Short Report

Probability cueing influences miss rate and decision criterion in visual searches

Kazuya Ishibashi
Graduate School of Humanities and Sociology, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan;
e-mail: kzy.ishibashi@gmail.com

Shinichi Kita
Graduate School of Humanities, Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe 657-8501, Japan;
e-mail: kita@lit.kobe-u.ac.jp

Received 10 February 2014, in revised form 19 July 2014; published 12 August 2014

Abstract. In visual search tasks, the ratio of target-present to target-absent trials has an important effect on miss rates. The low prevalence effect indicates that we are more likely to miss a target when it occurs rarely rather than frequently. In this study, we examined whether probability cueing modulates the miss rate and the observer’s criterion. The results indicated that probability cueing affects miss rates, the average observer’s criterion, and reaction time for target-absent trials. These results clearly demonstrate that probability cueing modulates two parameters (i.e., the decision criterion and the quitting threshold) and produces a low prevalence effect. Taken together, the current study and previous studies suggest that the miss rate is not just affected by global prevalence; it is also affected by probability cueing.

Keywords: visual search, low prevalence effect, probability cueing.

1 Introduction

In our everyday lives, we sometimes fail to find a target. We are more likely to miss a target when it occurs rarely rather than frequently, such as in airport security searches (Wolfe, Brunelli, Rubinstein, & Horowitz, 2013; Wolfe, Horowitz, & Kenner, 2005; Wolfe et al., 2007) or medical screening tasks (Evans, Birdwel, & Wolfe, 2013; Evans, Tambouret, Evered, Wilbur, & Wolfe, 2011). This phenomenon is known as the “low prevalence effect” (Gur et al., 2004). A recent study has demonstrated that the low prevalence effect can also occur in haptic searches (Ishibashi, Watanabe, Takaoka, Watanabe, & Kita, 2012b). These previous studies show that the low prevalence effect is very robust in everyday search tasks.

In addition to modulating miss rates, target prevalence alters reaction times (RTs) in target-absent trials and the observer’s criterion (Rich et al., 2008; Wolfe & Van Wert, 2010). RTs for target-absent trials decline as target prevalence declines. Moreover, observers may decide to be conservative and say “no” more often when target prevalence is low. On the other hand, sensitivity and RTs for target-present trials do not vary with target prevalence. In accordance with previous findings, Wolfe and Van Wert (2010) suggest that target prevalence influences two parameters, the decision criterion and the quitting threshold. The decision criterion governs the series of perceptual decisions about individual items, and the quitting threshold governs RTs for target-absent trials. Wolfe and Van Wert (2010) argue that both of these would influence miss rates.

Lau and Huang (2010) investigated the low prevalence effect further. They showed that the low prevalence effect is caused by the global prevalence of the target and that it is not affected by probability cueing. In their study, observers were told that one background color meant low prevalence (10%) of a target, whereas another color meant high prevalence (50%). The global prevalence was 30%. Although RTs for target-absent trials were influenced by probability cueing, miss rates were not (see Ishibashi, Kita, & Wolfe, 2012a).

In the present study, we examined two additional questions about the effect of probability cueing on visual search. The first question is whether probability cueing modulates the observer’s criterion. A previous study suggests that target prevalence influences two parameters: the decision criterion and the quitting threshold (Wolfe & Van Wert, 2010). Although some studies have demonstrated that
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probability cueing affects RTs for target-absent trials (i.e., the quitting threshold) (Ishibashi et al., 2012a; Lau & Huang, 2010), it is still unclear whether probability cueing affects the observer’s decision criterion. Second, we investigated whether the miss rate is completely unrelated to probability cueing. Previous studies of the effect of probability cueing on miss rates have used 6%–10% (or greater) target prevalence conditions (Ishibashi et al., 2012a; Lau & Huang, 2010). However, recent studies showed that extremely low target prevalence has a stronger effect on miss rates than does moderately low target prevalence (e.g., Mitroff & Biggs, 2014). For example, Wolfe et al. (2005) showed that a target prevalence of 50% produced 7% misses, 10% target prevalence produced 16% misses, and the miss rate soared to 30% at 1% target prevalence. It may be that probability cueing only influences miss rates at extremely low prevalence rates (i.e., less than 5% target prevalence). We addressed these questions in this study.

Figure 1 shows the procedures for this study. Observers pressed one key for target present and another for target absent as quickly and accurately as possible. They received accurate feedback after each trial. Fixation cues (50% cue or extreme cue) appeared for each trial, informing the observer about the prevalence of a target on that trial. The cues were presented randomly for each trial. In each experiment, target prevalence was 50% when the 50% cue appeared. We did not inform the observers of the target prevalence across trials. Thus, we treated the first 100 trials as practice trials to allow the observers to learn the target prevalence. In Experiment 1, we tried to replicate the results of Ishibashi et al. (2012a) and examined whether probability cueing modulates the observer’s criterion. In Experiment 1a, target prevalence was 6% when the extreme cue appeared and the global prevalence was 20%. In Experiment 1b, target prevalence was 94% when the extreme cue appeared and the global prevalence was 80%. In Experiment 2, we investigated whether miss rates are modulated by probability cueing with extremely low prevalence. In Experiment 2, target prevalence was 3% when the extreme cue appeared and the global prevalence was 18%.

2 Experiment 1

2.1 Prevalence effect
First, we checked whether the error rates were modulated by probability cueing. In Experiment 1a, miss and false alarm rates in the 6% prevalence condition (miss: 18%, false alarm: 0.4%) did not differ significantly from those in the 50% prevalence condition (miss: 14%, false alarm: 1%) \( t(17) = 1.31, p = 0.21 \) for miss; \( t(17) = 1.34, p = 0.20 \) for false alarm. In Experiment 1b, miss and false alarm rates in the 94% prevalence condition (miss: 4%, false alarm: 5%) did not differ significantly from those in the 50% prevalence condition (miss: 5%, false alarm: 5%) \( t(17) = 0.86, p = 0.40 \) for miss; \( t(17) = 0.12, p = 0.90 \) for false alarm. As reported in the previous studies, we did not find any effect of probability cueing on error rates.

2.2 Other effects
Second, we tested whether probability cueing modulated RTs for target-absent trials and the observer’s decision criterion. In Experiment 1a, RT in the target-absent trials and the decision criterion in the 6% prevalence condition (RT: 1645 ms, criterion: 0.76) were slightly different from those in the 50% prevalence condition (RT: 1690 ms, criterion: 0.45) \( t(17) = 1.72, p = 0.10 \) for RT; \( t(17) = 5.10, p < 0.01 \) for criterion. In Experiment 1b, RT in the target-absent trials and the criterion in the 94%
prevalence condition (RT: 2879 ms; criterion: 2.08) were slightly different from those in the 50% prevalence condition (RT: 2773 ms; criterion: 2.01) \( t(17) = 5.22, p < 0.01 \) for RT and \( t(17) = 2.14, p = 0.05 \) for criterion. These results clearly indicate that probability cueing modulates two parameters (i.e., the decision criterion and the quitting threshold).

In Experiment 1a, RT for target-present trials and sensitivity \( (d') \) in the 6% prevalence condition (RT: 1279 ms; criterion: 3.52) were slightly different from those in the 50% prevalence condition (RT: 1386 ms; \( d' \): 3.28) \( t(17) = 1.91, p = 0.07 \) for RT and \( t(17) = 2.62, p = 0.02 \) for \( d' \). In Experiment 1b, RT for target-present trials (1428 ms) and sensitivity (3.30) in the 94% prevalence condition (RT: 1428 ms; criterion: 3.30) did not differ significantly from those in the 50% prevalence condition (RT: 1407 ms; \( d' \): 3.41) \( t(17) = 0.63, p = 0.53 \) for RT and \( t(17) = 1.11, p = 0.28 \) for \( d' \).

### 3 Experiment 2

In Experiment 1, we replicated the results of Ishibashi et al. (2012a). We found that probability cueing modulates RTs for target-absent trials (i.e., the quitting threshold) and the observer’s criterion (i.e., the decision criterion). In Experiment 2, we investigated whether the miss rates were modulated by probability cueing with extremely low prevalence.

#### 3.1 Prevalence effect

We checked whether the error rates were modulated by probability cueing with extremely low prevalence (Figure 2a). The miss rate in the 3% prevalence trials was 35%, whereas it was 20% in the 50% prevalence trials \( t(19) = 4.37, p < 0.01 \). Moreover, the false alarm rates increased from an average of 0.3% in the 3% prevalence condition to 1% in the 50% prevalence condition \( t(19) = 2.26, p = 0.04 \). This shows that the error rates were modulated by probability cueing with extremely low prevalence.

#### 3.2 Other effects

RTs in the target-absent trials in the 3% prevalence condition (1456 ms) were significantly different from those in the 50% prevalence condition (1825 ms) \( t(19) = 4.98, p < 0.01 \) (Figure 2b). The criterion in the 3% trials was 1.14, whereas it was 0.65 in the 50% prevalence trials (Figure 2c). These results clearly indicate that probability cueing modulates two parameters (i.e., the decision criterion and the quitting threshold). As reported in the previous studies, RTs for target-present trials and sensitivity did not differ significantly between the 3% (RT: 1565 ms; \( d' \): 3.17) and 50% (RT: 1490 ms; \( d' \): 3.19) prevalence conditions \( t(19) = 0.95, p = 0.35 \) for RT and \( t(19) = 0.14, p = 0.89 \) for \( d' \).

#### 3.3 Time course of the probability cueing effect

A previous study (Hon, Yap, & Jabar, 2013) has shown that the time course of the target probability effect is different for each target probability. To determine when observers begin to use the information available in probability cueing, we analyzed the time course of the probability cueing effect on miss rates, RTs for target-absent trials, and the decision criterion (Figure 3). We separated 600 trials into three bins, each with 200 trials. We conducted a 2 (prevalence) \( \times \) 3 (bins) ANOVA and found a significant main effect of prevalence on miss rates \( F(1, 19) = 21.79, p < 0.01 \), RTs for target-absent trials \( F(1, 19) = 29.39, p < 0.01 \) and criterion \( F(1, 19) = 189.34, p < 0.01 \). In addition, we found a significant main effect of bins on RTs for target-absent trials \( F(2, 38) = 10.06, p < 0.01 \). However,
there was no significant main effect of bins on miss rates ($F(2, 38) = 1.34, p = 0.28$) and criterion ($F(2, 38) = 0.74, p = 0.49$). There was no significant interaction between prevalence and bins ($F(2, 38) = 0.20, p = 0.82$ for miss rates; $F(2, 38) = 0.33, p = 0.72$ for RTs; $F(2, 38) = 0.13, p = 0.88$ for criterion). These results show that observers were able to learn the probabilities associated with the cues and quickly use that information (within 200 trials).

4 Discussion

In the present study, we examined two further questions about the effect of probability cueing on visual search. The first question was whether probability cueing modulates the observer’s decision criterion. Previous studies showed that probability cueing affects RTs in target-absent trials (i.e., the quitting threshold) (Ishibashi et al., 2012a; Lau & Huang, 2010). However, it was still unclear whether probability cueing affected the observer’s decision criterion. In this study, we found a probability cueing effect on RTs in target-absent trials and the average observer’s criterion. The results of this study clearly show that probability cueing not only modulates the RTs in target-absent trials (i.e., the quitting threshold), but also influences the observer’s decision criterion. It may be that observers can use the information inherent in probability cueing to set their quitting threshold and the decision criterion.

Second, we asked whether the miss rate is completely unrelated to probability cueing. We found a strong effect of probability cueing on miss and false alarm rates at extremely low prevalence rates (i.e., less than 5% target prevalence). Moreover, we found that observers could begin to use the information provided by probability cueing quickly. These results indicated that miss rates were quickly modulated by probability cueing with extremely low target prevalence. Previous studies have shown that extremely low target prevalence has a stronger effect on miss rates than does moderately low target prevalence (e.g., Mitroff & Biggs, 2014; Wolfe et al., 2005). It may be that extremely low target prevalence produces stronger target prevalence learning than does moderately low target prevalence. However, it is still unclear how much experience is required to learn the cue validity and when observers start to use this information. Further studies are needed to resolve these questions.

Taken together, the previous studies (Ishibashi et al., 2012a; Lau & Huang, 2010) and the current study suggest that probability cueing modulates not only the quitting threshold but also the decision criterion. Moreover, this study suggests that the miss rate is not only affected by global prevalence but also by probability cueing.

5 Methods

5.1 Observers

Twenty people (aged 19–24 years, mean age = 21.6 years, SD = 1.6 years; 8 women and 12 men) participated in Experiment 1. Another twenty people (aged 19–27 years, mean age = 21.9 years, SD = 2.0 years; 6 women and 14 men) participated in Experiment 2. According to self-report data, they had no history of eye or muscle disorders. None of the observers was color blind (Ishihara plates) and none had a visual acuity worse than 20/25 with correction. Informed consent was obtained from all observers and each observer was paid 1,000 yen/hour for their time.
5.2 Visual search task

Figure 1 shows the procedures for this experiment. We used a conjunction search task (with half the distractors sharing the shape but not the color of the target, and half sharing the color but not the shape). Throughout the experiment, we used a single set size of 24 items. Items were placed in slightly irregular $6 \times 4$ arrays. Target-present trials had only one target, and the positions of targets and distractors were randomized. Stimuli were presented on a white background (77.5 cd/m²). Observers searched for targets defined by a conjunction of color and form. Stimuli were colored circles and squares (red, green or blue), and color luminance was equal across the three colors (12.0 cd/m²). The squares subtended 3.3° by 3.3° of visual angle and the diameter of the circles subtended in 3.3° of visual angle. In target-present trials only one target appeared. In some target-present trials the target was a blue square or a green circle and the distractors were blue circles and green squares. In other target-present trials the target was a green square or a red circle and the distractors were green circles and red squares. In target-absent trials, there were no targets. Target items were randomly selected across trials.

5.3 Procedure

In each trial, a fixation cue was presented for 1,000 ms, followed by a stimulus, which was presented until the observer responded. Observers pressed one key for target-present and another for target-absent as quickly and accurately as possible. They received accurate feedback after each trial. Observers were given 50 practice trials at 50% prevalence before each experiment, and they were allowed to take a break after every 50 trials. In this experiment, a fixation cues was presented on each trial to inform the observer about the prevalence of a target on that trial. Experiment 1 consisted of two conditions, the order of which was randomized for each observer. In Experiment 1, there were 96 “50% cue” trials and 204 “extreme cue” trials. The fixation cue was randomly chosen for each. In each experiment, the likelihood of a target was 50% when the 50% cue appeared. In Experiment 1a, the likelihood of a target was 6% when the extreme cue appeared and the global prevalence was 20%. In Experiment 1b, the likelihood of a target was 94% when the extreme cue appeared and the global prevalence was 80%. In Experiment 2, there were 192 “50% cue” trials and 408 “extreme cue” trials. The likelihood of a target was 50% when the 50% cue appeared and 3% when the extreme cue appeared. The global prevalence was 18%. Because we did not inform the observers of target prevalence, we treated the first 100 trials as practice trials to allow them to learn the target prevalence.

5.4 Data analysis

Only correct response trials were analyzed for RTs. RTs over 10,000 ms and under 200 ms were excluded from analysis. In Experiment 1, two observers committed 100 outliers, so we removed their data from the analysis.

Acknowledgments. This research was supported by grants from MEXT #22300091. The authors are deeply grateful to Mao Okada and Tatsuya Nishimura for their help in conducting the experiments.

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