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Predictability Matters: On the Stimulus-Driven Account of the Multiple-Cue Effect

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To examine the issue of whether attentional focus can split among noncontiguous locations, Wright and Richard (2003) used a multiple-cue display and found the validity effect for each of the multiple cues. However, they argued against the multiple foci account by claiming that the multiple-cue effect they obtained was stimulus-driven. We doubt whether their cues were indeed exogenous as they claimed since their target could appear in any one of the eight possible locations but the cue validity was set at 50%. In this case, the cue was in fact predictive as to the target location. In the current study, we showed that when the cues were designed to be truly nonpredictive (12.5%), the multiple-cue effect was eliminated (Experiment 2). We replicated the multiple-cue effect when the cue validity was 50%, as in Wright and Richard (Experiment 1), and showed that there was a cue-triggered, attentional-orienting effect but not visual search advantage when the cue remained on the target display (Experiment 3). Our results, therefore, highlight the possibility of involvements of top-down controls in the validity effect found for multiple-cue displays and the importance of taking predictability into consideration in the testing of hypotheses derived from attention theories.

Keywords: top-down, bottom-up, spatial cueing, cue validity, probability

In the debate on whether attentional focus can split into different spatial locations, some argue that attention can split and process multiple stimuli at nonadjacent spatial locations (e.g., Awh & Pashler, 2000; Alvarez & Cavanagh, 2005; McMains & Somers, 2004; Schmidt, Fisher, & Pylyshyn, 1998), while others argue that attention cannot split and the effects observed from multiple locations are in fact achieved by a unitary focus. For those who defended the latter position, they explained the apparent effect of multiple foci by a unitary focal attention that shifts rapidly between locations (e.g., Kramer & Hahn, 1995; VanRullen, Carlson, & Cavanagh, 2007), distributes across continuous space in a gradient fashion (e.g., LaBerge & Brown, 1989), or is mediated by preattentive, stimulus-driven “indexes” (e.g., Pylyshyn & Storm, 1988; Solomon, 2004; Wright, 1994; Wright & Richard, 2003).

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Among those advocates of the unitary-attentional-focus view, Wright and Richard (2003) emphasised that while attentional focus is unitary, multiple locations can be “registered” *preattentively* (i.e., stimulus driven) and receive higher priority in further processing. For this argument to be valid, ensuring that the multiple-location effect is *purely* stimulus-driven rather than controlled by several top-down attentional foci is important. Wright and Richard reported such a case in a multiple-cue display. However, we suspect that their multiple-cue conditions were confounded with the validity manipulation of the cues, making part of their findings not purely stimulus-driven. Specifically, we argue that the cues they used were not exogenous because their target could appear at one of eight possible locations but the cue validity was set at 50%. We aimed at empirically demonstrating that once the cue validity is manipulated at chance level according to the number of the cues (i.e., 12.5% for one cue and 25% for two cues, etc.), the multiple-cue effect should disappear. If so, this should indicate the involvement of top-down controls, and thus, it cannot be purely stimulus-driven.

In Wright and Richard (2003)’s Experiment 1, one, two, three, or four cues were shown before the presence of the target. (Figure 1 shows the two-cue condition). The task was to judge the orientation of the target, which was a tilt bar. The cues were horizontal bars presented at the possible locations of the target. When the target was presented on top of any one of the cues, it was defined as the *valid condition* (Figure 1C), and when the target was presented at an empty space that was not preoccupied by any cue, it was defined as the *invalid condition*. The validity effect refers to a significant difference in response times between the valid and F1

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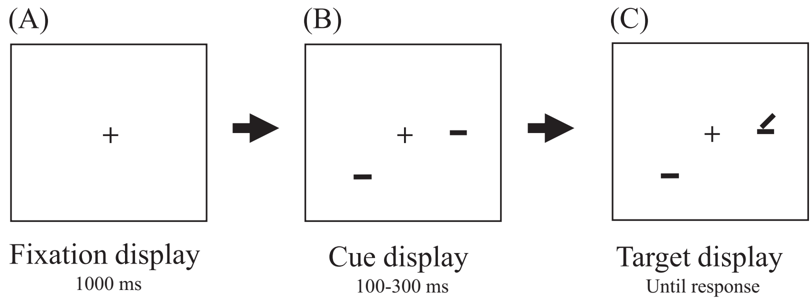

Figure 1. The procedure of the cueing task used in Wright and Richard's (2003) study and in the current study. (A) The fixation display. (B) The cue display, showing the two-cue condition. (C) The target display. Here is seen a valid trial in which the target is presented at the cued location. In Experiment 3 of the current study, the cue display (B) was not shown in order to create a 0-ms cue-to-target onset asynchrony condition.

invalid conditions. They found equally large validity effects in the conditions with two, three, and four cues (*the multiple-cue effect),* and the largest validity effect in the one-cue condition (*the one-cue advantage).* The one-cue advantage was explained by no selection in the one-cue condition since there was no competition for attentional resources. In the two-, three-, or four-cue conditions, however, attentional selection operated at one cued location from among multiple locations, causing a smaller validity effect. They argued that attentional focus could not split among separated locations; rather, a single unitary focus selected any one of the cued locations to process the target.

Wright and Richard (2003) suggested that the multiple-cue effect was mainly stimulus-driven because, in their design, the target would be presented at the cued location for half of the trials (50% cue validity), regardless of the number of cues in that trial. To ensure this, they carried out further experiments and showed that the multiple-cue effect was found only at 100-ms cue-to-target onset asynchrony (CTOA) but not at longer CTOAs (Experiment 2). Also, the validity effect increased with the luminance of the cue (Experiment 3). On the basis of these findings, Wright and Richard argued that the multiple-cue effect was a sensory-mediated, stimulus-driven effect: The equal-sized validity effect for different multiple-cue conditions was due to bottom-up activations at these cued locations (e.g., Pylyshyn & Storm, 1988) rather than shared top-down resources (e.g., LaBerge & Brown, 1989).

We suspect that the multiple-cue effect might not be purely stimulus-driven, because the cues used in Wright and Richard (2003) were actually predictive in some conditions. Conventionally, a cue validity that is one over the number of possible target locations (i.e., 1/2, or 50%, for a display with two possible target locations) is considered nonpredictive, and the observed validity effect is considered exogenous or reflexive. Cue validity above this chance level is a predictive cue, leading to a validity effect that can sustain even after long CTOAs (e.g., Jonides, 1981; Muller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Posner & Cohen, 1984).

The calculation of cue validity becomes more complex in multiple-cue displays, such as in the case of Wright and Richard (2003). In their two-cue condition (as shown here in Figure 1), for example, if the target was presented at any one of the two cued locations, it was a valid trial. If the target was presented at any one of the other six uncued locations (not shown in Figure 1), it was an invalid trial. Wright and Richard considered these cues *involuntary* because the target would be at the cued location for only half of the trials. However, there were eight possible locations for the target, making 50% cue validity actually *predictive* in some cue-number conditions. In particular, the target should be present in the cued location for 1/8 probability in the one-cue condition to be nonpredictive, for 2/8 probability in the two-cue condition, and so forth. That is, cue validity needs to vary with the number of the cues if it is indeed nonpredictive. Thus, for the one-, two-, and three-cue conditions, 50% cue validity provides more information about possible target locations than does the chance level because the chance level for these conditions should be 12.5%, 25%, and 37.5%, respectively. Thus, some top-down expectations should have been involved in the process. Although the cue was totally nonpredictive in the four-cue condition (4/8 equals 50%), the mixed presentation of all the cue-number conditions in a session may lead to higher expectations regarding cued locations in the entire experimental session. This expectation, in turn, may have contributed to the multiple-cue effect observed in Wright and Richard.

The goal of our study was to test whether *cue validity* could indeed affect the findings in the multiple-cue displays as used in Wright and Richard (2003). In particular, we asked whether the multiple-cue effect could still be obtained when the cue validity was adjusted to be truly nonpredictive in terms of possible target locations. Because there was no such confounding of cue validity in the four-cue condition, we did not test this condition and focused on the comparison of results from the one-, two-, and three-cue conditions. Three experiments were carried out. Experiment 1 was designed to replicate the findings of the multiple-cue effect and the one-cue advantage in our labouratory. In Experiment 2, the cue validity was redesigned to make the cue nonpredictive, regardless of the number of cues. In Experiment 3, a 0-ms CTOA condition was additionally tested to rule out the possibility that the results in Experiment 2 might have come from some spatial interaction between the cue and the target. As predicted, we found that the multiple-cue effect was eliminated when the cue was truly nonpredictive, suggesting that the effect was not determined by purely stimulus-driven factors as Wright and Richard had claimed.

Experiment 1

To achieve our goal, we needed to first replicate the basic findings of the multiple-cue effect and the one-cue advantage observed in Wright and Richard (2003). In this experiment, the cue validity was fixed at 50%; that is, the target was presented at a cued location in half of the trials, regardless of the number of cues in the display. In addition, three CTOA levels (100, 200, or 300 ms) were also manipulated to test whether the validity effect varied with CTOA.

Method

Participants. Seventeen undergraduates of National Taiwan University participated in this experiment. All had normal or corrected-to-normal vision and received extra course credit as a reward.

Apparatus and stimuli. Stimuli were presented on a 17" EIZO F553-M monitor, driven by an IBM-compatible personal computer. The screen refresh rate was 70Hz. Participants sat in a dim chamber with a chinrest at a viewing distance of 55 cm from the screen. The layout of stimuli is shown in Figure 1. The fixation was a cross with $0.52° \times 0.52°$ in visual angle, and the cue was a $1.04° \times 0.21°$ horizontal bar. The target was a $1.04° \times 0.16°$ tilt bar, either 45° or 135°, occupying a $0.74° \times 0.74°$ space. The target, if it was presented at the cued location, was one pixel above the cue at the nearest end. The target and the cue were presented in an imaginary circle (eight possible locations) with a radius of 5.17°. In the centre of the circle was the fixation cross. Three CTOA levels were manipulated: 100 ms, 200 ms, and 300 ms.

Procedure. At the beginning of each trial, a fixation display was presented for 1000 ms, followed by a cue display for the duration of the predesignated CTOA. After that, the target was presented until the participant made a response. The cue and fixation cross remained on the screen when the target was presented, as done in Wright and Richard (2003). There was no intertrial interval; the next trial began immediately after the participant's response.

Participants were instructed to judge the orientation (left- or right-tilted) of the target as quickly and correctly as possible by pressing a corresponding key. To emphasise both speed and accuracy in response, they were instructed that a wrong key press or a response exceeding 1500 ms would be treated as an error, and a beep would be provided as immediate feedback for such a response. There was a 30-trial practice session before data collection, and the mean response time (RT) and accuracy were presented after the end of the practice session. Participants were requested to maintain their accuracy above 95% and keep the mean RT below 500 ms in the experimental session. A display with the word *break* and the mean RT and accuracy in that block of trials was presented after each 72 trials during the experiment. Participants pressed any key to return to the task after the self-paced break.

There were 576 trials in total, comprised of $2 \times 3 \times 3 \times 8 \times 4$ (target tilt to left or right $\times$ cue number one, two, or three $\times$ CTOA 100, 200, or 300 ms $\times$ possible cue-target locations $\times$ repetition) trials. The target was presented at the cued location for half of the trials (50% cue validity); that is, for the 192 trials in each cue-number condition, the target was presented at the cued location for 96 trials. The sequence of the trials was completely randomized for each participant. It took about half an hour to complete this experiment.

Results

Results of correct mean RTs and accuracies are shown in Table 1. The validity effects in each CTOA condition are shown in T1 Figure 2A. The RT data were submitted to a three-way analysis of F2 variance (ANOVA) with the within-subject factors of cue number, CTOA, and validity. Results showed that RTs were faster at valid than at invalid locations, $F(1, 16) = 64.23$, $MSE = 976.89$, $p <$

Table 1
The Mean Reaction Times (ms) with Standard Deviations in Parentheses and Accuracy (%) in Each Condition of Each Experiment

Cue-number		One-cue			Two-cue			Three-cue		
CTOA		100 ms	200 ms	300 ms	100 ms	200 ms	300 ms	100 ms	200 ms	300 ms
Experiment 1										
Valid	*RT*	489 (31)	470 (41)	461 (36)	490 (30)	482 (33)	479 (34)	502 (35)	482 (36)	476 (28)
	ACC	98.2	96.5	95.6	96.7	96.0	92.8	95.2	96.9	95.6
Invalid	*RT*	533 (36)	520 (44)	517 (48)	519 (34)	498 (28)	499 (36)	517 (33)	492 (36)	493 (37)
	ACC	96.9	96.7	95.2	96.5	94.9	94.7	96.3	96.0	96.0
Experiment 2										
Valid	*RT*	468 (39)	463 (51)	456 (46)	477 (46)	467 (50)	474 (52)	481 (45)	464 (50)	466 (48)
	ACC	97.2	96.3	98.6	97.2	97.7	96.5	95.7	95.8	96.6
Invalid	*RT*	505 (49)	489 (53)	480 (50)	490 (47)	472 (47)	476 (55)	486 (47)	468 (47)	469 (49)
	ACC	96.4	96.4	95.4	95.9	96.2	96.1	96.4	95.6	96.3
Experiment 3										
CTOA		0 ms	100 ms		0 ms	100 ms		0 ms	100 ms	
Valid	*RT*	628 (97)	567 (79)		623 (119)	592 (90)		643 (113)	605 (87)	
	ACC	98.3	100.0		100.0	99.2		99.4	97.8	
Invalid	*RT*	629 (75)	638 (89)		636 (81)	618 (79)		631 (89)	610 (87)	
	ACC	98.3	99.3		97.2	98.3		98.3	98.7	

Note. CTOA = Cue-to-target onset asynchrony (ms); RT = reaction time (ms); ACC = accuracy (%).

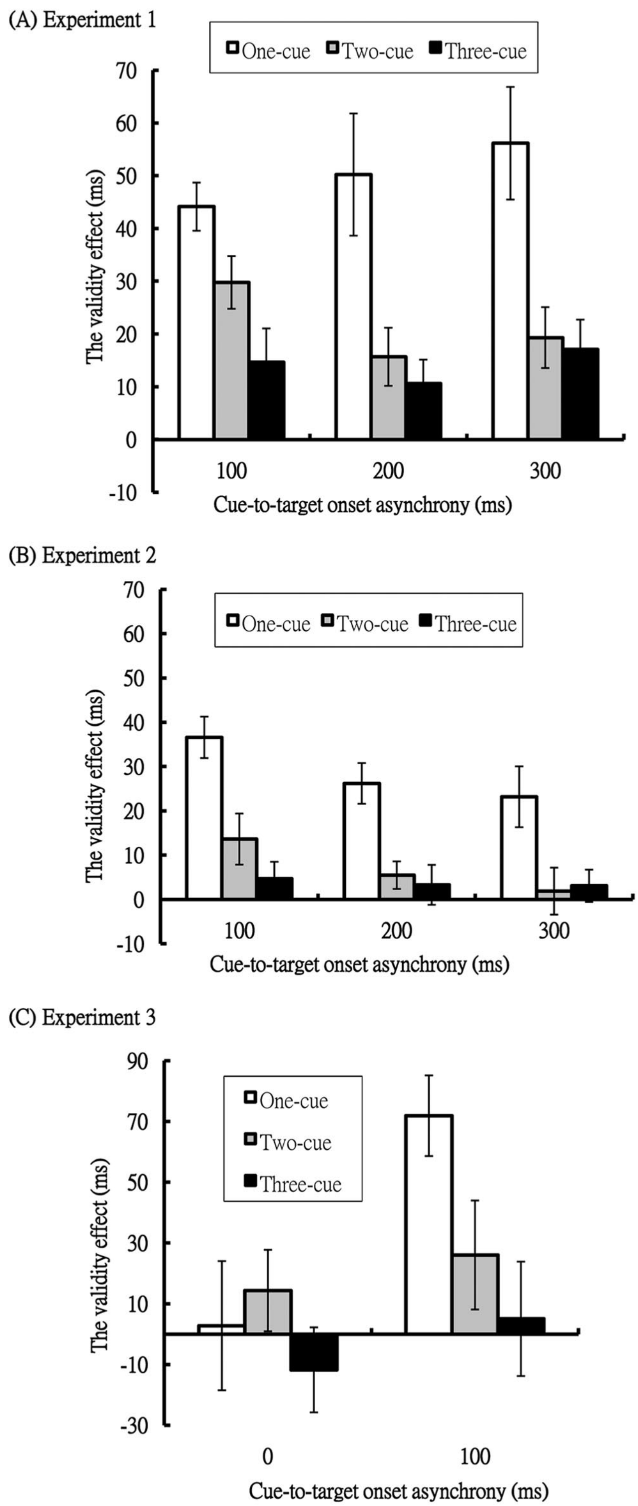

Figure 2. The validity effect in each cue-to-target onset asynchrony condition.

.0001. The post hoc analysis (Tukey test) of the main effect of CTOA, $F(2, 32) = 34.59$, $MSE = 370.10$, $p < .0001$, showed that the RTs were longer in the 100 ms than in the other CTOA conditions, $ps < .01$. The two-way interaction of cue number and validity was also significant, $F(2, 32) = 19.41$, $MSE = 475.95$, $p < .0001$; the validity effect was obtained in one-cue, $F(1, 48) = 99.91$, $MSE = 642.93$, $p < .0001$; two-cue, $F(1, 48) = 18.51$, $MSE = 642.93$, $p < .0001$; and three-cue, $F(1, 48) = 7.91$, $MSE = 642.93$, $p < .01$, conditions. Further analysis of the validity effect (a two-way ANOVA on RTs in the invalid condition minus that in the valid condition) showed that the validity effect was significantly larger in the one-cue condition than in the other two conditions, $F(2, 32) = 19.41$, $MSE = 951.91$, $p < .0001$, which indicates that we replicated *the one-cue advantage* in all the CTOA conditions (Figure 2A). Also, the validity effects did not differ from each other in the two- and three-cue conditions, thus demonstrating *the multiple-cue effect*. The main effect of CTOA, $F(2, 32) = .75$, $MSE = 530.56$, $p = .48$, and the two-way interaction, $F(4, 64) = 1.15$, $MSE = 571.93$, $p = .36$, were not significant.

Mean accuracy was 95.92%. A three-way ANOVA on accuracy showed that the main effect of CTOA, $F(2, 32) = 5.03$, $MSE = 001$, $p < .05$, was obtained. The post hoc Tukey test showed that the accuracy was higher in the 100-ms than the 300-ms CTOA condition, $p < .05$. Other effects were not significant. There was no evidence of a speed–accuracy trade-off.

Discussion

In this experiment, we replicated the basic findings of the multiple-cue effect and the one-cue advantage as reported by Wright and Richard (2003). First, the validity effect was obtained in every multiple cue-number condition (two- and three-cue conditions), and the sizes of the validity effect did not differ from each other (i.e., the multiple-cue effect). Second, the validity effect was larger with one cue and smaller with multiple cues (i.e., the one-cue advantage). Thus, our experimental settings were capable of further exploring the role of cue validity in multiple-cue conditions.

In addition to the above two observations, the effect of CTOA was also explored in this experiment. The results showed that the CTOA did not interact with cue validity or cue number; that is, the multiple-cue effect and the one-cue advantage were constant across different CTOA conditions (see Figure 2A). In fact, how the multiple-cue effect and the one-cue advantage varied with CTOA was not manipulated in Experiment 1 of Wright and Richard (2003) because they fixed the CTOA at 100 ms. The validity effect that was observed at 100-ms CTOA was taken as a piece of evidence for stimulus-driven effects of attentional orienting in Wright and Richard. However, top-down, attentional control setting has been shown to modulate the validity effect even at 50-ms CTOA (Folk, Remington, & Johnston, 1992), not to mention the longer CTOAs. Thus, although we replicated the multiple-cue effect at 100-ms CTOA, this effect is not necessarily stimulus-driven, as hinted by the multiple-cue effect at 200-ms and 300-ms CTOAs.

Experiment 2

In this experiment, we changed the cue validity to be nonpredictive and tested whether predictability of the cue influences the multiple-cue effect. More specifically, the target would be presented at the cued location for 1/8, 2/8, and 3/8 of the trials in the

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one-, two-, and three-cue conditions, respectively. By doing so, the cued location would be statistically independent of the target location, making the cue nonpredictive. If the multiple-cue effect and the one-cue advantage are not modulated by the top-down expectation from cue predictability, we should obtain the same result as that in Experiment 1.

Method

Twenty-seven undergraduate students at National Taiwan University participated in this experiment. They had normal or corrected-to-normal vision, and received extra course credit as a reward. The experimental design was the same as in Experiment 1, except that the numbers of valid trials were 24, 48, and 72 for the one-, two- and three-cue conditions, respectively. Since the total number of trials in each cue-number condition was 192, the cue validity was 12.5%, 25%, and 37.5% for each condition, respectively.

Results

An ANOVA on correct RTs revealed a significant validity effect, $F(1, 26) = 52.79$, $MSE = 396.55$, $p < .001$, and a main effect of CTOA, $F(2, 52) = 20.67$, $MSE = 522.85$, $p < .001$; RTs were shorter at 100-ms CTOA than at the other two CTOAs (ps < .01). The interaction of validity and cue number, $F(2, 52) = 19.23$, $MSE = 386.54$, $p < .001$, showed significant validity effects for the one-cue, $F(1, 78) = 85.29$, $MSE = 389.86$, $p < .0001$, and two-cue, $F(1, 78) = 5.11$, $MSE = 389.86$, $p < .05$, conditions, but not for the three-cue condition. Although the validity effect was found in the two-cue condition, the effect was small (13.65 ms, 5.50 ms, and 1.89 ms in the 100-ms, 200-ms, and 300-ms conditions, respectively). Also, since there was no significant validity effect in the three-cue condition, the multiple-cue effect was, thus, not reliable in this experiment. To further understand the validity effect at each CTOA, a two-way ANOVA on the validity effect (i.e., the RT difference between invalid and valid trials) was conducted. The post hoc analysis on the main effect of cue number, $F(2, 52) = 19.24$, $MSE = 773.23$, $p < .001$, showed that the validity effect was larger in the one-cue condition (28.66 ms) than in the other cue-number conditions (7.01 ms for two-cue and 3.71 ms for three-cue, respectively, ps < .01), with no difference between the two-cue and three-cue conditions. Thus, the one-cue advantage was still obtained. The main effect of CTOA, $F(2, 52) = 2.95$, $MSE = 592.24$, $p = .06$, and the two-way interaction of CTOA and cue number, $F(4, 104) = .62$, $MSE = 477.96$, $p = .65$, were not significant. Mean accuracy was 96.46%. The three-way ANOVA on accuracy showed only the validity effect, $F(1, 26) = 4.31$, $MSE = .002$, $p < .05$. There was no speed–accuracy trade-off.

To compare the data of Experiments 1 and 2, we collapsed the two groups into a four-way ANOVA with cue predictability (Experiment 1 predictable vs. Experiment 2 unpredictable) as a between-subjects factor, and cue number, CTOA, and validity as within-subject factors. In general, responses were faster in valid trials than in invalid trials, $F(1, 42) = 132.51$, $MSE = 617.96$, $p < .001$. Also, responses were slower at longer CTOAs, $F(2, 84) = 50.35$, $MSE = 464.80$, $p < .001$. Furthermore, the main effect of cue number, $F(2, 84) = 3.43$, $MSE = 386.18$, $p < .05$, suggests that responses were slower in the three-cue condition than in the one-cue and two-cue conditions. The interaction between validity and cue number, $F(2, 84) = 39.44$, $MSE = 420.65$, $p < .001$, showed the existence of the one-cue advantage. More importantly, there was an interaction between validity and cue predictability, $F(1, 42) = 18.28$, $MSE = 617.96$, $p < .001$. That is, the validity effect was larger in Experiment 1 (28.64 ms) than in Experiment 2 (13.13 ms). As shown in Figure 2, the result patterns of Experiment 1 and 2 were similar. However, the magnitude of the validity effect was smaller in Experiment 2, making the one-cue advantage smaller and providing nearly no validity effect in the multiple-cue conditions in Experiment 2. In other words, removing cue predictability eliminated the multiple-cue effect.

Discussion

In this experiment, when cue validity was controlled to be nonpredictive, we found no multiple-cue effect. In particular, no validity effect was observed in the two-cue condition at 200-ms and 300-ms CTOAs, and the validity effect was barely observed in the three-cue condition at all CTOAs. The multiple-cue effect, however, as was reported in Experiment 1 with a 50% validity, was characterised as a reliable and equal-sized validity effect in both the two-cue and three-cue conditions. The difference between the results in Experiments 1 and 2, therefore, suggest that the multiple-cue effect is not purely stimulus-driven; rather, it is partly a result of expectation from the predictability provided by the cues.

As shown in Figure 2B, the two-cue condition elicited a significant validity effect, though we expected to have no significant validity effect in this condition. We do not think this is a reliable effect for two reasons. First, the validity effect was very small (on average 7.01 ms). Second, the magnitude of the validity effect was not different between the two-cue and three-cue conditions, and the validity effect was not statistically significant in the three-cue condition. In addition, we suspect that the unreliable validity effect may not even be an attentional effect. Typical validity effect induced by orienting of attention is usually larger at longer CTOAs than at shorter ones (e.g., Brignani, Guzzon, Marzi, & Miniussi, 2009), and exogenous orienting seldom elicits effects only at 100-ms CTOA but not at 200-ms CTOA (Muller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Posner & Cohen, 1984). Regardless of whether there was a validity effect in the two-cue condition, the insignificance in the three-cue condition and the overall result pattern suggest the abolishment of the multiple-cue effect in Experiment 2.

Note that the validity effect was found in the one-cue condition at all CTOAs. One of the reasons that the validity effect was prevalent when there was only one cue in the display may be due to the design of the multiple-cue display in Wright and Richard (2003), which encouraged the emergence of validity effect, especially in the one-cue or two-cue condition. In particular, the cues remained on until the participant responded (i.e., discriminated the target), which makes the display very different in the valid and invalid conditions. For example, in the one-cue condition, the cue was presented beneath the target in the valid trial, making the total number of items in the display one. In contrast, the cue and the target were separately presented in the invalid trial, making the total number of items two. Thus, it is possible that the cues could have provided visual search advantage in the valid trial compared

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to the configuration in the invalid trial, which might also have led to the validity effect. This effect, then, would not be the cue-triggered attentional orienting effect that the conventional cuing paradigm would have assumed (Posner & Cohen, 1984). We examined this possibility in Experiment 3.

Experiment 3

In Wright and Richard (2003), the cues remained on when the target was presented, creating a possible interplay of cue validity and display configuration (i.e., fewer number of items in the valid trials than in the invalid trials), rather than the deployment of attention. To test if the way in which the cue was presented, rather than attentional orienting to the cue, contributed to the validity effect observed in previous experiments, we tested the 0-ms CTOA condition in Experiment 3. Since cue-triggered attentional orienting requires time to develop (Brignani et al., 2009; Muller & Rabbitt, 1989; Nakayama & Mackeben, 1989), any validity effect found at 0-ms CTOA would imply that the results of Experiments 1 and 2 may have been confounded with the presence of the cue in the target display, rather than attentional shift.

Method

Another group of 15 undergraduates participated in this experiment in return for extra course credit. They had normal or corrected-to-normal vision, and were not informed of the purpose of this experiment. The experiment was the same as that in Experiment 2, except that the CTOAs were 0 ms and 100 ms. In the 0 ms CTOA condition, after the 1000-ms fixation display (Figure lA), the target display (Figure lC) was presented immediately; that is, the cue and the target were presented simultaneously on the screen. There were 4, 8, and 12 valid trials for the one-, two- and three-cue conditions, respectively, in each CTOA condition. The total number of trials in each cue-number condition was 32. Therefore, the cues remained nonpredictive as in Experiment 2. In total, each participant completed 192 trials.

Results

Results of correct mean RTs and accuracies are shown in Table 1, and the validity effects are shown in Figure 2C. The RT data were submitted to a three-way repeated ANOVA with factors of cue number, CTOA, and validity. Results showed that RTs were faster at valid than at invalid locations, $F(1, 14) = 5.46$, $MSE = 2685.94$, $p < .01$. Responses were also faster at 100-ms CTOA than at 0-ms CTOA, $F(1, 14) = 20.46$, $MSE = 1621.38$, $p < .001$. There was an interaction between CTOA and validity, $F(1, 14) = 9.25$, $MSE = 1288.72$, $p < .01$, suggesting that the validity effect was observed only at 100-ms CTOA, $F(1, 28) = 13.34$, $MSE = 1987.33$, $p < .01$, but not at 0-ms CTOA, $F(1, 28) = .036$, $p = .85$. Planned t tests showed that the validity effect was significant only in the one-cue condition at 100-ms CTOA, $t(14) = 5.80$, $p < .0001$, (Figure 2C), but not in the other cue-number conditions. The result pattern at 100-ms CTOA replicated that in Experiment 2 (Figure 2B), while there was nearly no effect at 0-ms CTOA. Thus, the validity effect observed at 100-ms CTOA should not be a result of the presence of the cue in the target display.

Mean accuracy was 98.5%. The three-way ANOVA on accuracy showed that valid trials (99.1%) were more accurate than invalid trials (98.4%), $F(1, 14) = 4.84$, $MSE = .001$, $p < .05$, and no other effects were significant. Such a finding rules out the possibility of speed–accuracy trade-off. To further understand whether the two-cue condition elicited a larger validity effect than the three-cue condition at 100-ms CTOA, the cue validity effects of Experiments 2 and 3 were collapsed into a larger data set for further analysis. On average, the validity effect was 49 ms, 18 ms, and 5 ms, for one-, two-, and three-cue conditions, respectively. The main effect of *CTOA*, $F(2, 80) = 10.84$, $MSE = 2010.89$, $p < .001$, was found, and the post hoc analysis showed that the validity effect in the one-cue condition was significantly larger than that in the two- and three-cue conditions, ps $< .01$, while the validity effects in the two-cue and three-cue conditions were not different from each other, $p = .10$. Thus, the validity effect in the two-cue condition at 100-ms CTOA in Experiment 2 was not a reliable finding.

Discussion

In this experiment, the results of Experiment 2 were replicated: The validity effect was found in the one-cue condition at 100-ms CTOA, but not in the two-cue and three-cue conditions (Figure 2C). In addition, no validity effects were obtained at 0-ms CTOA in the one-cue, two-cue, or three-cue conditions. This result argued against the possibility that the differences of the presence of the cue in the target display between valid and invalid trials leads to the validity effect. Furthermore, we found that the validity effect was not significant at 100-ms CTOA in the two-cue condition, suggesting that the validity effect at 100-ms CTOA in Experiment 2 was not a reliable finding either. In summary, there was no evidence for the multiple-cue effect when the cues were not predictive to the location of the target.

General Discussion

Wright and Richard (2003) found validity effects for each of the multiple cues, but attributed such multiple-cue effects to purely sensory-mediated, stimulus-driven effects at each cued location, in an attempt to maintain their view that top-down attention is unitary. We reported three experiments and demonstrated that the multiple-cue effect was in fact modulated by top-down expectation as induced by cue validity. More specifically, in Experiment 1 we found the same magnitude of validity effect for each of the multiple cues when they were presented above chance to predict the target location, replicating the multiple-cue effect in Wright and Richard. In Experiments 2 and 3, however, we found no reliable validity effect in the two-cue and three-cue conditions when the cues appeared at the target location at chance level. Therefore, we demonstrated that the multiple-cue effect was determined by the location probability provided by the cues, rather than purely sensory-mediated, stimulus-driven effects as claimed by Wright and Richard.

Although we found that cue validity could modulate the multiple-cue effect, we did not reject the possibility that some bottom-up factors could affect the multiple-cue effect as well. For instance, Wright and Richard (2003) demonstrated that the validity effect in the four-cue condition decreased with CTOA (their Ex-

tapraid5/cae-cae/cae-cae/cae00112/cae0143d11z | xppws | S=1 | 2/29/12 | 12:37 | Art: 2011-0163

periment 2) and increased with cue luminance (their Experiment 3). Because the 50% validity they used was the chance level in the four-cue condition when there were eight possible target locations, some stimulus-driven, bottom-up factors should also affect the validity effect in the multiple-cue displays.

In addition to Wright and Richard (2003), Solomon (2004) also showed that multiple noninformative cues generated a facilitation effect to a cued, briefly presented (25 ms) Gabor at 108-ms CTOA. The noninformative cues lowered the discrimination threshold of the Gabor even though all possible target locations were "cued," and Solomon suggested that this facilitation was mainly stimulus-driven. Some differences between Solomon and the current study are worth mentioning here. First, in Solomon, the target was briefly presented at the threshold level, while in our experiment the target was clearly visible, and it was presented until response. The underlying processes in these two conditions could be very different. Second, in Solomon a posttarget mask was presented, which may serve as another kind of "cue" since only the target location was masked. As reviewed by Solomon, the postmask plays a crucial role in threshold decrement. Nevertheless, in Wright and Richard and our study here, no location indication was presented other than the cues. We do not deny that the cues could generate stimulus-driven sensory effect in certain circumstances; nevertheless, the multiple-cue effect in Wright and Richard and in our Experiment 1 was simply not derived from that kind of stimulus-driven effect.

In contrast to the multiple-cue effect, the one-cue advantage remained when the cue was not predictive as to the location of the target (12.5% in Experiments 2 and 3). As shown in Figure 2B, the validity effect was consistently obtained in the one-cue condition at all CTOAs in Experiment 2. Thus, a dissociation between the validity effect in the one-cue condition and that in the multiple-cue conditions was found. Our Experiment 3 ruled out the possibility that the presentation of the cues in the target display may have affected the response differences between the valid and invalid trials. The finding of the one-cue validity effect, therefore, replicated the classical findings in the literature of exogenous orienting, namely, that a noninformative periphery cue elicits the validity effect within 300-ms CTOA (Posner & Cohen, 1984; Styles, 2006). However, we notice that the validity effect in the one-cue condition seems to be larger in Experiment 1 than that in Experiment 2, especially at longer CTOAs. For example, the validity effect in Experiment 1 was 44.15 ms, 50.23 ms, and 56.18 ms, at 100-ms, 200-ms, and 300-ms CTOAs, respectively, while it was 36.60 ms, 26.19 ms, and 23.19 ms in Experiment 2. The difference between these two experiments was significant at 200 ms, $t(42) = 2.28$, $p < .05$, and 300 ms, $t(42) = 2.80$, $p < .01$. The reduction of the validity effect at 200-ms and 300-ms CTOA may partly be ascribed to the nonpredictive cue information in Experiment 2. Thus, not only the multiple-cue conditions but also the one-cue condition was modulated by the cue validity.

We suggest that a top-down expectation such as the predictive cue used in Wright and Richard (2003) and in the current study can affect the multiple-cue effect, which argues against the stimulus-driven account for unitary attentional focus as proposed by Wright and Richard. The critical link between our work and the hypothesis testing in Wright and Richard is the assumption that the attentional focus is considered to be under top-down control (Theeuwes, 2010). Wright and Richard suggest that the multiple-cue effect is purely stimulus-driven, which leads to the conclusion that the attentional focus does not need to split to generate the multiple-cue effect. However, since our data suggest that the multiple-cue effect could be under top-down control, there is a possibility that the attentional focus actually splits onto the cued locations simultaneously. Note that we do not argue against the possibility that the cued locations may have some sensory activations that enable priority entry in attentional selection. However, the sensory activations might not coexist with a single, unitary attentional focus; rather, these activations might operate at multiple attentional foci.

Nevertheless, our data could not lead to the conclusion that attention can split. In the literature of visual attention, evidence for multiple attentional foci usually faces more challenges than that for unitary attentional focus (Cavanagh & Alvarez, 2005; Yeh & Li, 2005). This is because various types of unitary accounts can also explain effects that seem to reveal simultaneous multiple processes (e.g., Kramer & Hahn, 1995; LaBerge & Brown, 1989; Pylyshyn & Storm, 1988; Solomon, 2004; VanRullen et al., 2007; Wright, 1994; Wright & Richard, 2003). For example, a unitary attentional focus may diffuse into a larger extent in a multiple-cue condition, while it may concentrate on a single cue in the one-cue condition. This explains why we found a larger validity effect for one cue than multiple cues: More of the resource was allocated to the single cued location. However, how the attentional resource remains on the cued location and avoids the uncued location in a diffused state is unclear. Another possibility is that a single attentional focus shifts rapidly between the cued locations. In this case, in the multiple cue conditions, the validity effect should be obtained in some trials when attention selects a cued location among several locations, and it should not be obtained in some other trials when attention selects an uncued location. This explains why the validity effect for multiple cues was smaller than that for a single cue (i.e., the one-cue advantage).

One may argue that the multiple-cue effect is not due to preattentive registration or multiple attentional foci as discussed above; rather, it may be due to some other factors. For example, in the multiple-cue condition, the probability that all cues are adjacent is larger for two cues than for three cues. Since adjacent cues generate a larger validity effect than nonadjacent cues (Posner, Snyder, & Davidson, 1980), the validity effect should be larger in the two-cue than in the three-cue conditions. Indeed, the validity effect seems to be larger in the two-cue condition than in the three-cue condition at 100-ms CTOA (see Figure 2). Although this difference was not significant in Experiment 3 and was very small in Experiment 2, we could not exclude this possibility. Another possibility is that the higher-than-chance validity used in our Experiment 1 and in Wright and Richard (2003) may have encouraged participants to pay attention to the combined configuration of the adjacent target and cue (as a visual template), leading to the multiple-cue effect. This kind of visual template is less likely to form when the cue validity is reduced to chance level. This explanation also emphasizes the role that top-down strategy plays in the multiple-cue effect; however, it is unrelated to attentional orienting. Regardless of one possibility or the other, the fact that the multiple-cue effect disappeared when the cue was uninformative argues against the stimulus-driven account of Wright and Richard.

In conclusion, we found that when multiple locations were precued, the target that was shown at one of these cued locations indeed was responded to faster—and with similar magnitude of response facilitation—than at other uncued locations. However, this multiple-cue effect was not purely stimulus-driven since it was obtained only when these cues could predict the possible locations of the target but not when they were truly nonpredictive. Our results, thus, argue against the stimulus-driven account for unitary attentional focus as proposed by Wright and Richard (2003) and highlight the importance of taking cue predictability into consideration when examining issues related to the deployment of attention. As humans are so sensitive to probability distribution of the stimuli, any erroneous assumptions and/or manipulations may lead to very different conclusions, as we have demonstrated here.

Résumé

Afin d'examiner si le focus attentionnel peut se diviser entre deux localisations contiguës, Wright et Richards (2003) ont utilisé une présentation è plusieurs indices et ont trouvé un effet de validité pour chacun des multiples indices. Cependant, ils ont rejeté l'explication des foci multiples en affirmant que leur effet des indices multiples était guidé par le stimulus. Nous doutons que leurs indices étaient exogènes puisque leur cible pouvait apparaître è n'importe laquelle d'une des huit localisations, mais la validité était fixée è 50%. Dans ce cas, l'indice était donc prédictif de la localisation de la cible. Dans la présente étude, nous avons montré que lorsque l'indice est réellement non-prédictif (12,5 %), l'effet des indices multiples est éliminé (Expérience 2). Nous avons répliqué l'effet des indices multiples lorsque la validité était de 50%, comme dans Wright et Richards (Expérience 1), et avons démontré qu'il existe un effet d'orientation attentionnelle engendré par l'indice, mais pas de bénéfice pour la recherche visuelle lorsque l'indice demeure sur la présentation cible (Expérience 3). Nos résultats soulignent ainsi le rôle possible de mécanismes de contrôle descendants dans l'effet de validité trouvé pour les présentations è indices multiples ainsi que l'importance de prendre la prédictibilité en considération lors de tests d'hypothèses dérivées des théories attentionnelles.

Mots-clés : processus descendants, processus ascendants, indiçage spatial, validité de l'indice, probabilité.

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