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Improving Visual Perception in Older Observers[1]

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Younger observers (M = 21 years) proved to be better than older observers (M = 68 years) at discriminating one direction of motion from another, highly similar one. Several days' practice steadily improved performance for both groups equally. Improvement was well restricted to the direction with which that observer practiced, and the full gains were retained for at least 1 month. Control measurements with various degrees of optical blur demonstrate that direction discrimination does not require a well-focussed retinal image. This rules out optical factors as the potential cause of the prepractice differences between groups.

Key Words: Aging, Motion perception, Discrimination, Training

PRACTICE can sharpen perception, enabling an observer to distinguish between stimuli that formerly were indistinguishable. This enhanced ability to differentiate one stimulus from another is a hallmark of perceptual learning (Gibson, 1969). Because motion perception is particularly susceptible to practice, we have been using this form of perception to explore perceptual learning more generally. In one study, training produced a steady improvement in observers' ability to discriminate between two highly similar directions of motion (Ball & Sekuler, 1982). This improvement was fairly restricted to the single direction on which an observer had practiced and was retained without decrement for at least 2 months.

Our original study used young, college-age observers exclusively. Now we wished to determine whether older observers also might benefit from similar visual training. If effective, such training might help older observers compensate for visual functions that decline with advancing age (Pitts, 1982; Weale, 1982).

EXPERIMENT 1

Before comparing older and younger observers' capacities for perceptual learning, we needed information about any preexisting age-related differences in performance. We began by testing direction discrimination in a total of 30 observers, young and old. This relatively large sample should highlight individual differences within each age group, as well as any differences between groups. Subsequently, a randomly chosen subset of these 30 observers was given practice at making direction discriminations.

METHOD

Observers. — The 15 members of the pretraining younger group spanned the ages of 18 to 28 years (M = 21); the 15 members of the pretraining older group ranged from 62 to 72 years (M = 68). Younger observers were students at Northwestern University; older observers were university employees (n = 6), members of a drop-in senior citizens group (n = 6), acquaintances (n = 2), and the second author's mother (n = 1).

Nearly all older observers had middle- and upper-class backgrounds at least roughly similar to those of the younger observers. To check that observers in the two age groups were comparable in general cognitive ability, we administered the Digit Symbol and Vocabulary subtests of the Wechsler Adult Intelligence Scale (WAIS). These subtests are differently affected by age, with vocabulary performance showing little change with age and digit-symbol performance showing marked decline (Botwinick, 1978). The average vocabulary score for the younger age group was 72.5 (SD = 13.46), and the average for the older age group was 71.7 (SD = 26.26). These statistics capture the great overlap between the two age groups; in fact, the groups did not differ significantly, $t(28) = 0.299$, p

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> .9. Each group's vocabulary performance corresponds to an age-normed score of 19 (*M* of age norms = 10; *SD* of age norms = 3). On the Digit Symbol subtest the younger group's mean was 74.4 (*SD* = 30.21); the older group's mean was 51.3 (*SD* = 40.16). Here, as expected, the groups did differ significantly, $t(28) = 5.08$, $p < .01$. Expressed as age norms, each group's mean score is 13 (age norm *M* is 10; SD of age norms is 3). So, in terms of their respective age norms, the groups performed above average on both subtests and did not differ remarkably from one another.

Cognitive differences between younger and older observers are not the only differences that might affect direction discrimination. In particular, age brings on many ocular changes, some of which might be important for direction discrimination. To minimize the impact of such changes, we sought older observers in very good ocular health. By self-report, all of the younger observers enjoyed good ocular health. We screened out volunteers who reported poor acuity, significant hypertensive retinal changes, or appreciable cataract (all of the observers, but 1, were below grade 1). In addition, 13 of the 15 older observers underwent ophthalmological exams (examinations could not be scheduled for the other 2 older observers) that supported their claimed ocular health. (A table summarizing the results of these ophthalmological examinations is available on request from the authors.)

We wanted each observer to have the sharpest vision possible under our experimental test conditions. Because we would be testing discrimination over a viewing distance of 57 cm, each observer was individually refracted for that same distance. The Bailey-Lovie (1980) chart for near-vision gauged best-corrected visual acuity at 57 cm. Because our subsequent experimental tests would be conducted with binocular viewing, only binocular acuities were taken. In terms of minimum angle resolvable, best-corrected "near" visual acuities averaged 0.85 minutes of arc for the young observers (*SD* = 0.14 minutes) and 1.35 minutes of arc for the older observers (*SD* = 0.27 minutes).

Procedure. — Stimuli were 256 bright, spatially random dots that travelled parallel paths over the face of a cathode ray tube (CRT) at 10° per second. Observers viewed the display binocularly, while fixating a small dark, central point. The luminance of the dots was approximately 50 times contrast threshold, making the dots, and their movement, highly visible.

The CRT was masked down with a circular aperture 8° in diameter. As a result, an average of 201 dots were visible to the observer at any moment. A new array of random dots was presented in each observation interval.

Each trial consisted of two test intervals, 500 ms long, separated by 500 ms. Dots were presented only during the two test intervals; at other times the CRT screen was blank, steadily illuminated by a veiling luminance of 0.06 cd/m^2.

Two kinds of trials, *same* and *different*, were randomly intermixed. On *same* trials the dots moved in the same direction during both intervals (hereafter, a standard direction). On *different* trials, dots moved in the standard direction during one interval and in some different direction during the other interval. Which interval, first or second, would contain the standard direction was determined randomly. The two directions presented on *different* trials were separated from one another by either 2, 4, 6, or 8° (either clockwise or counterclockwise from the standard direction). Each 50-trial block trials had a fixed standard direction and a constant separation between directions on *different* trials. For each observer, three standard directions were used. Two were cardinal directions (either upward, downward, leftward, or rightward) and one oblique direction (midway between two cardinal directions). Pairs of cardinal directions were assigned randomly to various observers, with each observer's two cardinal directions differing by 90°.

The observer judged whether the trial's two directions had been the same or different. This judgment was communicated by a switch-throw to the computer controlling the experiment. To encourage observers to do their best, we provided feedback after each response and paid observers 2 cents for each correct response, whereas we reduced their earnings by 1 cent for each incorrect response.

Pretraining regimen. — During a session, an observer made 50 same-different judgments for each of four separations (2, 4, 6, and 8°) and three directions (two cardinals and an oblique).

After initial, pretraining performance had been assessed, we solicited further help from our observers, asking each to participate in our training regimen. Eight young and 9 older observers agreed to take part in the complete study consisting of seven sessions spread over 10 to 14 days. Observers who agreed to complete the study were primarily people employed on Northwestern's Evanston campus; they came before or after work several times per week. Observers who agreed to continue training were representative of the original larger sample.

The average WAIS scores for continuing observers differed by about one point from the average of the other observers in each age group. In addition, the continuing observers had discriminated direction of movement in a manner quite representative of their age group.

Training regimen. — In Sessions 1 (pretraining), 4, and 7 each observer was tested on two cardinal directions and an oblique direction, as described for the pretraining regimen. Discrimination was measured for all three directions assigned to an observer, in combination with varying separations between test directions (2, 4, 6, and 8°). The order of testing was randomized anew for each session and observer.

Recall that each observer was tested with two cardinal and one oblique directions. Prior to the first session in which an observer was to participate, one of his/her two cardinal directions was designated as the direction on which that observer would be trained (hereafter, the training direction). Different observers had different training directions, subject to the constraint that all four possible training directions (up, down, left, and right) be represented in each age group as evenly as possible.

In Sessions 2, 3, 5, and 6 an observer practiced on his/her training direction. Each of these sessions involved a total of 500 trials, in 10 blocks of 50 trials. Between blocks the amount of separation between directions on *different* trials alternated between 2° and 4°.

RESULTS

Responses in each block of trials were reduced to a pair of conditional probabilities: Pr(Hit) and Pr(FA). A hit was defined as a response of "different" on a *different* trial; a false alarm, or FA, was defined as a response of "different" on a *same* trial. Pr(Hit) and Pr(FA) were then converted to d'.

Pretraining results. — Figure 1 shows the pretraining performance of all observers. Results are shown for direction separations of 2, 4, 6, and 8° and for one cardinal direction for each observer. If an observer continued on in the training phase of the study, the cardinal direction represented in Figure 1 is his/her training direction. These continuing observers are represented with filled symbols (circles for the younger observers and squares for the older observers). Figure 1 shows three noteworthy things. First, discrimination performance steadily improved as separation increased; second, for each separation, the average young observer (represented with a horizontal bar) did somewhat better than did the average older observer; finally, for each separation, older and younger individuals overlapped considerably.

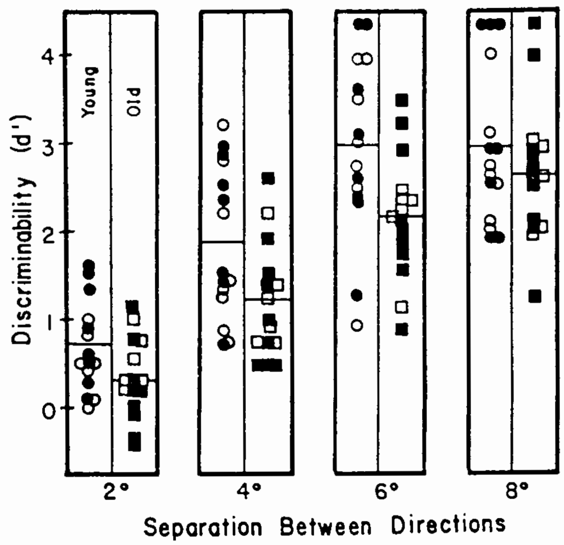

Figure 1. Discrimination performance (d') of each observer at separations of 2, 4, 6, and 8°. Filled symbols are for observers who continued in the training regimen and show their initial performance on the training direction; open symbols are for those who did not participate in the training regimen. Circles denote younger observers and squares denote the older observers. Horizontal bars indicate the average performance for young and older observers for each separation.

An analysis of variance (ANOVA) on the data from Figure 1 confirmed that age affects discrimination performance, with older observers doing more poorly overall than did younger observers, F (1, 28) 5.54, $p < .05$, $\omega^2 = .04$. Follow-up, Newman-Keuls tests showed statistically significant differences between older and younger observers at the intermediate separations — 4 and 6° — but not at the smallest or largest separations — 2 and 8°. Examination of Figure 1 explains this pattern of results. Most likely, with an 8° separation, many observers were approaching the upper limit of attainable performance (a so-called ceiling effect). With a separation of only 2°, many observers approached chance performance (a basement effect). Only with intermediate amounts of separation could the full, potential difference between observers find expression.

Previous research (Ball & Sekuler, 1980) revealed an oblique effect in direction discrimination: Small differences were more easily discriminated around cardinal directions than around oblique directions. To see whether a comparable result existed in our present data, we compared each observer's performance for two cardinal directions with his/her performance for an oblique direction. The oblique effect was defined by the *difference* between the mean d' for an observer's cardinal directions and the d' for his/her oblique direction. Note that values greater than zero signify an oblique effect. To avoid the complications of basement and ceiling effects, we analyzed only data from intermediate degrees of separation.

Consider first the results with a separation of 4°. For all 30 observers, the mean d' for the cardinal effect for young observers was 1.66 (SD = 0.74). Though the mean oblique effect for all older observers was smaller, 1.33 (SD = 0.64), oblique effects for young and older observers did not differ significantly, $t(28) = 1.27, p > .20$. For a separation of 6°, every young observer showed an oblique effect, and 14 of the 15 older observers did, too. Here, younger observers had a mean oblique effect of 1.85 (SD = 0.79), whereas older observers showed a mean oblique effect of 1.60 (SD = 1.17). Again, the difference between young and older observers was not statistically significant, $t(28) = 0.66, p > .20$.

Training. — Figure 2 shows how practice affected discrimination, d', for each observer's training direction. An ANOVA confirmed that, overall, practice does improve performance, $F(2, 30) = 8.46, p < .001, \omega^2 = .029$. Separation size also proved to be a significant source of variance, $F(3, 45) = 171.23, p < .001, \omega^2 = .477$, confirming that larger separations support better discrimination. The interaction of these two variables, training and separation size, was not significant, $F(6, 90) = 1.37, p > .20$. We were interested primarily, though, in another issue: the contributions of age. Note that for each pair of data points plotted in Figure 2, the younger observers' data point lies above that of the older observers. Consonant with this consistent superiority, the ANOVA yielded a significant main effect of age, $F = (1, 15) = 8.07, p < .02, \omega^2 = .078$. None of the interactions was significant (all $p > .20$). The lack of significant interaction between age and training, $F(2, 30) = 0.562, p > .20$, showed that practice benefitted both age groups to about the same degree.

A supplementary ANOVA examined the specificity of practice's effect. With data from nontraining directions as well as training directions, this ANOVA used an orthogonal contrast to compare performance on the training direction against performance on the two nontrained directions. The ANOVA showed significantly greater changes in d' for the training direction than for other two directions, $F(2, 30) = 10.01, p < .0001, \omega^2 = .0057$. As expected, then, training had the greatest effect on the training direction itself.

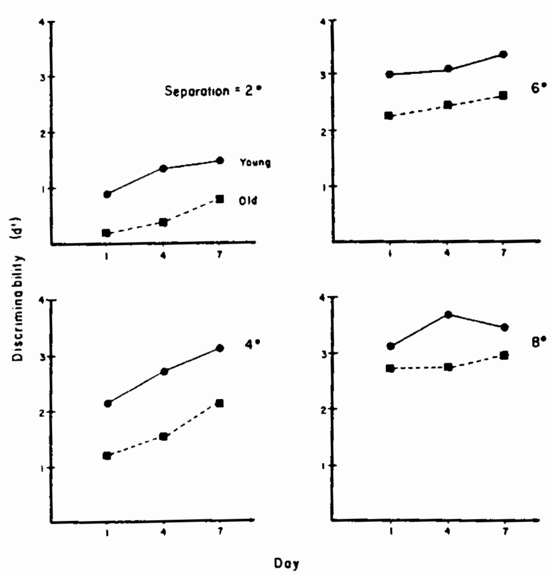

Figure 2. Average discrimination performance (d') for 8 young and 9 older observers on the training direction for separations of 2, 4, 6, and 8°.

Retention. — In a previous study, other younger observers managed to retain improvement in direction discrimination over a 10-week rest period (Ball & Sekuler, 1982). To see if older observers would show comparable retention of training, we succeeded in getting 5 of our 9 older observers to return for a retest following a month's time with no further training. An ANOVA showed no significant difference between performance on the observers' final day of training and on the delayed retest, $F(1, 4) = 0.29, p > .50$. Thus, improvement was retained for a month in the absence of any additional practice.

EXPERIMENT 2

Before training, older observers showed slightly poorer discrimination than did younger observers. Concerned that this difference might have been caused by the older observers' poorer visual acuity, we measured direction discrimination by young observers whose acuities had been experimentally degraded.

METHOD

Observers. — The observers were 4 young volunteers whose ages varied from 18 to 30. Each was screened for 20/20 or better acuity at distance.

Procedure. — Discrimination of direction of motion was measured while observers viewed the stimuli through various trial lenses, ranging in optical power from 0.0 to +4.0 diopters, in 0.5 diopter steps. If an observer normally used glasses or contact lenses, the trial lenses were worn over his/her normal prescription. First we assessed how each of the lenses would affect the observer's visual acuity. Using the Bailey-Lovie near-vision chart, acuity was measured at the same viewing distance, 57 cm, over which observers viewed the moving dots. For measurements of visual acuity, as well as for measurements of direction discrimination, different power lenses were used in a new random order with each observer.

As before, each trial consisted of two intervals with two types of trials — *same* and *different* — randomly intermixed. On *same* trials the dots moved in the same standard direction during both intervals; on *different* trials the dot motion in one interval differed from the direction in the other interval by 1, 2, 3, 4 or 5° (either clockwise or counterclockwise). During each 50-trial block the separation (1 to 5°) varied randomly, with 10 trials for each separation.

RESULTS AND DISCUSSION

As before, d' was calculated from the hit and false alarm rates. The results are summarized in Figure 3. The lower abscissa denotes the optical power of the blurring lens; the upper abscissa portrays the mean minimum angle resolvable achieved by the observers while they were looking through a particular lens. The ordinate shows d', discrimination performance. Each curve represents the data for one separation size.

Consider first the abscissas. Generally, as the optical power of the blurring lens increased (lower abscissa), the acuity decreased (upper abscissa). Note, though, that the change in acuity was distinctly nonlinear, showing no change between 1 and 2 diopters and large changes thereafter. As expected, overall discriminability improved with increasing separation size. The fact that each curve tends to be constant across the range of blurs tested indicates that discrimination of direction is unaffected by blur. An ANOVA showed no significant effect of blur, F (8, 24) = 2.09, $p > .10$, and no

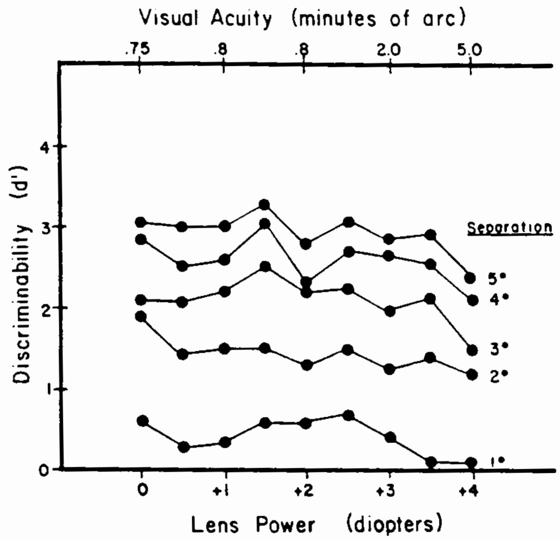

Figure 3. Discrimination performance is shown for 4 young observers viewing through trial lenses ranging from 0 to +4 diopters. The lower abscissa denotes the optical power of the lens; the upper abscissa portrays the average minimum angle resolvable in minutes of arc. Data are shown for separations of 1, 2, 3, 4, and 5°.

significant interaction between blur and separation, F (32, 96) = 2.55, $p > .05$. Thus, even with substantially reduced visual acuity, ability to distinguish between highly similar directions of motion seems unimpaired. This confirms preliminary observations reported earlier (Ball & Sekuler, 1982); the result is also consistent with the observation that the direction selectivity of neurons in the mammalian visual cortex is unchanged by small amounts of blur (Hill & Ritchie, 1974).

GENERAL DISCUSSION

Experiment 1 had two noteworthy results: Before training, younger observers outperformed older observers in discriminating between similar directions of motion, and observers in both age groups benefitted equally from discrimination training. Each of these results demands additional comment.

Pretraining differences between groups. — There are several possible causes for the pretraining differences, including the possibility that older observers' slightly poorer visual acuities impaired their discrimination. Experiment 2, however, demonstrated unequivocally that acuity plays a negligible role in an observer's ability to discriminate one direction of motion from another. We do not claim that a sharp retinal image is never consequential for any aspect of motion perception, but for random dot patterns of the type used here it is unlikely that the older observers' diminished acuity could account for their poorer ability to discriminate direction of motion.

Another possibility is that our older observers may not have understood the task as well as our younger observers did. We tried to obviate this possibility by constituting both groups with observers from comparable socioeconomic backgrounds. The WAIS subtests further confirmed the comparability of the two groups. Though these arguments are merely circumstantial, the discrimination data themselves clearly refute the contention that older observers had a poorer comprehension of the task. Consider the discrimination results obtained on the first day of testing, particularly the results from the easiest discrimination — a cardinal direction and an 8° separation between directions. Young observers averaged a d' of 2.94; the older observers averaged a d' of 2.75. If older observers had not understood the task, it is hard to imagine how they achieved virtual parity of performance in any test condition.

A third hypothesis is that some form of response bias caused older observers to perform more poorly than younger observers. This hypothesis gains plausibility from reports that older observers sometimes appear to be more cautious (Rees & Botwinick, 1971) and, thereby, less efficient observers. In our study, response bias could take several different forms. For example, older observers might not use the two-response alternatives equally often. Out of a desire to be cautious, perhaps, older observers might shy away from calling two directions of motion "different." In a same-different procedure such as that of Experiment 1, an observer will perform optimally (giving full expression to his/her sensory prowess) only if he/she does not have a bias either for or against either response category — same or different. We determined whether our older and younger observers had differing response biases at the start of Experiment 1. For the 9 older observers and 8 younger observers who took part in the training regimen, we calculated the proportion of trials on which they made "different" responses (a nonconditional probability). To simplify calculation we considered only those data collected at the observer's training direction. Consider the results with a separation of 4°: Younger observers judged 52.2% of trials "different," whereas older observers judged 51.3% of the trails "different." Recall that in actuality, 50% of the trials were *different*. The similarity between groups suggests that the response proclivities of the two groups did not differ appreciably from one another.

Having rejected poor acuity, cognitive differences, and response bias as explanations for age-related differences in performance, we are left with the idea that younger and older observers differ perceptually.

What actually changes with training? — In Experiment 1, observers of all ages benefitted equally from training. Although the design and nature of our study does not allow a detailed description of the mechanisms underlying the training, we can refine our understanding of the improvement somewhat.

According to one view, perceptual learning is essentially a matter of increased differentiation — stimuli that were not originally distinguishable become distinguishable. This view attributes the improvement to the observers' increased ability to recognize subtle differences between directions. Specifically, this view predicts that performance improves largely because of an increase in the proportion of *different* trials that the observer correctly judges to be different.

Note, though, that this is not the only possible view. From one presentation to the next, a fixed stimulus does produce somewhat variable sensory responses. For example, the perceived orientation of a briefly presented line seems to fluctuate between presentations (Andrews, 1967). Similarly, the direction in which a briefly presented pattern appears to move fluctuates between presentations (Ball et al., 1982). Consider how such random fluctuations would affect observers in our study. If large enough, fluctuations of perceived direction could occasionally cause the identical directions presented on *same* trials to appear different from one another. As a result, an observer would have to learn not to respond "different" every time the two presentations in a trial did not appear perfectly identical. He or she would need to learn how much sensory events would have to differ in order for their difference to be diagnostic of the fact that two different stimuli had been presented. More specifically, this view predicts that performance improves largely because of a decline in the proportion of *same* trials that the observer mistakenly judged "different."

So improvement of direction discrimination could have come about *either* from an increase in Pr("different"/*different*) *or* from a decrease in Pr ("different"/*same*) — or from both sources. The data from Experiment 1 allowed us to examine the

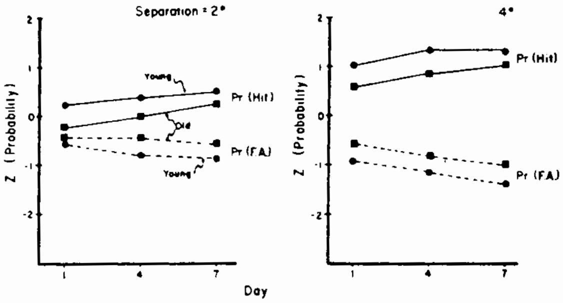

Figure 4. Z-transformed values for Pr(Hit) and Pr(False Alarm) are shown for both young and older observers. Pr(Hit) is indicated with solid lines and Pr(FA) is denoted with dashed lines. Circles indicate younger observers, and squares denote the older.

validity of these views of perceptual learning. For the 9 older and 8 younger observers who underwent training we examined two conditional probabilities — the Pr("different"/*different*), or Pr(Hit), and the Pr("different"/*same*), or Pr(FA). Figure 4 shows how both quantities changed with training. The lefthand panel shows the results with one training separation (2°), and the righthand panel shows the results with the other training separation (4°). All data are for observers' training directions. In order to make the data linear the probabilities have been transformed into standard, normal scores (z transformed).

Note that upper and lower curves in each panel are virtually mirror images of one another. This horizontal symmetry testifies that each view of perceptual learning (already described) can make some claim to truth: Observers improve equally in two different ways, with Pr("different"/*different*) increasing at just about the same rate that Pr("different"/*same*) decreases.

Implications for adult perceptual learning. — Training improved older observers' direction discrimination, ultimately making it equal to the initial level for the younger observers. Although we cannot as yet identify the mechanisms for such improvement, these results demonstrate quite clearly that older observers can profit from perceptual training. The success of our simple training program suggests that similar procedures may be used to remediate age-related visual losses more generally. There may be distinct limitations, however, to the benefits of such perceptual training. For instance, though direction discrimination is relatively independent of optical factors, many other visual functions are not, and, unless the optical quality of the older eye can be improved, little can be done to enhance older observers' performance on such optics-limited functions.

Fortunately, functions not limited by optics include some that are most important in everyday activities. We have in mind visual guidance of locomotion and mobility (Leibowitz et al., 1982). Because motion perception contributes importantly to locomotion and mobility, improvement in direction discrimination might enhance the everyday activities of older people, including older people with considerably reduced visual acuity.

REFERENCES

Andrews, D. P. (1967). Perception of contour orientation in the central fovea. Part I: Short lines. *Vision Research, 7,* 975–997.

Bailey, I. L., & Lovie, J. E. (1980). The design and use of a new near-vision chart. *American Journal of Optometry and Physiological Optics, 57,* 378–387.

Ball, K., & Sekuler, R. (1980). Models of stimulus uncertainty in motion perception. *Psychological Review, 87,* 435–469.

Ball, K., & Sekuler, R. (1982). A specific and enduring improvement in visual motion discrimination. *Science, 218,* 697–698.

Ball, K., Sekuler, R., & Machamer, J. (1982). Detection and identification of moving targets. *Vision Research, 23,* 229–238.

Botwinick, J. (1978). *Aging and Behavior.* Springer Publishing Co., New York.

Gibson, E. J. (1969). *Principles of perceptual learning and development.* Appleton-Century-Crofts, New York.

Hill, R. M., & Ritchie, G. D. (1974). Directional discrimination — Tolerance of visual cortical cells to severe stimulus degradation. *Experientia, 30,* 628–629.

Leibowitz, H. W., Post, R. B., Brandt, T., & Dichgans, J. (1982). Implications of recent developments in dynamic spatial orientation and visual resolution for vehicle guidance. In A. Wertheim, W. Wagenaar, & H. W. Leibowitz (Eds.), *Tutorials on motion perception.* Plenum Press, New York.

Pitts, D. G. (1982). Visual acuity as a function of age. *Journal of the American Optometric Association, 53,* 117–124.

Rees, J., & Botwinick, J. (1971). Detection and decision factors in auditory behavior of the elderly. *Journal of Gerontology, 26,* 133–136.

Weale, R. A. (1982). *A biography of the eye.* H. K. Lewis & Co., London.