1040-5488/08/8512-1135/0 VOL. 85, NO. 12, PP. 1135–1141
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Recognition Speed Using a Bioptic Telescope

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ABSTRACT

Purpose. This study sought to quantify the training and the asymptotic efficiency of novice users of spectacle-mounted bioptic telescopes.

Methods. Fifteen subjects with simulated 20/200 central acuity were fitted with bioptic telescopes. We measured the speed with which subjects were able to use a bioptic telescope to locate and identify a small letter, which was presented peripherally in a crowded array of letters at ±45° eccentricity. Both the target onset and its location were random. Subjects participated in four experimental sessions for a total of 500 (short session group) or 1000 trials (long session group).

Results. After training, the letter recognition speed with a bioptic telescope decreased by about 800 ms. Most of the improvement, however, occurred within the first ~150 trials. There were no systematic differences between groups. The asymptotic recognition speed with a bioptic telescope was about 1000 ms, 450 ms longer than the recognition speed in the same task but with 20/20 vision. Preliminary measurements suggest that these learning effects persist over a period of several years.

Conclusions. Evidently, novice users can quickly acquire proficiency in using a spectacle-mounted bioptic telescope. This task could be used to train new bioptic telescope users in a safe environment and to evaluate their progress.

(Optom Vis Sci 2008;85:1135–1141)

Key Words: bioptic telescope, low vision, peripheral vision, eye movements, device training

Numerous studies indicate that multidisciplinary visual rehabilitation of patients with low vision provides better outcomes than dispensing of optical devices alone.[1–5] The effectiveness of this training, however, is sometimes difficult to measure because the performance goals vary between devices and with the intended uses and motivations of the patients. Training has been evaluated by improvement in subjective quality of life, as measured by patient questionnaires[6] such as the National Eye Institute Visual Function Questionnaire. These questionnaires, were found to be insufficient, however, for assessing outcomes of training in the use of low vision devices.[1]

The present study investigated training speed and efficiency of new users of spectacle-mounted bioptic telescopes. Bioptic telescopes are a viable option for low vision patients requiring increased magnification due to certain visual conditions, such as macular degeneration and Stargardt maculopathy. A telescope is mounted in the upper portion of the patient's spectacle prescription or carrier lens. The patient's refractive correction is present throughout the carrier lens as well as inside the optics of the telescope, hence the name bioptic. In a bioptic system, the patient generally views through the carrier lens but tilts the head downward to spot objects through the telescope in order to resolve fine details in the distance. Driving is the primary use for bioptics. In the United States, at least 5000 to 6000 drivers use bioptic telescopes (C. Huss, personal communication). As of 2001, use of bioptics for driving was permitted in 34 states,[7] and recent information suggests that this has grown to approximately 40 states (C. Huss, personal communication).

Spectacle-mounted bioptic telescopes constitute a significant improvement over hand-held telescopes for tasks such as driving.[8] Clinically, bioptic telescopes have proven to be widely accepted as an aid for identifying distant objects,[9] but successful use is heavily dependent upon training.[10] Levin and Kelleher[11] have offered training guidelines for using bioptics for driving, but training programs and bioptic performance measures have not yet been standardized.

The effectiveness of training in using bioptics for driving has been examined in two experimental studies. Szlyk et al., used a battery of

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psychophysical tests to measure the effectiveness of training for bioptic drivers.[10] One of their tests measured the accuracy of detecting and then identifying peripheral letter optotypes presented at the corners of a 13 inch computer monitor at a close viewing distance. They found a significant improvement in peripheral identification by trained vs. non-trained individuals. Generalizing from this laboratory task to everyday driving tasks is uncertain, however, partly because everyday driving tasks may demand a greater range and variability of eye movement target locations. Politzer[12] described a bioptic training program for preparing low-vision patients for driving, using a complex regimen of spatial awareness, tracking and fixation, and dynamic visual acuity tasks. These training tasks have an intuitive rationale, but not all are easily reproduced. Politzer's patients were trained and judged to be competent in performing specific tasks, though their performance before training is unclear.

The current study complements these two previous laboratory studies by quantifying the training progress and the asymptotic efficiency of novice bioptic telescope users. Specifically, we evaluated the speed with which typically sighted subjects with simulated 20/200 central acuity were able to use a bioptic telescope to locate and identify a detailed peripheral target presented in a crowded array. The targets were presented randomly in the left and right visual fields at ±45° eccentricity. The aim was to design a quantifiable, controlled laboratory task relevant to driving, requiring substantial head and eye movements to identify peripheral targets using the bioptic telescope. As in the study of Szlyk et al., the variability of target locations and the variability of head and eye movements in our task was probably less than in natural driving, but the speed and accuracy of target identification in this controlled laboratory task should provide a useful benchmark for comparison with performance under less controlled conditions. The present testing and training system may also be useful for patients with varied visual capacities and skills.

METHODS

Subjects

Sixteen subjects, 8 male and 8 female, age range 19 to 31, with vision correctable to 20/20 and no ocular disease or prior bioptic telescope experience, were chosen to participate. One female subject did not complete the study. Exclusion criteria included myopia greater than −4.00 D, hyperopia greater than +1.00 D, or astigmatism >1.00 D. Subjects were screened using automated refraction and keratometry (Nikon Speedy K). All experiments complied with Vanderbilt University Institutional Review Board procedures and the tenets of the Declaration of Helsinki, and all subjects gave informed consent.

Apparatus

Dioptic Blur Simulation

All subjects were fit with hydrogel contact lenses to blur their vision. The contact lenses had +4.00 diopter (D) added to the auto-refraction. These lenses blurred each subject's vision and simulated 20/200 central acuity at the testing distance (matching normal peripheral acuity).

Bioptic Telescopes

Eye dominance for each subject was determined by the subject sighting the examiner through a small aperture. A 3.0× Galilean bioptic telescope with plano carrier and a +1.00 D reading cap was fit to the dominant eye. Interpupillary distance for the bioptic telescope was fixed at 60 mm.

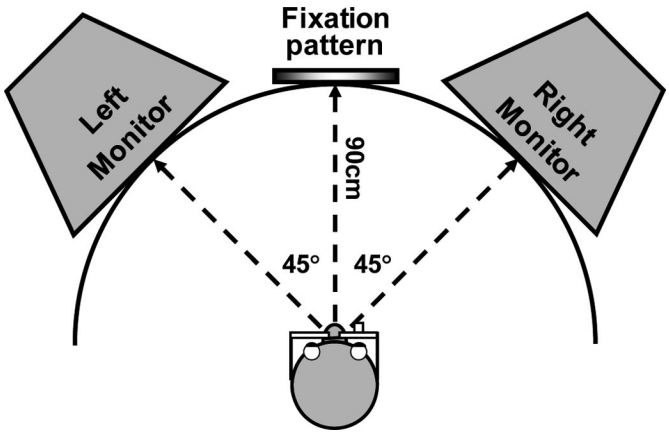

FIGURE 1.
A schematic of the experimental set-up. A subject with a spectacle-mounted bioptic telescope was seated 90 cm from the fixation pattern, with stimulus presentation monitors placed ±45°.

Stimulus Presentation

Stimulus patterns were created in MATLAB with the Psychophysics Toolbox[13] and Video Toolbox[14] and shown on two linearized 21-in monitors (1600 × 1200 pixels resolution, 85 Hz). Monitors were located 90 cm from the subject, yielding 0.92 × 0.92 arcmin per pixel. A highly visible bull's-eye pattern was used for fixation at 90 cm viewing distance. Monitors were placed at ±45° on each side and vertically centered at the same level as the fixation pattern (Fig. 1). A chin rest was used to indicate required head position, but to allow natural head mobility, subjects were instructed not to rest on the chin rest. The ambient illumination was 4.8 cd/m^2 and the background luminance on the monitor was 60.5 cd/m^2.

Stimuli and Procedure

Each trial started with the subject looking at the fixation pattern through the carrier portion of the bioptic telescope and both monitors displaying a gray (60.5 cd/m^2) background. The subject would then initiate stimulus presentation by a key press. Triggered by the key press, a 5 × 5 array of white (116 cd/m^2) alphanumeric characters was presented on each monitor (Fig. 2A, upper-case Monaco, about 1° tall). Character arrays, which were the same on each monitor, consisted of alphanumeric characters that were randomly sampled with replacement, excluding the letter "Q" and the number "0." Because of stimulus eccentricity (45°), character size, and the effects of visual crowding,[15] characters were not visually resolvable when looking at the fixation pattern. Before moving head and eyes to fixate these peripheral displays, subjects perceived a group of highly blurred white characters. Similarly, because of the dioptic blur from contact lenses, letters in the stimulus array were not resolvable without the magnification of the bioptic telescope.

Following trial initiation by a subject, the characters on a randomly chosen monitor (left or right) became black (4.8 cd/m^2, Fig. 2A). This occurred at a randomly chosen time, but not earlier than

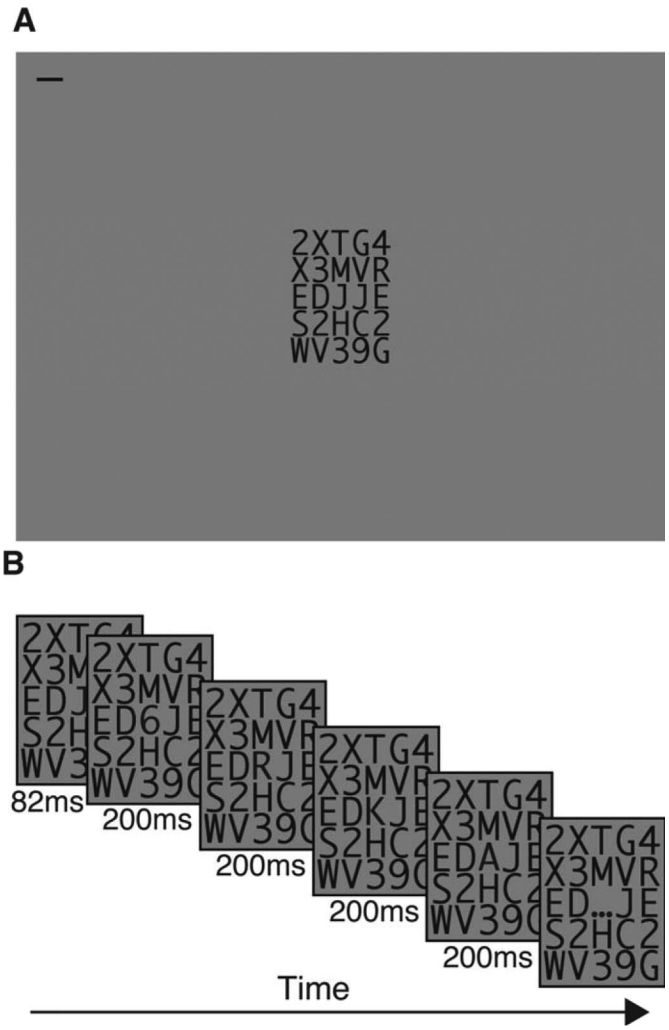

FIGURE 2.

Stimulus display illustration. A, A full screen capture. A 5 × 5 array of ~1° tall letters was shown in the center of the computer monitor. The scale bar is 1°. B, An example showing a temporal sequence of stimulus events in the center of a display screen. Note that the only change is in the center of the 5 × 5 array, where the first character is shown for variable duration (1 to 200 ms) and all subsequent characters are presented for 200 ms.

2 s after each trial initiation[a]. At the same time, the central character started changing every 200 ms (Fig. 2B, details below). This change of contrast polarity of the peripheral characters was easily perceivable and was a cue for the subject to look at the monitor with black characters. This required both eye and head movements. The task was to look quickly as possible at the monitor with black characters and then identify the first central character perceived. The subject then verbally indicated the first central character perceived, and the experimenter recorded the response. Both monitors were then cleared, allowing the subject to initiate the next trial.

The time of the first identifiable character corresponds to the time required to make the appropriate head and eye movements, fixate and then identify the central character. Thus, this procedure measures the recognition time elapsing from the onset of the contrast change to the first identifiable character. This procedure is similar to that used by Sperling and Reeves,[16] who studied how long it takes to shift attention between two character sequences presented near fovea.

Details of the changing character sequence were as follows: A new character was chosen every 200 ms and sampled without replacement. In the rare event that all characters were used, the character sequence was repeated. To increase the temporal precision of measuring recognition time, the first character was presented for a randomly chosen duration—between 1 and 200 ms. Consider an example where the subject responds "K" for the following central character sequence (Fig. 2B):

J (82ms), 6 (200ms), R (200ms), K(200ms),

A (200ms), ...

Recognition time for this example would be 82(J) + 200(6) + 200(R) + 100(K) = 582 ms. Note that 100 ms are included for the character (K). This choice is somewhat arbitrary, based on the possibility that "K" might have been recognized at the beginning, middle, or the end of its 200 ms presentation. Another value, say 200 ms, would simply add or subtract a constant for all data. In summary, the sequence of events constituting one trial was as follows:

1. subject looks straight ahead at the fixation pattern
2. subject initiates the trial by a key press
3. white character arrays appear on both monitors at ±45° eccentricity
4. 2 to 10 s later[a]; the characters on one of the monitors become black (Fig. 2A) and the central character starts changing (Fig. 2A)
5. subject quickly looks at the monitor with black characters, using both head and eye movements
6. first central character recognized is verbally reported
7. experimenter stops the character sequence by a key press
8. experimenter records subject's response
9. both monitors are cleared and subject gets ready for the next trial

Subjects were randomly assigned to two groups: a short session group (involving four 125-trial experimental sessions, n = 8) and a long session group (involving four 250-trial experimental sessions, n = 7). Before the experiment, all subjects were familiarized with the task and the character display, but were not allowed any practice trials. A session started with 25 control trials, without contact lens or bioptic, followed by an experimental run (125 or 250 trials) in which the subject wore contact lenses along with the bioptic. This procedure was then followed by a second set of 25 control trials. For control trials, subjects used their normal or corrected-to-normal vision. Thus, a short session consisted of a total of 175 trials (25 + 125 + 25), while a long session consisted of 300 trials (25 + 250 + 25). Each subject participated in four sessions. Sessions were completed on different days within a 2-week period. One of the short session subjects completed an additional (fifth) session 2 years after completing the main experiment (using the identical experimental set-up). This re-test indicated whether the effects of training persist over an extended period of time.

[a]The onset of the black character array was determined by a Poisson process to make the occurrence of the black character array effectively random. Starting 2 s after the trial initiation, at every 10 ms interval there was a 0.45% chance that the black peripheral stimulus would appear (with the constraint that the stimulus had to appear within 10 s). This resulted in a median wait time of 3.5 s (mean = 4.2 s, standard deviation = 2.0 s).

For the purpose of data analysis, the first trial of every experimental and control run was treated as a warm-up and discarded. Mistake trials—when the subject reported a character that did not occur—were also discarded. All recognition times faster than 200 ms were discarded (given the head movements required to execute the task, recognition times <200 ms are not possible). Finally, recognition times more than three standard deviations longer than the average recognition time for a given experimental or control run were also discarded. In total, 2% of the trials were excluded for one of these reasons, with only 0.13% trials faster than 200 ms.

RESULTS

Over four sessions, recognition times decreased by about 800 ms (Fig. 3), indicating a substantial improvement in the use of the bioptic telescope. The improvement was observed for both the

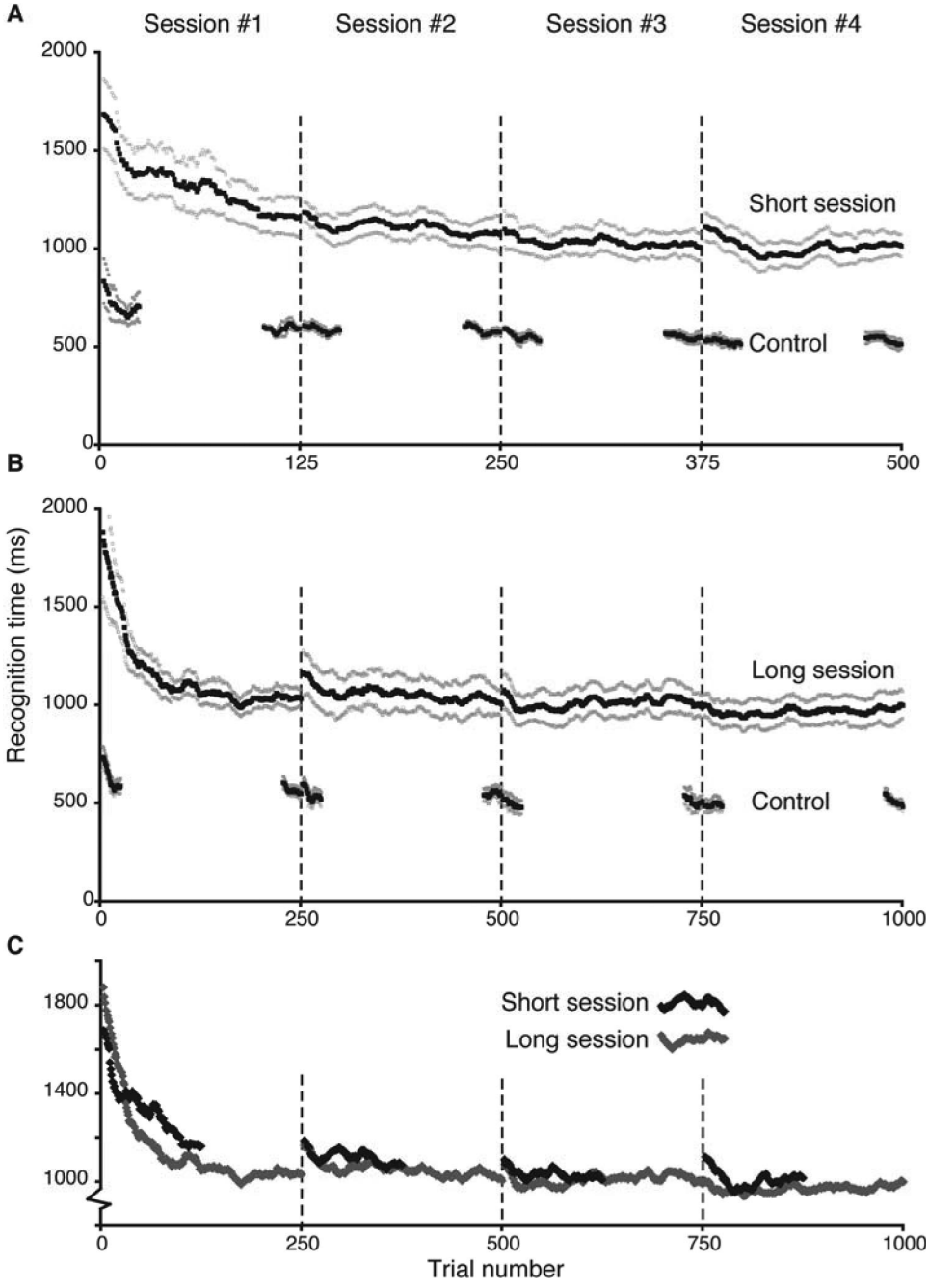

FIGURE 3.

Trial-by-trial results. For illustration purposes, the resulting function showing the dependency of the mean recognition times for each group on the trial number was smoothed with a moving boxcar function. The width of the boxcar was 9 trials for the control runs, and 17 trials for the experimental runs. A, Recognition times (ms) for short session subjects. Upper trace shows recognition times with a bioptic telescope device, whereas the bottom traces show the results from the blocks of control trials conducted before and after each experimental session. Pale lines depict ± SEM. B, Recognition times (ms) for long session subjects. Panel conventions are same as in (A). C, Comparison of short and long session results. For clarity, y axis is truncated and ± SEM lines are omitted.

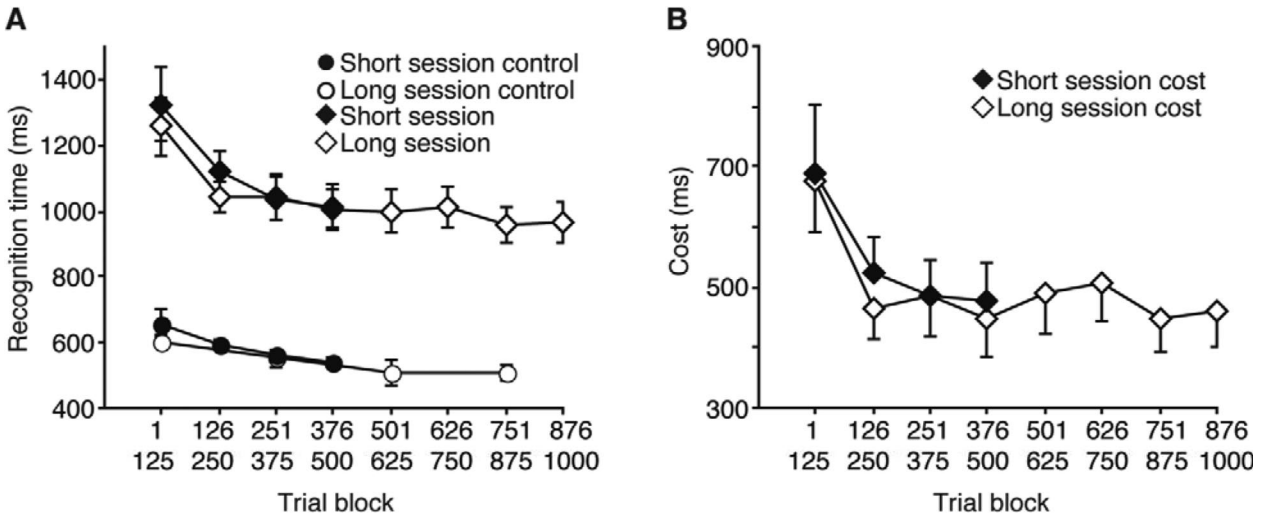

FIGURE 4.

Results average for sequential 125-trial blocks. A, Average recognition times for short and long session groups (black and white diamonds). Circles show control task results for each group. B, Average time cost associated with bioptic telescope use. Cost estimates are obtained by subtracting the control recognition times from the recognition times with bioptic telescopes. Error bars are between-subject standard error of the means.

short and the long session groups (Fig. 3A, B). Notably, it is apparent that the majority of the improvement occurred within the first ~150 trials, with relatively minor subsequent improvements. Differences between the short and the long session data (Fig. 3C) were relatively small, with short session recognition times being slightly higher. Recognition time using a bioptic telescope, however, was still at least 450 ms longer than the recognition time for the same task in the control condition. The difference between the bioptic and the control conditions remained stable in the last two sessions, indicating a likely limit on the speed with which a bioptic can be used to foveate and recognize a peripheral target. For a target at a 45° eccentricity, this asymptotic efficiency was about 1000 to 450 ms longer than in the control condition.

Fig. 4A shows the average recognition times for each 125-trial block. As in Fig. 3, most of the improvement is seen within the first two trial blocks. Moreover, the long session group has slightly better recognition times than the short session group (also see Fig. 3C). In the control condition, however, short-session subjects also performed slightly worse than the long-session subjects (on average 40 ms slower recognition times). This likely reflects sampling differences between the two groups. To compare better the experimental results between the groups, we subtracted the control results from the experimental results (Fig. 4B). This subtraction also yields an estimate of the "time cost" associated with the use of the bioptic telescope. These cost estimates again show that most of the improvement occurred within the first two trial blocks, but demonstrate no systematic differences between long and short session groups. The cost estimates seem to have a lower bound that is around 450 ms, which likely indicates the best performance attainable in the present task with a bioptic telescope. Participant cost measurements were analyzed with a 2×4 analysis of variance with group (short or long session) as a between-subject factor and sequential 125-trial blocks as a within-subject factor. As the long session group performed twice as many trials as the short session group, we only included the first four trial blocks for the long session group in this analysis. This analysis verified a main effect of trial block [$F(3, 39) = 19.98$, $p < 0.001$] and no main effect of either group or group-by-trial-block interaction (both F's < 0.33).

Some types of perceptual learning effects persist over long periods of time,[17] whereas others deteriorate over time.[18] Thus, we examined the persistency of the learning effect in one of our subjects that was available 2 years after his initial training. Remarkably, his performance 2 years after the initial experimental sessions was just as good as his best result 2 years before (Fig. 5).

DISCUSSION

We investigated the rate at which novice users learn to use a bioptic telescope. This study was conducted in a controlled environment using typically sighted subjects with simulated 20/200 central acuity. The task estimated the speed with which a bioptic telescope can be used to recognize a peripheral form. Nearly all the training-related improvement in this task occurred within the first 150 trials in both the long- and short-session groups (Figs. 3 and 4). Thus, with a small amount of training, the subjects quickly acquired proficiency in performing this new and unfamiliar task. We also found that 2 years after training, the task could be performed at essentially the same speed as at the end of the training (Fig. 5). Although noting that the follow-up was restricted to a single subject, this result suggests that, once learned, the ability to effectively use a bioptic device persists over time.

Given the significant attentional demands of operating a motor vehicle, the speed and efficiency with which novices can learn to use a bioptic in driving are important considerations. The carrier lens alone suffices for the largest portion of driving time; and the telescope is used only for detailed identification of distant targets, such as street signs that are detected and located with the carrier lens. The asymptotic recognition time for the present task with a bioptic telescope was about 1 s—with a "cost" of about 450 ms longer than the time needed with normal vision. Evaluating the impact of this additional time requirement on safe driving was beyond the scope of the present study. The demonstrated success

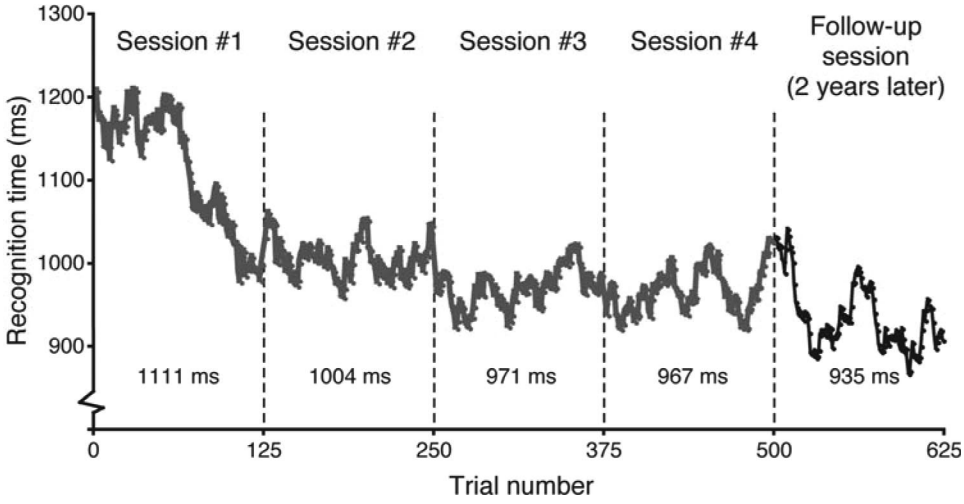

FIGURE 5.

Two-year follow up for one subject (black lines) in comparison with the initial training data (gray). Per-session averages are shown below trial-by-trial results. Data are smoothed as in Fig. 2.

of low-vision drivers in using bioptic telescopes indicates, however, that this added time for recognizing distant targets does not compromise safe driving, particularly when the need for recognizing such details can be anticipated. The predictability of eye movements may have been less in the present task than in natural driving tasks, but other visual demands may have been greater: The target stimuli were relatively small letters (~1°) and were presented in a small region crowded with 24 similar letters (Fig. 2). Nevertheless, this study offers a useful starting point for future studies of driving safety with bioptic telescopes.

The design of the present task and the "recognition time" measure offer some advantages over a conventional reaction-time task using verbal responses or manual key-presses. The present character-identification task eliminated secondary effects of age[19] and other individual differences that influence the speed, variability, and speed vs. accuracy criteria in executing the motor response.[20,21] The present recognition time measures are influenced by motor processes in the subjects' head and eye movements and by visual processes in target identification, but these processes are basic aspects of bioptic telescope use.

The present experimental set-up necessarily involved methodological simplifications that may be relevant to generalizations from this task to driving and other everyday tasks. First, the temporal onset and the location of the target were both random, but the temporal and spatial predictability may have been greater than in other natural tasks. The eye and head movements typical in driving are also predictable, however. Bioptic telescopes are generally used to read the details of signs that have already been located without the telescope; and most road signs in the United States are located a certain distance from the roadside on the right side of the road. The potential influence of eye movement predictability on the rapid learning speed observed in this study is unknown. Second, this study does not address the time required to leave the telescope and return to viewing through the carrier lens. Third, the viewing distances to targets (90 cm) in the present study were much less than those involved in driving. Distant peripheral targets were not feasible in this laboratory setting. Thus, a reading cap was added to accommodate the telescope to the close distances in this study, as is common in testing peripheral fields with a bioptic[22] and in using the bioptic for reading and other close work.[23] Finally, all our subjects were young adults, whereas typical bioptic telescope users are often older.[7] Older adults can exhibit difficulties in learning new tasks,[24] but the rapid learning of this new task by our subjects (~150 trials & <30 min) is encouraging. The rapid learning observed in the present study may also constitute a benchmark relevant to studies with older individuals.

In summary, we show that novice bioptic telescope users can quickly acquire proficiency in using a spectacle-mounted bioptic telescope. In one subject, this improvement in bioptic use was present 2 years after the completion of the experiment, suggesting that the effects of training are relatively permanent. This training task could be used to quickly train new bioptic users in a safe, non-threatening environment.

ACKNOWLEDGMENTS

We thank Doug Morse, MA, Jeff Nyquist, PhD, Molly Kaplan, MA, and Davis Glasser for help with the manuscript preparation. We also thank Paul Mayo, OD, and Michelle Wang, MD, PhD for help with the execution of the study.

This work was partly supported by National Institutes of Health/National Eye Institute, Bethesda, MD, grant R03EY015558 (to JSL).

This paper was presented at the 2004 annual meeting of the American Academy of Optometry, Tampa, Florida.

Received May 6, 2008; accepted June 26, 2008.

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