The Effects of Reading Speed on Visual Search Task

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Abstract

Speed reading training enhances one's reading speed. Typically, those who train using the Park-Sasaki training method can read all the characters sequentially with the reading speed of over 10,000 characters per minute (about over 4,000 words per minute in English sentences). It means that they take in a huge amount of information during speed reading. Our study investigated the training effect on visual perception and attention using a visual search task and revealed that speed reading changes the performance of a visual search task. In the conjunction task, compared with novices, the slope of response times for experts as a function of set size was shallow, which suggests that experts watch a wider area than do novices, or that experts conduct a parallel search, at least in part. The measurements of eye movements during the experiments support this explanation; experts could respond with fewer episodes of fixation than could novices. As we used a simple non-letter-based feature as the stimulus, the results suggest that training improves general ability to process visual stimuli, regardless of language. We think that speed reading training improves attention which plays an important role in the conjunction task.

Introduction

Speed reading training enhances one's reading speed. Typically, those who train using the Park-Sasaki training method can read all the characters sequentially with the reading speed of over 10,000 characters per minute (about over 4,000 words per minute in English sentences). The trained people assert that they understand the contents of the books read at such high speed. If true, besides comprehending sentences, it means that they take in a huge amount of visual information during speed reading. That is interesting in terms of training and visual attention. To take in a huge amount of visual information, they must have a larger spotlight of attention than normal readers have, and/or they must move their spotlight of attention more quickly than normal readers do. As trained people acquire their speed reading ability by training, not by talent, this attentional change might be brought by the training. However, no study has examined the effects of speed reading training on visual attention [for a review, Carver (1990)].

The aim of this study is to verify that trained people can really take in visual information faster than normal readers can, and to investigate whether they have a larger spotlight of attention or they move it more quickly than normal readers, by using visual search task. The visual search task was introduced by Treisman and Gelade (1980), and has become a widely used measure in the study of visual perception and attention. In a speeded visual search task, subjects can look at objects (called *items*) on a screen for as long as they like, and a target that differs from uniform distractors in only one feature dimension is presented on the screen. The response time usually does not increase with the number of distractors. This is usually regarded as a reflection of spatially parallel processing (Treisman & Gelade, 1980). Treisman and Gelade (1980) argued that if a target is similar to a distractor (*e.g.*, conjunction), the response time is largely dependent on the number of distractors, which they called serial processing. Although subsequent research has shown that a conjunction search can be quite efficient in some cases (*e.g.*, Nakayama and

Silverman, 1986), there are some rules for the allocation of visual attention (Wolfe, 1998).

The set-size dependency of the response time in a visual search task changes in proportion to the amount of training (Sireteanu and Rettenbach, 1995, 2000; Leonards *et al*., 2002). However, it is not known whether the training effect is paradigm specific, as these studies used the same paradigm for both training and testing. In speed-reading training, there is no task similar to a visual search task; the readers are trained with respect to eye movements, breathing, and posture, in order to concentrate on the sentences they read. Consequently, if speed-reading training changes the performance of a visual search task, this should be owing to an improvement in some cognitive process (perhaps visual attention) that is not specific to the task.

Here, we show that speed reading changes the performance of a visual search task, that is, trained people can find a target much faster than untrained people. As we used a simple non-character-based feature as the stimulus, this suggests that the training improves one's ability, regardless of both language and the stimulus/paradigm of the visual search task.

Methods

Apparatus and stimuli

The experiment was conducted in a quiet, dimly lit room. A computer monitor (RDF173H, NEC Mitsubishi Electric Visual System) with a refresh rate of 85 Hz was positioned 50 cm in front of each subject's face and a chin-rest was used to maintain the subject's head position. In some cases, an infra-red eye tracker (EMR-NL8, NAC Image Technology) was placed just below the CRT monitor to record the subject's eye movements, at a sampling rate of 60 Hz. The stimuli were many short lines or small solid circles, called *items*, with a visual angle of about 0.55°. The luminance of the red and green solid circles was adjusted to 21.5 cd/m^2, the luminance of the short lines was 103 cd/m^2, and the background luminance was 1.93 cd/m^2. The items were presented on the CRT monitor under the control of a MATLAB (MathWorks) script with Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997) running on a Macintosh G4 (Apple Computers). An ordinary keyboard was connected to the computer to record the subjects' button presses.

We used three search tasks: a red circle among green circles (feature 'color'); a short upward line among short downward lines (feature 'orientation'); and a short upward red line among short downward red lines and short upward green lines (the conjunction of the features 'color' and 'orientation') as shown in Figure 1. The items were presented in one of three set sizes, referred to as *S*, *M*, and *L*, consisting of 49 (7 × 7), 121 (11 × 11), and 225 (15 × 15) simultaneously presented items, respectively. The items were aligned horizontally and vertically in a square grid with a visual angle of 7, 11, and 16°, respectively. The distance between items was constant across set sizes.

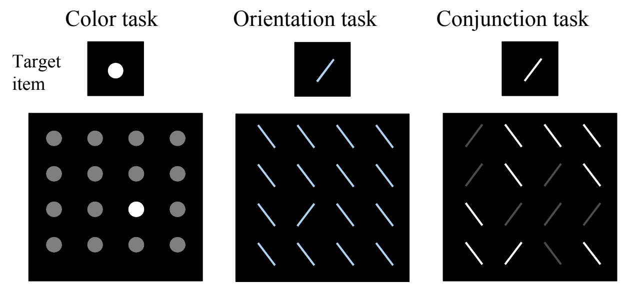

Figure 1: Stimuli used in color, orientation, and conjunction tasks. For each task, a target item was shown in upper panel, and an example of spatial configuration of a target and distractors was shown in lower panel. Gray indicates green, and white indicates red in experiment.

Subjects

Eight paid subjects (four men, four women) between 24 and 37 years of age (standard deviation: 4.8 years) participated in the experiment as novices. Another eight paid subjects (seven men, one woman) between 24 and 57 years of age (standard deviation: 12.5 years) participated in the experiment as speed-reading experts. The average self-reported reading speed of the experts was about 70,000 characters per minute (cpm) with a standard deviation of about 40,000 cpm. The average training duration was 39 months, and the standard deviation was 29 months. All had normal or corrected-to normal vision and normal hearing. They were naïve as to the purpose of the experiment. They gave informed consent, following an explanation of the experimental procedures.

Procedure

The subjects were asked to press the "L" key on the keyboard when they found a target on the screen or to press the "S" key when they found that there was no target on the screen. They were also asked to make decisions as quickly as possible without making errors. We measured the response time (RT) and ratio correct as indices of performance. The stimuli were presented at the beginning of each trial and disappeared as soon as the subjects pressed either key. Following a 1-s interval, the next trial started and new stimuli were presented. There were nine experimental conditions [3 tasks × 3 set sizes]. Each block included one experimental condition and 160 trials so that each subject experienced 1440 trials in total. In half of the trials, a target was included somewhere on the screen (the position was randomized), and in the rest of the trials, no target was presented. The order of trials was randomized. When the conjunction task was tested with set sizes S, M, and L, each block was divided into two or three sub-blocks so that the time for completion was the same as for the other blocks. The order of blocks / sub-blocks was also randomized. It took approximately 5 minutes to complete a block or a sub-block. Breaks could be taken at the subjects' request. Each subject spent one day in our laboratory to complete all the experiments. It took about three hours including breaks. Eye direction was recorded for set size L for the color and orientation tasks, and this was done with all set sizes for the conjunction task.

Data analysis

The mean RT was calculated for each experimental condition, but was separated according to whether a target was present or absent, and was then averaged within subject. The ratio correct was calculated similarly. We analysed two indices (frequency of saccades, duration of fixation) from the eye tracker data. These values were also calculated for each experimental condition and then averaged within subject.

As for analyses of eye movements, to reduce the complexity of the results and the factors that explain our results, the frequency of fixation was calculated using data from set size L, and the duration of fixation (*i.e.*, the looking time between saccades) was calculated using data from the conjunction task.

Results

Reaction time

A three-way repeated-measures analysis of variance (ANOVA) was conducted with the factors target, set size, and subject group for each task.

Figure 2 shows the RT as a function of set size for novices and experts for the color task. Almost all the lines overlap and the slopes are essentially flat on this time scale. A repeated-measures ANOVA revealed main effects of target [F(1,14)=15.63, p=.001] and set size [F(2,28)=4.67, p=.018]. This means that the subjects could respond more quickly when the target was present, than when the target was absent. We also found that the RT was dependent on set size. These effects were relatively small compared to the other tasks, but were statistically significant. A main effect of group was marginally significant [F(1,14) = 4.26, p=.058]. This suggests that the RTs of the novices and experts might differ for the single-feature task. We did not find any interaction effect in this condition.

Figure 3 shows the RT as a function of set size tested for novices and experts in the orientation task. Repeated-measures ANOVA revealed main effects of target [F(1,14)=48.436, p<.001], set size [F(2,28)=31.289, p<.001], and group [F(2,28)=15.231, p=.002]. The main effect of group means that the experts responded more quickly than the novices. We also found an interaction effect between target and group [F(1,14)=14.829, p=.002], which means that the RTs of novices were more dependent on the factor target than the RTs of experts. Moreover, the interaction effect between set size and group [F(2,28)=8.031, p=.002] means that the slope of experts' RTs was significantly shallower than that for novices, *i.e.*, experts responded relatively independent of set size. An interaction effect between target and set size [F(2,28)=24.783, p<.001] was also found, which means that the slope was relatively flat in the target-present condition.

Figure 4 shows the RT as a function of set size for novices and experts for the conjunction task. Repeated-measures ANOVA revealed main effects of target [F(1,14)=47.557, p<.001], set size [F(2,28)=29.582, p<.001], and group [F(2,28)=9.81, p=.007]. We also found interaction effects between target and group [F(1,14)=15.85,

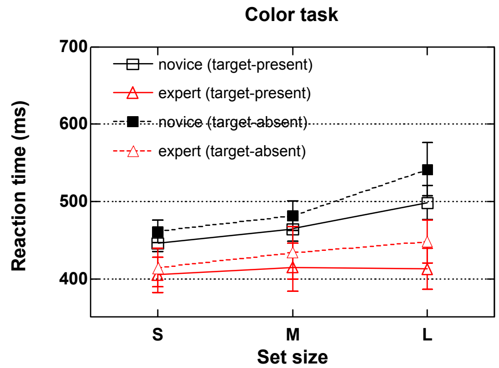

Figure 2: The mean response time (RT) as a function of set size in color task. The RTs for experts are written in black lines and RTs for novices are written in gray line. Solid lines are for the target-present condition, dashed lines are for the target-absent condition. Error bars are S.E.M.

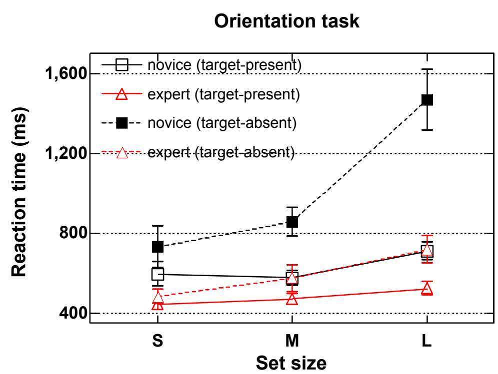

Figure 3: The mean RT as a function of set size in orientation task. Error bars are S.E.M.

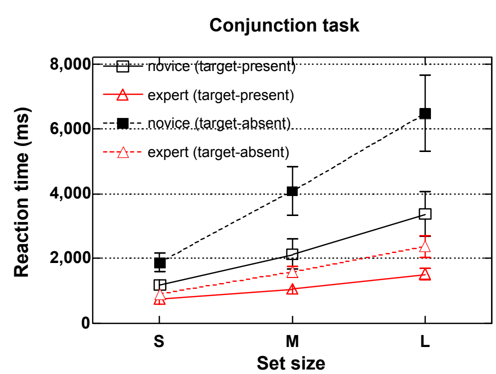

Figure 4: The mean RT as a function of set size in conjunction task. Error bars are S.E.M.

p=.001], between set size and group [F(2,28)=7.584, *p*=.002], and between target and set size [F(2,28)=51.844, *p*<.001]. All of these effects were also observed in the orientation task, but the effect was greater in the conjunction task.

Ratio Correct

The average ratio correct was .961, *i.e.*, subjects averaged about six mistakes in 160 trials. For the color task, repeated-measures ANOVA revealed a main effect of target [F(1,14)=27.432, *p*<.001], which means that the subjects' responses were less accurate in the target-present condition (mean = .969) than in the target-absent condition (mean = .990). There was no significant difference for the other main effects or interactions.

For the orientation task, we found the same main effect of target [F(1,14)=21.058, *p*<.001: average .969 for the target-present condition and .992 for the target-absent condition]. There was no significant difference in the other main or interaction effects.

For the conjunction task, repeated-measures ANOVA revealed main effects of target [F(1,14)=54.017, *p*<.001: average .991 for the target-absent condition and .855 for the target-present condition] and set size [F(2,28)=23.006, *p*<.001: the average was .956, .936, and .876, for set sizes S, M, and L, respectively]. Multiple-comparison revealed that the ratio correct for set size L was significantly lower than in the other conditions. We also found an interaction effect between set size and target [F(2,28)=23.809, *p*<.001], which means that the slope was relatively flat in the target-absent condition, *i.e.*, there was a tendency for subjects to judge that a target was absent, even when the target was present.

Eye movements

Eye movements during the experiment were measured for six experts and four novices. The remaining subjects were not measured because they wore glasses or contact lenses, which limits our eye tracker.

The frequency of saccades A two-way repeated-measures ANOVA was conducted with the factors task and subject group. As shown in Figure 5, experts made fewer saccades than novices [F(1,7)=49.321, *p*<.001], and the frequency of saccades depended on the task [F(2,14)=24.337, *p*<.001]. We also found an interaction between group and task [F(2,14)=4.993, *p*=.021]. Multiple comparisons revealed that in the color task, the frequency of saccades was not different [t(7) = 2.298, n.s.], but in the orientation and conjunction tasks, the experts made fewer saccades than novices [t(7)=2.595, *p*=.032 in the orientation task; t(7)=2.455, *p*=.0396 in the conjunction task].

The duration of fixation The duration of fixation was calculated from the data for the conjunction task. A two-way repeated-measures analysis of variance (ANOVA) was conducted with the factors set size and subject group. This revealed that the looking time between each saccade was dependent on set size [F(2,14)=5.684, *p*=.014; the averages

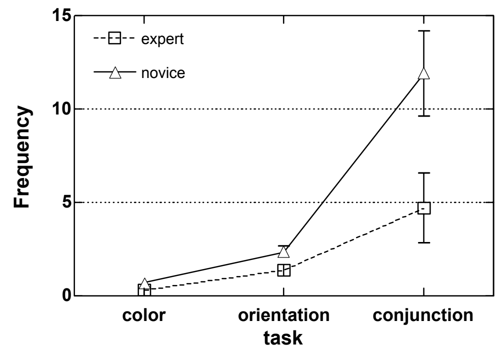

Figure 5: The frequency of saccades as a function of three tasks for experts (solid line) and novices (dashed line). Error bars are S.E.M.

were 476, 386, and 343 ms for set sizes S, M, and L, respectively]. We did not find a main effect of group [F(1,7)=1.792, n.s.] or an interaction effect between set size and group [F(2,14)=1.138, n.s.].

Discussion

In all three tasks, the subjects responded more quickly when a target was present than when a target was absent. This is easy to explain, because the subjects could stop searching when they found the target, but they had to look at all the items on the screen to be certain that there was no target in it, which takes more time. Overall, the RT depended on set size, which suggests that subjects could search a smaller area more quickly. The dependency was smaller for the color and orientation tasks than for the conjunction task, which is consistent with other studies (*e.g.*, Treisman and Gelade, 1980). We found large differences between the RTs of experts and novices in the orientation and conjunction tasks, as shown in Figures 3 and 4, and also found that experts made fewer saccades than novices in these tasks (see Figure 5). One can argue that the enhanced RTs of experts were owing to a speed-accuracy trade-off, *i.e.*, novices and experts use different strategies: novices put greater weight on making no errors than on responding quickly, while experts use the opposite strategy. However, it does not hold in this case, for there was no main or interaction effect of group factor on the ratio correct. We also noted that the subjects followed our instructions well, since they averaged only six mistakes in a block.

In the color task, the slope of RTs as a function of set size was almost flat for both experts and novices. In this task, targets 'pop out' among other distractive items and the pre-attentive process is believed to be involved in this phenomenon.

In the orientation task, when a target was present, it is apparent that the increase in RT as a function of set size (or slope) was smaller (or shallower) than the increase in RT in the conjunction task. This was independent of group factor, which also suggests that both experts and novices found the target pre-attentively.

In terms of group difference, experts could find targets more quickly than novices in both 'pop out' tasks, especially in a large set size [although it was not significant in color task, but marginally significant (p=.058)]. This indicates that experts could process visual information more quickly than novices in pre-attentive process. Sireteanu and Rettenbach (1995, 2000) also showed that those who trained single-feature visual search task could process visual information pre-attentively.

In the conjunction task, the group difference was very clear. Compared with novices, the slope of RTs for experts as a function of set size was shallow (see Figure 4), which also suggests that experts could process visual information more quickly than novices in non pre-attentive processes.

Why could experts respond more quickly than novices? If the ability to speed-read does not require special talents (our speed reading school declares that speed reading is for every one), the reason must reflect the potential of speed-reading training. Some studies have investigated the training effect on a visual search task (Sireteanu and Rettenbach, 2000; Leonards *et al*., 2002). Sireteanu and Rettenbach (2000) investigated the effect of training in a visual search task extensively and showed that the performance of a naïve subject doing a single-feature task was improved by training and the effect occurred in both target-present and target-absent conditions. This result is essentially the same as ours. In the conjunction task, however, the training effect was limited in their experiments: the effect occurred in the target-present condition, but not in the target-absent condition after training for 11 days. In our experiment, by contrast, the RTs of experts in the target-absent condition were shorter than the RTs of novices, as shown in Figure 4, which implies that the effect of training in speed reading is not limited to the target-present condition. The important point in which our experiments differ from theirs is that our experts had never experienced a visual search task; nevertheless, their performance was better than that of the novices. Again, note that in speed-reading training, students are trained in terms of eye movements, breathing, and posture, in order to concentrate on the sentences that they read.

In speed reading training, trainees are required to enlarge their visual span, which might be related to the improvement. In fact, our results from conjunction task suggest that the spotlight of attention becomes wider for experts than novices, rather than the moving speed of the spotlight becomes faster. In conjunction task, experts could respond with fewer episodes of saccade than could novices (see Figure 5), and experts could respond more quickly than could

novices too. Additionally, experts could respond more quickly than novices in orientation task where subjects could respond with only some episodes of saccade (see Figure 5). This also suggests that experts could process visual information in a wider area at a glance. Wolfe *et al.* (2000) showed that in a searching task, even if subjects know in advance where the target will appear, the time needed to check for its existence is longer than the time needed to find the target in the case of subjects who do not know the expected position of the target. Their results suggest that widening spatial attention is more efficient than focusing attention on a small area (like a moving searchlight) for a visual search, which appears consistent with our results.

Green and Bavelier (2003) demonstrated that attention is strengthened by video games, in terms of visual attention capacity, and the spatial and temporal distribution of visual attention. They also showed that action-game training led to greater performance improvement than did a control game (Tetris). Their results are very similar to ours, except that the action game required the subjects' attention to search for objects, which is basically the same as a visual search, while in reading there is no target or distractor.

Recently it was revealed that neural activation in trained subjects differed from that in untrained subjects (Fujimaki *et al.* 2004; Kato *et al*. 2005). Their data showed that the neural activity of trained subjects during speed reading decreased near Wernicke' s and Broca's areas. This suggests that trained people use fewer phonological processes, such as phonological transformation and inner speech, than the untrained when they speed-read. Here, we showed that speed-reading not only changes neural activity at higher levels, such as phonological processes, but also changes the performance of a visual search. As we used a simple non-letter-based feature as the stimulus, the results suggest that training improves ability, regardless of language.

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