Title
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Don't Blink!
Evaluating Training Paradigms for Overcoming the Attentional Blink

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Abstract

A lot of people show a decline in performance when they have to report a second target stimulus in a stream of distractor stimuli. Curiously, this decline only happens when the second target appears approximately 200-500ms after the first target. Recently, Choi, Chang, Shibata, Sasaki, and Watanabe (2012) have shown that a short, one-hour training can eliminate this "attentional blink". Up to now, it is still unclear why this training works. In this paper, we have evaluated a range of different training paradigms to test several hypotheses about the mechanism behind the reduction of the attentional blink. Our results show that none of these training paradigms have a large training effect when administered in isolation. The training by Choi et al. (2012) outperforms them all. The most likely explanation for this effect are temporal expectations relative to the first target.

Keywords: Attentional Blink, Training, Strategy Choice, Temporal Expectations

Introduction

The attentional blink is a deficit in reporting a second target stimulus in a rapid stream of visual stimuli, first reported by Raymond, Shapiro, and Arnell (1992). When a stream of visual stimuli is shown at a rate of approximately 10 items per second (see Figure 1), it is easy to spot one divergent, or target, stimulus. However, when a second target stimulus is presented after the first target, people often do not report this second target. The second target can be presented at different distances, or lags, from the first target (T1). The distance between two targets influences the difficulty with which the second target (T2) is reported. When the lag is between two and five stimuli, accuracy of reporting the second target is considerably reduced.

For a long time, the attentional blink has been thought of as a robust effect that stems from a structural limitation, which cannot be trained away by practice. Therefore it was remarkable when Choi et al. (2012) reported a training paradigm that significantly reduced the attentional blink. This training paradigm is very similar to the original task. In this training, the second target in a stream was made more salient by giving it a red color. In addition, during training the second target was always presented as the second item from the first target (lag 2), but during the pre- and posttest other lags were present as well. After training on this paradigm for only an hour, the attentional blink was almost eliminated and this effect lasted for several months.

Choi et al. (2012) concluded that the results after the colored-target training are due to an increase in temporal resolution: the ability to distinguish between the presented stimuli, which could be the result of top-down attentional processes and bottom-up perceptual processes. From these two hypotheses, Choi et al. (2012) favored a more top-down explanation. We will look at both aspects more closely, using two different experimental conditions.

In this paper, we investigate the mechanisms behind the succes of colored-target training by Choi et al. (2012). To this end, we conducted an experiment with 125 participants, that a) replicates Choi's colored-target training, and b) tests four possible explanations of the training effect. The four explanations that we test are speed of processing, a change in strategy, the implicit use of feedback, or temporal expectations relative to the start of the stream. Before we introduce the experiment, we will first discuss those explanations in more detail.

Processing Speed

A possible explanation for an increase in temporal resolution is a bottom-up increase in perceptual processing speed. To test this, we have trained people to perceive target stimuli faster. We have used a task that was developed by Choi et al. (2012), called the *letter-mask task*. In this task, a letter is presented, followed by a mask. The letter has to be reported as quickly as possible. Presentation time of the letter is constantly updated to represent the accuracy of the participant, i.e. reduced when accuracy increased and vice versa. Choi et al. (2012) found that people improved on this task after the colored-target training.

Because the tasks adapts itself to the level of the participant by modifying the presentation time of the letter, it would be very suitable as a training task as well. We hypothesized that after training on the letter-mask task, discrimination of stimuli in the attentional blink task would be increased, resulting in a similar effect as the colored-target training.

Additionally, if speed of processing is indeed the relevant training aspect in the letter-mask task, we would expect to find no effect when the presentation time of the letter is kept constant. Therefore we also use a letter-mask training with a constant presentation time of 100ms.

Strategy

The second interpretation of temporal resolution is as a top-down process. By using a different cognitive strategy, top-down control can reduce the attentional blink.

Evidence that strategy may play a role in the attentional blink comes from earlier studies that have shown that the attentional blink can be reduced by forcing people to approach the task in a different manner. For example, several studies have shown that a second task, increases performance on the attentional blink task (Olivers & Nieuwenhuis, 2005; Taatgen, Juvina, Schipper, Borst, & Martens, 2009). This could indicate that a disruption of the general strategy people use for the attentional blink actually improves performance.

A study by Ferlazzo, Lucido, Di Nocera, Fagioli, and Sdoia (2007) showed that the attentional blink is significantly reduced when people are instructed to report the two targets as one entity: instead of reporting two letters, they were asked to report a syllable. This shows that the attentional blink is not only caused by low-level attentional and visual processes, but that top-down strategies play a role as well.

To test whether the colored-target task induces a similar strategy change, we have used a training paradigm similar to the tasks used in Ferlazzo et al. (2007). Instead of having to report each target separately, participants had to combine both targets into one entity. In this training task, two digits have to be identified in a stream, the combination of digits had to be reported as a word. For example, the digits 5 and 9 had to be reported as the word fifty-nine. We therefore refer to this task as the *number-word task*.

Feedback

In addition to the explanations for the temporal resolution hypothesis, as posed by Choi et al. (2012), we hypothesized that implicit feedback in the colored-target task may play a role in the reduction of the blink, perhaps by affecting the strategy particpants used. An important aspect of the colored-target task (Choi et al., 2012) is that the second target always appears at the same lag, lag 2. Combined with the salient color, this makes a second target very hard to miss. This setup ensures that a participant knows that something was missed if only one target was perceived. To test the role of feedback in the reduction of the blink, we used a training task in which explicit feedback was given to the participant.

Temporal Expectations

Finally, we also looked at the temporal expectation hypothesis. This hypothesis was put forward by Tang, Badcock, and Visser (2014). They found that varying the number of distractors before T1 in the pre- and posttest, or the number of distractors between T1 and T2 (the lags) in the training reduced the effect of the colored target training. They suggest that the colored-target training paradigm merely shows that strong expectations about timing can ameliorate the attentional blink indirectly, but cannot eliminate the structural limitations. In addition, Willems, Damsma, Wierda, Taatgen, and Martens (2015) found that in their study the colored target was not necessary for reducing the attentional blink, but training on a single lag was. In both interpretations temporal expectations are a stimulus driven process that arises from the fixed temporal locations of the targets during training.

Temporal expectations may exist from the first stimulus of the processing stream, or the expectation may be relative to

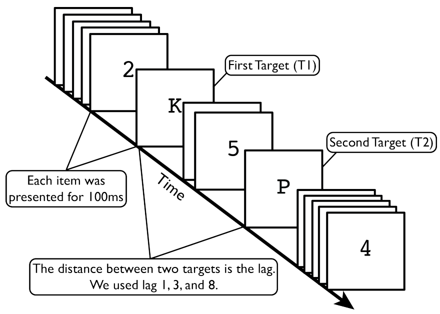

Figure 1: The attentional blink task used in the pretest, the posttest and the control condition.

the first target. We will focus on the first interpretation of temporal expectations: expectations from the start of the stimulus stream. To test this, the first target in the stream of the pre- and posttest can have three different positions in the stream: item 3, item 5, or item 7. If the temporal expectations created by the colored-target training are indeed relative to the beginning of the stream, we expect to find a larger effect of training for position five, the position that was used in the training.

The Current Experiment

To test these hypotheses, we designed an experiment with different training conditions, but an identical pre- and posttest. The pre- and posttest consist of the standard attentional blink task (see Figure 1). However, to test for temporal expectations from the beginning of the stream, we manipulated the position of T1, so it could appear as either the third, the fifth or the seventh item in the stream. The training conditions we used were a control condition, identical to the pre- and posttest, the colored-target condition, to replicate the effect found by Choi et al. (2012), and the four training manipulations mentioned above: letter-mask, letter-mask 100ms, feedback, and number-word.

Methods

All participants performed three tasks in the experiment:the pretest, a training, and the posttest. The pre- and posttest consist of the RSVP task commonly used in attentional blink experiments. The training task could be one of six tasks, all of which are described in the Tasks section.

Participants

In total 125 people participated in the experiment, 25 participants per training condition. Overall, the mean age was 21.84 (SD: 2.67), 85 of the participants were female. All participants had normal or corrected-to-normal visual acuity. Written informed consent was obtained prior to the experiment. No participants were excluded.

Apparatus and Stimuli

All tasks were presented using the software package E-Prime (Schneider, Eschman, & Zuccolotto, 2002), version 2.0.10.

The stimuli were black on a white background in a bold 12-point Courier New font and consisted of consonants, excluding the "Q", "V", and "Y", and digits, excluding "0" and "1". Viewing distance was approximately 60 cm.

Tasks

The participants did two different tasks in three parts: the attentional blink task in the pre- and posttest and the training task in the training. The training task was different in every condition. In the control condition, participants performed the same task in the training as in the pre- and posttest. The other conditions consisted of the letter-mask task, a variation of the letter-mask task, the attentional blink task with feedback, the colored-target task, and the number-word task.

The Attentional Blink Task The attentional blink task was used in pre- and posttest, and as a training for the control group. This task required the identification of two letter targets amongst a stream of rapidly presented digit distractors. Each item was presented for 100ms. The first target (T1) was presented as either the third, the fifth, or the seventh item in the stream, with an equal number of trials in each group. The second target appeared either immediately following T1 (lag 1), as the third item following T1 (lag 3), or as the eighth item following T1 (lag 8). As mentioned in the introduction, an attentional blink is likely to occur at lag 3 (300ms after T1 onset) and unlikely to occur at lag 1 (100ms after T1) or lag 8 (800ms after T1). Targets were chosen at random from the set of letter stimuli, with the constraint that no letters were repeated within a trial and distractors were randomly chosen from the set of digits such that two successive digits were never identical. No feedback was given.

The Attentional Blink Task with Feedback The attentional blink task with feedback is the same task as the attentional blink task, but feedback is given at the end of each trial. The feedback consists of a number of points per correctly reported target. The participant could obtain 5 points per target, so that a maximum of 10 points per trial could be reached.

The Letter-Mask task The LM task required the identification of only one letter, the target, which was initially presented for 70ms, and followed by a mask: the pound sign #. The target was chosen at random from the set of letter stimuli. To ensure that the task was equally difficult for all participants, the duration of the target was updated on every fourth trial, depending on the accuracy of the participant. If the accuracy was lower than 75%, 3ms were added to the target duration. When the accuracy was above 80%, 3ms were subtracted from the target duration.

The Letter-Mask 100ms task The letter-mask 100ms task is similar to the letter-mask task. The only difference is the presentation time of the stimuli. In the letter-mask 100ms task, every letter was presented for 100ms, the same presentation duration as the stimuli in the attentional blink task. The mask was always presented for 100ms.

The Colored-Target Task The Colored-Target task is based on the training task used by Choi et al. (2012). This is similar to the attentional blink task, but the second target is given a salient red color, and the distribution of the lags is different. In the colored-target task only lag 3 is used.

The Number-Word Task In the number-word task participants are presented with two digits, each for 100ms and followed by a mask (#). The task was to identify the two-digit number that those two digits form. The answer had to be selected from four options and was always the two digit number in words. For example, if the two digits are 5 and 9, the correct answer would be fifty-nine. The other three answer options would always be: first digit and a randomly digit, a randomly selected digit and the second digit, and the two randomly chosen digits used in the previous answers. Answers were presented in a random order. The response had to be given by selecting answer a, b, c, or d, and pressing the corresponding key on the keyboard. Feedback was given in the form of text and points.

Procedure and Design

The experiment was composed of three parts, a pretest in which people performed the attentional blink task, a training in which people practiced on either the letter-mask task, the letter-mask 100ms task, the feedback task, the colored-target task, the number-word task or the control task (the attentional blink task). It ended with a posttest that was identical to the pretest. Before the pretest, a short practice block was given. See Figure 1 for the procedure of the standard attentional blink task. The pretest started with a practice block that was followed by four experimental blocks of 90 trials each. The practice block consisted of 9 trials, one trial for each combination of T1 position (3, 5, or 7) and lag (1, 3, or 8). All experimental blocks contained 90 trials, 10 trials for each combination of jitter and lag. Within blocks the lags were chosen at random.

Prior to each pretest trial, a fixation cross was shown in the middle of the screen, participants were asked to start the trial by pressing space bar. After pressing space bar, the fixation cross stayed on the screen for a duration of 1000ms, followed by a blank screen. After 100ms a stream consisting of 22 stimuli appeared in the center of the screen. Each stimulus was presented for 100ms without inter stimulus interval. After each stream participants were asked to report two letters, by pressing the corresponding keys on the keyboard. They were instructed to press space bar whenever they did not see a target. Although they were encouraged to enter the targets in the order of presentation, responses were counted correct in either order. Participants did not get feedback on their performance.

The training part of the experiment also started with a practice block, followed by four experimental blocks. The practice block consisted of 9 trials, while each of the experimental blocks was 126 trials.

As in the pretest, each trial started with a fixation cross in

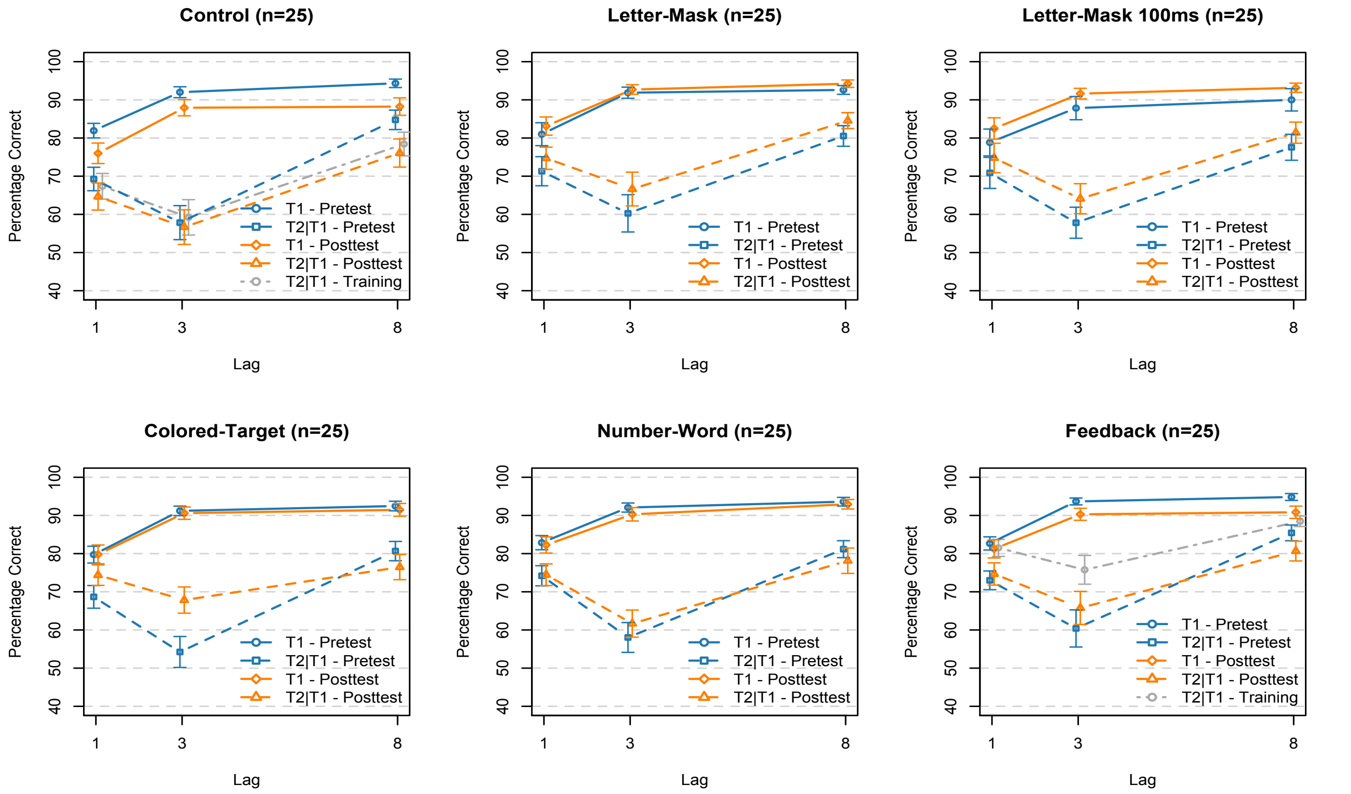

Figure 2: Blink sizes in pre- and posttest for all training conditions and T1 positions. Blue lines show the results for the pretest, while orange lines depict the results for the posttest. Dashed lines are $T2|T1$ results. For the control condition and the feedback condition, mean T2 accuracy during training is shown as a dotted gray line. Error bars depict standard errors.

the middle of the screen. After the fixation cross, either the stimuli stream or the target letter appeared on the screen. Afterwards, participants had to enter the key(s) corresponding to the target. In the letter-mask task, one response had to be given, and participants were instructed to do this as fast as possible. In the number-word task, the response had to be given in the form of a multiple-choice question. In the letter-mask task, the letter-mask 100ms task, the number-word task and the feedback task feedback was given in the form of points: 5 points were awarded for every correct response. The posttest was identical to the pretest, except the practice block. The experiment took approximately two hours to complete.

Results

Results are shown in Figure 2. When applicable, T2 accuracy during training is shown as a gray line. In all training conditions, an attentional blink is present in the pretest (blue lines): performance on T2 is lower on lag 3 than on lag 1 and 8. There seems to be a small reduction in blink size for most training conditions in the posttest (orange lines), and a larger reduction for the colored-target condition.

To establish whether each training regime differs from the control condition, linear mixed effect models (R package lme4) with the dependent factor blink size were fitted on the data, and the independent factors Part (pretest and posttest) and Training (control and the training of interest). The letter-mask and letter-mask 100ms condition are combined in one model, as they test the same question: the processing speed hypothesis. T2 accuracy was only calculated when T1 was correct, this is denoted as $T2|T1$. Blink size is calculated by subtracting the mean $T2|T1$ accuracy on lag 3 from the mean $T2|T1$ accuracy on lag 1 and 8. We used likelihood ratio tests to test for each factor, comparing the full model to the model with that factor removed.

As shown in Table 1, there is a significant effect of Part in all models: the blink is larger in the pretest than in the posttest. However, the colored-target training is the only training condition that shows a decrease in blink size compared to the control condition.

To test whether the temporal expectation hypothesis uses implicit time estimation from the start of the stimulus stream, we have tested the effect of T1 position on the difference in blink size between pre- and posttest for the colored-target and control condition, see Figure 3. The model includes the random factor Subject, and fixed factors Part (pre- and posttest), T1 position (3, 5, and 7), and Training (control and colored-target).

There is a significant effect of Part ($\chi^2(6) = 64.38, p < .01$)

Table 1: Results of the linear mixed-effect models for the decrease in blink size by training, compared to the control condition.

Training	χ^2	Difference in Df	*p*-value
Colored-target			
Part	60.20	2	$< .01$
Training	16.71	2	$< .01$
Part x Training	16.37	1	$< .01$
Feedback			
Part	23.82	2	$< .01$
Training	2.66	2	$> .1$
Part x Training	2.57	1	$> .1$
Letter-Mask & Letter-Mask 100ms			
Part	12.49	3	$< .01$
Training	.61	4	$> .1$
Part x Training	0.10	2	$> .1$
Number-Word			
Part	16.05	2	$< .01$
Training	1.08	2	$> .1$
Part x Training	1.05	1	$> .1$

and of Training ($\chi^2(6) = 18.82, p < .01$). The main effect of T1 position is significant ($\chi^2(8) = 16.29, p = .04$). There is only one interaction effect, between Training and Part ($\chi^2(3) = 17.54, p < .01$). This means that we replicate the effect found in Choi et al. (2012), the colored-training greatly reduces the attentional blink. However, this effect does not seem to be mediated by the position of T1.

Post-hoc testing revealed that the later T1 was presented, the more participants thought to see non-existing targets before T1, so called 'ghost targets'. We tested for these ghost targets by looking at pretest responses where T1 was reported as T2 and T2 was incorrect These ghost-targets were reported more for position 5 than for position 3 ($\beta = -.4, SE = .07, z = -5.66$), and more for position 7 than for position 5 ($\beta = .3, SE = .06, z = 5.30$).

Discussion

First of all, we replicated the results by Choi et al. (2012). After training on the colored-target task, the blink is significantly reduced as compared to the control condition. We have tested several explanation for this phenomenon. Each explanation will be discussed below.

Processing Speed

We tested whether the reduction of the attentional blink could be explained by a speed up in target processing by training participants on the letter-mask task with an adaptive presentation time and the letter-mask task with a constant 100ms presentation time. Training on these tasks did not reduce the blink size, as compared to the control condition. This indicates that the effect of processing speed is either very small, or nonexistent and cannot explain the effect of the colored-target training.

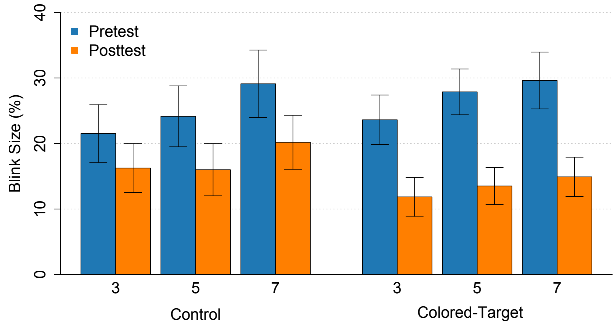

Figure 3: The influence of T1 position on blink size.

Strategy

Our next training condition, the number-word task, tested the influence of a strategy change. Training on the number-word task also did not reduce the attentional blink. Of course, strategy change is very broad, and it is impossible to test all strategies. We can therefore not exclude an influence of strategy in the colored-target training. However, it is clear that this training did not improve the attentional blink in the same way as the colored-target training. There are at least two possible explanations for this. Either the strategy used in the number-word task is too similar to the strategy used in the standard attentional-blink task, or the superficial properties of the task are too different from the attentional blink task. The more dissimilar a training task is, the more training is needed to generalize strategies from that task (Taatgen, 2013). In that case, a one hour training might be too short to find an effect of strategy in this task.

Feedback

Because of the implicit feedback given in Choi et al. (2012), we hypothesized that this feedback might play a role in reducing the attentional blink. We found that feedback during training did not improve performance on the posttest. However, feedback did improve performance during the training task (see the gray lines in Figure 2). This result was surprising, because it is generally assumed that feedback does not influence performance on the attentional blink task (e.g. Martens, Wolters, & van Raamsdonk, 2002). However, the effect of feedback is not a lasting effect. When the feedback is not given anymore, the blink size is still reduced, but this did not differ from the control condition.

Temporal Expectations

We have also tested whether temporal expectations from the start of the stimulus stream influence the decrease in blink size after training. We found that our manipulation of T1 position only marginally impacted performance, but the effect was robust. It was present in all training conditions. A later T1 position was associated with a larger blink size in the pretest, as well as in the posttest. However, the effect of T1 position does not mediate the effect of training.

The temporal expectation hypothesis was first posited by Tang et al. (2014). They did find an influence of T1 position on the effect of training. When T1 position was varied in pre- and posttest, but not in training, the attentional blink became smaller but was not eliminated.

One difference between their study and our study is the different T1 positions that were used. Whereas we used positions 3, 5, and 7, Tang et al. (2014) used positions 2 to 5. However, they did not look at the influence of T1 position in more detail. We can therefore not directly compare the results found in the current study to the results of Tang et al. (2014).

Although we did not find an effect of temporal expectation on the size of the blink in this experiment, we did find an effect of T1 position on the blink size in general. One possible explanation for this effect could be 'ghost-targets', distractor stimuli that are interpreted as target stimuli. Many of our participants noted that they often saw more than two targets in the stream. Since they could only report two targets in every trial, they may have reported the ghost target instead of the real target. In trials where T1 is presented at a later position, there is a larger possibility of these ghost targets appearing before the real targets, thus increasing the blink.

That we did not find an effect of T1 position does not mean that temporal expectations do not play a role in the colored target training. In the current experiment we have only tested one possible expectation: the time between T2 and the start of the stream. Temporal expectations can also play a role between T1 and T2. Tang et al. (2014) have looked at this by manipulating the training session. When the colored-target training incorporated multiple lags, instead of only one short lag, the effect of training was diminished. Similarly, Willems et al. (2015) found that training the key manipulation in the colored-target training was the single training lag, as opposed to the color of the second target. Taken together, these results indicate that temporal expectations probably play a role in the colored-target training, but that these expectations are relative to the first target and not relative to the start of the stimulus stream. Furthermore, we have shown here that blink size can depend on the position of the first target of the stimulus stream. The later this target is presented, the bigger the blink is. A possible explanation for this effect is that a participant sees 'ghost-targets', while no target is present.

Conclusion

All training manipulations of strategy, feedback, letter-mask, and number-word, give similar results: there is a small increase in T2 accuracy after training, but this increase does not differ from the control condition, while the colored-target training does result in a significantly reduced attentional blink. These results either indicate that none of our training manipulation seem to be a factor in the training-induced reduction of the attentional blink, or the influence of strategy is too small to be distinguished in our sample. Either explanation means that we should look into other explanations for the colored-target training effect.

The most likely candidate for the explanation of the training effect of the colored-target training is the temporal expectation hypothesis (Tang et al., 2014; Willems et al., 2015). However, as opposed to what is expected based on research in time estimation (e.g. Taatgen & van Rijn, 2011), these expectations are not relative to the first stimulus on the screen, but relative to the first task-relevant stimulus on the screen.

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