longer RTs for the inner than the outer cue condition (Adam, 1992; Adam, Backes, et al., 2003; Miller, 1982; Reeve & Proctor, 1990). Thus, rather than spatial proximity, a lateralized (onset) event is necessary to generate the left–right advantage—which rules out a spatial proximity account.

Interactions between bottom-up and top-down processes

By underscoring the top-down process of effortful subgroup making, the Grouping Model explicitly suggests that top-down processes may change the nature of the bottom-up representations. A similar notion has been advanced by Rock (1973; cited in Kosslyn, 1994), who observed that people, when shown the Star of David, typically tend to organize it into two overlapping triangles. However, with effort, they can ''break-up'' some of the lines and symmetries and reorganize it into a central octagon and six small triangles. Likewise, the cue indicating the two inner positions may require ''breaking-up'' the initial bottom-up organization that tends to bind the two leftmost and two rightmost elements together. Congruent ideas can be found, among others, in the work of Bravo and Farid (2003), Goldsmith (1998), Kosslyn (1994), and Logan (1996), who all argued that top-down processes modulate the organization and quality of visual input.

The locus of response-cueing effects

According to the Grouping Model, the functional significance of cue encoding processes is to structure the stimulus display, which in turn may lead to a redefinition or resetting of the response buffer containing the appropriate response codes. In this sense, early (perceptual) cue encoding processes may benefit late (postperceptual) response selection processes by restricting the number of possible response codes in the response buffer. Thus, the processes that subserve selective visual perception interact intimately with those that selectively prepare the motor system for action (see also Cohen & Shoup, 1997; Hommel, 1997). Our conclusion that precueing effects arise at multiple loci in the information processing system is consistent with recent neurophysiological evidence indicating the involvement of distinct neural areas in response cueing (Adam, Backes, et al., 2003; Leuthold, Sommer, & Ulrich, 1996).

Input and output selection

Successful performance in the response-cueing task requires a process of input and output selection, and their coordination. The distinction between input selection and output selection has been prominent in many theories of selective processing. Broadbent (1971) was one of the first to propose such a distinction when he differentiated between stimulus set and response set, and argued that the former is input selective and the latter output selective. A similar notion was advanced by Posner and Boies (1971), who distinguished between attention and intention, with attention referring to the mechanism that decides what information to process, and intention referring to the mechanism that selectively prepares for action. More recently, Goldberg and Segraves (1987) suggested the term ‘‘motor attention’’ to emphasize its similarity with the process of visuospatial attention. By analogy with the selection process in the visuospatial domain, Goldberg and Segraves postulated that the process of motor attention involves a choice among competing internal motor signals rather than among conflicting external stimuli in the environment. Finally, Fuster (2003) recently distinguished between perceptual and executive attention. It should be noted, however, that despite some obvious similarities, perceptual attention and motor (executive) attention appear to be governed by distinct mechanisms (e.g., Adam & Pratt, 2004; Hommel & Schneider, 2002; Pashler, 1991; Schall, 2002).

Distinguishing between input and output selection raises the interesting question of how the two interact. According to the Grouping Model, the driving source of control in the response-cueing task is the appearance of the (visual) cue, implicating that perceptual grouping precedes, and thus drives, the motoric grouping. Evidence for this comes from experiments showing that in case of conflict between the spatial configurations of the stimulus and response sets, the pattern of precueing benefits generally follows the grouping manipulation present in the stimulus set, not the grouping manipulation present in the response set (e.g., Adam, Hommel, & Umiltà, 2003; Reeve et al., 1992). However, the nature of the response set is not always without influence and may impose constraints on the segmentations provided by the perceptual system. For instance, when four fingers on one hand are used instead of two fingers on both hands, the anatomically based left–right grouping in the response set is strongly reduced. Consequently, the perceptually well-defined left–right distinction loses its motoric counterpart, and the left–right advantage tends to disappear (Adam, Hommel, & Umiltà, 2003; Proctor & Reeve, 1986). In sum, according to the Grouping Model, vision is the driving agency in the response-cueing paradigm, so that the pattern of precueing benefits generally follows the grouping implied by the stimulus set; this on condition that the response set is amenable to the perceptually salient grouping principle.

The present results corroborate and extend this idea by showing that left–right grouping *per se* is not sufficient for the left–right advantage to materialize; type of cue is also important. Only exogenous (i.e., onset, peripheral cues, either valid or invalid) cues produced a left–right advantage; endogenous cues did not. This key outcome suggests that exogenous visual orienting underlies and drives the left–right advantage. Furthermore, the finding in Experiment 4 of significant left–right *response*-precueing benefits suggests that input and output selective processes can interact very proficiently (see also Craighero, Fadiga, Rizzolatti, & Umiltà, 1998, 1999; Müsseler & Hommel, 1997). Of course, the precise nature of this interaction needs to be further investigated.

CONCLUSION

Left–right peripheral, onset cues are extremely effective in generating response-cueing benefits, demonstrating that selective preparatory mechanisms in perceptual and motor systems can work together very efficiently, mapping selected chunks of visual information automatically onto specific chunks of motor information. On the other hand, less well-defined cues—like inner–outer cues—need slower, effortful, top-down processes to establish a selective preparatory set.

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