The Visual Function of Professional Baseball Players

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• PURPOSE: To measure the visual acuity, stereoacuity, and contrast sensitivity of professional baseball players.

• METHODS: Three hundred eighty-seven professional baseball players underwent several tests of visual function including distance visual acuity. Stereoacuity was evaluated at near by the Randot test and at distance by both contour and random dot targets. Distance stereoacuity was also tested under timed and untimed conditions. Contrast sensitivity was evaluated by the Vision Contrast Test System, Contrast Sensitivity Viewer, and Binocular Visual Acuity Tester.

• RESULTS: Visual acuity (measured with players' regular distance correction) in 774 eyes ranged from 20/8.89 to 20/100. Near stereoacuity ranged from 23 to 37 seconds of arc, mean untimed distance contour stereoacuity from 55 to 35 seconds of arc, and mean untimed distance random dot stereoacuity from 98 to 76 seconds of arc. The results under timed conditions were 86 to 65 seconds of arc (timed distance contour stereoacuity) and 104 to 83 seconds of arc (timed distance random dot stereoacuity). Statistically significant differences were found between major and minor league players on tests of untimed distance contour and random dot stereopsis, and on contrast sensitivity testing with the 3.0- and 6.0-cpd gratings using the Contrast Sensitivity Viewer.

• CONCLUSIONS: Professional baseball players have excellent visual skills. Mean visual acuity, distance stereoacuity, and contrast sensitivity are significantly better than those of the general population.

Accepted for publication April 16, 1996.

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AS EARLY AS 1925, SCIENTISTS[1] ATTEMPTED TO learn why "Babe" Ruth excelled at baseball. They subjected Ruth to a series of "eye, ear, brain, and muscle tests" and found that his eyes were not only 12% "faster" than those of the average human but also 90% more efficient. Although this study was informal and involved a single player, it did begin to describe the differences in visual function between baseball players and the general population.

More recently, several studies have attempted to delineate visual factors necessary for success in baseball. In 1942, Winograd[2] studied collegiate baseball players and found that their stereopsis and visual efficiency were better than those of both the general population and students who did not qualify for the team. More recently, Rouse and associates[3] reported that dynamic visual acuity (the ability to resolve detail while there is movement between the object and the subject) in a group of collegiate baseball players was better than that in normal controls. In addition, the relationship between athletic performance and several visual factors, including contrast sensitivity and stereoacuity, has been researched extensively. Hoffman, Polan, and Powell[4] reported an increased ability to detect small differences in luminance between an object and its background (contrast sensitivity) in baseball players compared with controls, and Solomon, Zinn, and Vacroux[5] described better dynamic depth perception (stereoacuity) in major league batters than in pitchers.

The overwhelming majority of baseball players studied previously have been at the Little League or collegiate levels. Although differences between these groups and the general population have been shown, a larger and more significant difference is likely to exist between professional baseball players (who have had to pass a difficult selection process) and the general population.

This report summarizes the results of a visual skills testing program carried out on the professional athletes of the Los Angeles Dodgers baseball team during the 1992 through 1995 spring training seasons. The testing program included the standard battery of visual skill tests previously applied and several new tests of stereoacuity and contrast sensitivity. The results are provided by year and by league, and are discussed in light of previously published studies of nonprofessional baseball players and other reference populations.

METHODS

WE EXAMINED 387 MAJOR AND MINOR LEAGUE PROFESSIONAL baseball players from the Los Angeles Dodgers baseball organization during the 1992 through 1995 spring training seasons. A series of testing stations was used, each responsible for assessing a different aspect of the examination. Each player started at the first station and progressed through each station in order.

A Los Angeles Dodgers trainer assigned each player a subject number and obtained the player's name, date of birth, handedness, native language, field position, and any history of corrective lens use. A comprehensive ocular history was also obtained. Visual acuity was assessed for each eye separately, using the player's regular distance vision correction, at 20 feet with the Binocular Visual Acuity Tester computerized monitor with Snellen letter optotypes (Mentor O & O, Inc., Norwell, Massachusetts). Visual acuity was scored as the last correct line read plus or minus the number of letters read correctly or incorrectly (for example, 20/20 −2, 20/20 +2). In 1992, the Binocular Visual Acuity Tester was calibrated for a testing distance of 20 feet. From 1993 through 1995, the Binocular Visual Acuity Tester was placed at 20 feet but was calibrated for a ten-foot testing distance. Each subject was evaluated using his refractive correction, when applicable. Visual acuity results were translated into logMAR (minimum angle of resolution) values. LogMAR values express visual acuities better than 20/20 as negative numbers and those worse than 20/20 as positive numbers. The logMAR scale permits statistical evaluation of visual acuity data. Near stereoacuity was determined using the Wirt rings in the Randot Stereo Test (Stereo Optical Co., Chicago, Illinois).

Each player's binocular contrast sensitivity was measured at ten feet using the Vistech 6500 Vision Contrast Test System (Vistech Consultants Inc., Dayton, Ohio) at a standard illumination of 5.8 foot-candles (fc). Contrast sensitivity was determined for each player at spatial frequencies of 1.5, 3.0, 6.0, 12.0, and 18.0 cycles per degree (cpd). Each player's contrast sensitivity threshold was determined by a three-alternative, forced-choice method (left, right, or vertical). Players were initially shown a high-contrast test grating at the beginning of the 1.5-cpd test row. They were then asked to specify, in order of decreasing contrast, the orientation of the remaining gratings in the row. The lowest contrast at which the grating orientation was correctly identified was taken as the contrast sensitivity for the 1.5-cpd spatial frequency. An identical procedure was then performed for the remaining spatial frequencies.

From 1993 through 1995, each player was then binocularly tested using the Contrast Sensitivity Viewer-1000 contrast sensitivity testing system (VectorVision, Inc., Dayton, Ohio) at standard room illumination and a testing distance of 8 feet. This unit senses the external light, allowing for automatic calibration of the instrument light level. Each player's contrast sensitivity threshold was determined using a three-alternative, forced-choice paradigm (top, bottom, or none). The test was composed of four sets of targets (representing 3.0, 6.0, 12.0, and 18.0 cpd in decreasing contrast). Each target was composed of a single suprathreshold test grating followed by eight pairs of progressively decreasing contrast gratings of the same spatial frequency. Each player was first asked to identify the presence of grating bars in the initial suprathreshold target. Following an affirmative answer, the player was asked to complete the row (of eight grating pairs) by stating whether the grating bars appeared in the top row, bottom row, or neither. An answer was obtained for each of the eight pairs, and the last correct answer was taken as the player's contrast sensitivity at that spatial frequency. An identical procedure was used for each of the remaining spatial frequencies.

Distance stereoacuity was tested under timed and untimed conditions using the Binocular Visual Acuity Tester computerized monitor at 20 feet, with the player wearing liquid crystal shutter glasses (Mentor O & O, Inc., Norwell, Massachusetts). A 20/320 tumbling E at reduced contrast and luminance was initially presented on the screen to approximate the apparent contrast of the binocular vision test. If the player was able to respond correctly to the orientation of the E, the binocular test was started. The hand control was used to change the display on the screen of the Binocular Visual Acuity Tester. A laptop computer was used to perform timed measurements and to record all answers.

Each player was shown a set of four circles, one of which (top, bottom, left, or right) was perceived in front of the screen. By manipulation of the hand piece, stereoacuity disparity was decreased sequentially from 240 to 180, 120, 60, 30, and 15 seconds of arc. At each stereoacuity level, the player was asked to identify which of the four circles he perceived as being three-dimensional. The test was continued until two consecutive mistakes were made. The last correct level was thus recorded as the player's contour stereoacuity threshold. The identical procedure was then repeated under timed conditions.

Distance random dot stereoacuity was then tested using the tumbling E presented randomly in one of three orientations: up, down, or horizontal. The player was asked to state the orientation of the letter raised off the screen. The stereo disparity of the letter to the background was then decreased progressively from 240 to 180, 120, 60, 30, and 15 seconds of arc until its direction could no longer be correctly identified by the player. The last correct stereoacuity level was thus called the random dot stereoacuity threshold. The identical procedure was then performed under timed conditions. On both the contour and the random dot test, the orientation of stereoscopic figures was changed randomly to minimize guessing correct answers by chance. Good distance stereoacuity (both timed and untimed) was defined as an ability to detect differences from 240 to 60 seconds of arc. Superior stereoacuity (both timed and untimed) was defined as an ability to detect differences of 30 to 15 seconds of arc. Following completion of contour and random dot stereoacuity testing, the computer was used to determine a timed distance stereoacuity level for each player. Timing of the test was performed to approximate "game-like" conditions and to minimize the luxury of waiting before giving an answer. A specially written computer program was started when the first stereoacuity target was presented, and it concluded when a player identified all six stereoacuity levels or made two consecutive errors (the program did not provide for alternations and a precise definition of threshold that one would obtain with a staircase procedure).

Finally, from 1993 through 1995, binocular contrast sensitivity testing was done using the Binocular Visual Acuity Tester II-SG/JAC system. This system is composed of a five-point test (1.5, 3.0, 6.0, 12.0, and 20.0 cpd). Each spatial frequency (point) can be tested using any of 31 contrast levels ranging from 0.10% to 98% contrast. Each contrast level differs by equal 0.1-log-unit steps. The Binocular Visual Acuity Tester monitor was placed at a testing distance of 20 feet, and subject answers were submitted to the system by way of the tester joystick. Using the joystick, players were asked to identify the presented sinusoidal gratings as oriented up or down or tilted to the left or right. The Binocular Visual Acuity Tester system automatically selected the next target based on the previous response and used a bracketing method to arrive at the final threshold contrast sensitivity for each spatial frequency. The system also automatically cycled through all five points in increasing spatial frequency and signaled when all testing was completed. The testing physician then printed a report detailing the threshold percent contrast for each of the five spatial frequencies tested. Contrast sensitivity was calculated by dividing 100 by the percent contrast.

Population reference data for distance stereoacuity, controlling for gender (not age), were obtained from a previous study of normal adults.[6] Contrast sensitivity reference data (obtained during the 1984–1985

TABLE 1

VISUAL ACUITY RESULTS* FROM 1992-1995 TESTING OF PROFESSIONAL BASEBALL PLAYERS

YEAR	NO. OF PLAYERS	MAXIMUM (R.E./L.E.)	MINIMUM (R.E./L.E.)	MEAN (R.E./L.E.)	MEDIAN (R.E./L.E.)	MODE (R.E./L.E.)
1992	87	15/15	40/40	16.4/16.4	15/15	15/15
1993	106	10.3/10.3	25.6/20.5	15.1/12.6	14.1/11.5	12.8/10.3
1994	103	9.2/9.2	24/25	13.4/13.8	13/13.5	13.5/13.3
1995	91	8.9/8.9	30/100	13.4/14.2	13/13	13/13.6

*Results are expressed as Snellen denominator.

United States Health-O-Rama in Dayton, Ohio) for the Vistech 6500 contrast test system were supplied by the manufacturer (Keep GF, Vistech Consultants, Inc., unpublished data, written communication, Sept. 1, 1992). Reference data for the Contrast Sensitivity Viewer (Evans DW, unpublished data, written communication, July 16, 1993) and Binocular Visual Acuity Tester[7] tests were provided by their respective manufacturers. Statistical analysis was performed using the independent two-tailed *t* test as well as the chi-square test. A P value of less than .05 was determined to signify a statistically significant result (rejection of the null hypothesis).

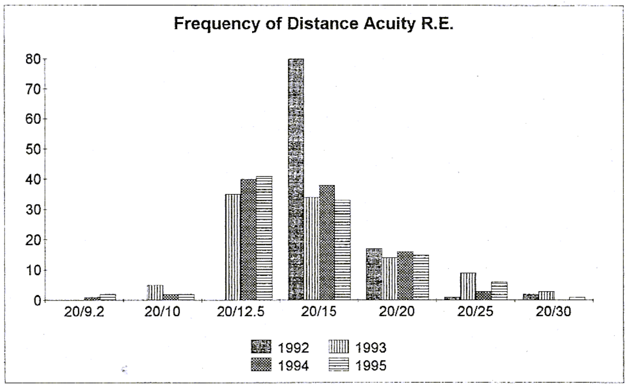

Figure (Laby and associates). Percentage of right eyes achieving each level of visual acuity for each of the testing years (1992–1995). Note that the maximal acuity tested in 1992 was 20/15, which was achieved by approximately 81% of the eyes tested.

RESULTS

DISTANCE VISUAL ACUITY WAS TESTED IN ALL FOUR testing seasons. The results of visual acuity testing of the right and left eyes are presented in Table 1. Although visual acuity was tested in the right and left eyes independently, there was no statistically significant difference in the acuities of the right vs left eyes (P = .838). In the initial 1992 season (87 players), the upper limit of visual acuity testing was 20/15. Review of the 1992 data disclosed that approximately 81% of the players achieved the maximal tested acuity of 20/15. Subsequently, the upper limit of visual acuity was raised to 20/7.5 for the 1993–1995 testing seasons (300 players). The frequencies of occurrence of each level of acuity for each year tested are displayed in the Figure.

Review of the 1993–1995 data reveals that 1.7% (10/600) of the eyes tested had acuity of 20/9.2 or better; 42% (253/600) had acuity of 20/12.5 or better; and 77% (461/600) had acuity of 20/15 or better. Only 1.3% (8/600) of the eyes tested were found to have distance visual acuity of 20/30 or less. Although the vast majority of eyes had excellent acuity, the range of visual acuity was 20/8.9 to 20/100. After removing the 1992 data (87 players), we found no statistically significant difference in the percentage of players achieving each level of visual acuity over the three testing seasons (P > .05).

Five different measures of stereoacuity were used. Distance stereoacuity was measured using the contour and random dot targets for 1992 through 1995. In addition, distance stereoacuity determinations were made under timed and untimed conditions. For 1993 through 1995, near stereoacuity was measured using the Wirt ring test.

Distance stereoacuity was measured using both the

TABLE 2

MEAN AND STANDARD DEVIATION FOR CONTOUR AND RANDOM DOT DISTANCE STEREO TESTING (TIMED AND UNTIMED) OF PROFESSIONAL BASEBALL PLAYERS

YEAR	NO. OF PLAYERS	UNTIMED CONTOUR*		UNTIMED RANDOM DOT*		TIMED CONTOUR*		TIMED RANDOM DOT*	
		MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
1992	87	46	78	89	133	67	95	83	134
1993	107	35	58	77	118	65	83	104	130
1994	104	38	54	76	107	69	92	96	126
1995	89	55	73	98	129	86	127	111	146
Zanoni and Rosenbaum[6]	50	41	38	168	153	N/A†	N/A	N/A	N/A

*All values are expressed in seconds of arc.
†N/A indicates not applicable.

contour and random dot methods. In addition, each test was performed under both timed and untimed conditions. Table 2 displays the results of distance stereoacuity testing during the four testing sessions (1992–1995). The mean distance untimed contour stereoacuity and S.D. ranged from 55 ± 73 to 35 ± 58 seconds of arc. The mean distance untimed random dot stereoacuity ranged from 98 ± 129 to 76 ± 107 seconds of arc. The mean distance timed contour stereoacuity ranged from 86 ± 127 to 65 ± 83 seconds of arc, and the mean distance timed random dot stereoacuity ranged from 111 ± 146 to 83 ± 134 seconds of arc. Timing of the stereoacuity tests reduced the stereoacuity by 15% to 30%. In addition, the random dot stereoacuity test provided a higher mean stereoacuity compared with the contour test on the identical population. Finally, there was no statistically significant difference in the results of distance stereoacuity testing over the study period ($P > .05$).

The distance stereoacuity data were also analyzed in terms of the percentage of players achieving superior stereoacuity. As previously defined, superior stereoacuity was taken to be any score of 30 to 15 seconds of arc on distance stereoacuity testing. Review of the data indicated that 78% (303/389) of the professional baseball players achieved this level on the untimed contour test, 58% (225/387) on the untimed random dot test, 62% (241/387) on the timed contour test, and 51% (197/387) on the timed random dot test.

TABLE 3

RESULTS OF NEAR RANDOT STEREO TESTING OF PROFESSIONAL BASEBALL PLAYERS

YEAR	NO. OF PLAYERS	MEAN*	S.D.*
1993	106	29	25
1994	104	23	10
1995	91	37	83

*Results are expressed in seconds of arc.

The results of near stereoacuity testing are presented in Table 3, which indicates that over the testing period, the near stereoacuity of professional baseball players ranged from 23 ± 10 to 37 ± 83 seconds of arc. Further analysis of these data demonstrates that 81% (244/301) of the players achieved a score of either 20 or 25 seconds of arc whereas only 0.33% (1/301) of the players were unable to identify correctly any of the stereoacuity targets.

Contrast sensitivity was tested with the Vision Contrast Test System in all testing years (1992–1995). Three hundred sixty-four examinations were performed. The means and S.D.s for each spatial frequency (by testing year) are presented in Table 4. There was no statistically significant difference between any of the testing years at any spatial frequency ($P > .05$). During the testing sessions, a significant

TABLE 4

VISION CONTRAST TEST SYSTEM CONTRAST SENSITIVITY TESTING OF PROFESSIONAL BASEBALL PLAYERS

YEAR	NO. OF PLAYERS	1.5 CPD* MEAN (S.D.)	3.0 CPD MEAN (S.D.)	6.0 CPD MEAN (S.D.)	12 CPD MEAN (S.D.)	18 CPD MEAN (S.D.)
1992	87	79 (31)	138 (52)	158 (54)	101 (37)	39 (19)
1993	107	122 (46)	177 (41)	233 (43)	149 (38)	75 (20)
1994	79	108 (37)	179 (33)	211 (44)	142 (37)	64 (22)
1995	91	98 (37)	178 (36)	201 (47)	130 (36)	62 (21)
1984-85†	32	68 (26)	142 (49)	154 (49)	91 (40)	29 (6)

*CPD indicates cycles per degree.
†Keep GF, Vistech Consultants, Inc., unpublished data, written communication, Sept. 1, 1992.

TABLE 5

CONTRAST SENSITIVITY VIEWER CONTRAST SENSITIVITY TESTING OF PROFESSIONAL BASEBALL PLAYERS

YEAR	NO. OF PLAYERS	3 CPD* MEAN (S.D.)	6 CPD MEAN (S.D.)	12 CPD MEAN (S.D.)	18 CPD MEAN (S.D.)
1993	107	94 (31)	159 (47)	84 (22)	31 (8)
1994	79	83 (33)	160 (35)	85 (20)	31 (7)
1995	91	62 (31)	135 (45)	73 (28)	26 (10)
†	23	57 (15)	107 (36)	56 (24)	23 (10)
†	153	37 (13)	67 (26)	38 (19)	16 (8)

*CPD indicates cycles per degree.
†Evans DW, unpublished data, written communication, July 16, 1993.

portion of the players correctly answered the most difficult target on the contrast sensitivity test. Therefore, the percentage of players correctly answering the most difficult level of the test was calculated. Twenty percent (71/364) of the players tested correctly answered the most difficult target at the 1.5-cpd level, 26% (93/364) at the 3.0-cpd level, 40% (146/364) at the 6.0-cpd level, 44% (162/364) at the 12.0-cpd level, and 29% (106/363) at the 18.0-cpd level. These results suggest that the Vision Contrast Test System did not fully evaluate the contrast sensitivity of up to 44% of those players tested.

In addition to the Vision Contrast Test System, contrast sensitivity was evaluated from 1993 through 1995 using the Contrast Sensitivity Viewer. The results of contrast sensitivity testing using this system are presented in Table 5. Once again, there were no statistically significant differences between any of the testing years at any spatial frequency ($P > .05$). In addition, a significant portion of players tested achieved the maximal score possible on this test (36% [101/277] at 3.0 cpd, 45% [124/277] at 6.0 cpd, 56% [155/277] at 12.0 cpd, and 58% [162/277] at 18.0 cpd). These results also indicate that the Contrast Sensitivity Viewer did not completely determine the contrast sensitivity of a significant percentage of those players tested.

The final test of contrast sensitivity was performed from 1993 through 1995 using the Binocular Visual Acuity Tester. The results of this testing are presented in Table 6. Analysis of these results demonstrates no statistically significant difference between any of the testing years at any spatial frequency ($P > .05$). In addition, a much smaller percentage of those tested achieved the maximal level tested on the Binocular Visual Acuity Tester (0.33% [1/301] at 1.5, 3.0, 12.0, and 20.0 cpd; 1.3% [4/301] at 6.0 cpd). The Binocular Visual Acuity Tester can produce targets ranging in contrast from 0.10% to 98%. None of the players required testing using the 0.10% contrast target.

In addition to evaluating these data from a single group of professional baseball players, we analyzed the data further for differences between the major and

TABLE 6

BINOCULAR VISUAL ACUITY TESTER CONTRAST SENSITIVITY TESTING OF PROFESSIONAL BASEBALL PLAYERS

YEAR	NO. OF PLAYERS	1.5 CPD* MEAN (S.D.)	3 CPD* MEAN (S.D.)	6 CPD* MEAN (S.D.)	12 CPD* MEAN (S.D.)	20 CPD* MEAN (S.D.)
1993	106	55 (26)	166 (75)	216 (118)	120 (90)	37 (23)
1994	104	89 (46)	200 (98)	240 (108)	124 (71)	42 (25)
1995	91	66 (36)	191 (76)	263 (117)	140 (76)	47 (32)
Corwin et al[7]	10	59	140	140	47	14

*CPD indicates cycles per degree.

TABLE 7

RESULTS OF STEREOACUITY TESTS FOR BOTH LEAGUES OF PROFESSIONAL BASEBALL PLAYERS

TEST	NO. OF PLAYERS*	MINOR LEAGUE				MAJOR LEAGUE				P†
		MEAN	S.D.	MIN	MAX	MEAN	S.D.	MIN	MAX	
Randot	233/65	31	55	20	800	23	12	20	100	.243
U-Con‡	299/86	47	73	15	480	30	35	15	180	.037
U-Ran‡	297/86	92	126	15	480	62	101	15	480	.047
T-Con‡	297/86	76	106	15	480	55	74	15	480	.077
T-Ran‡	297/86	103	136	15	480	85	127	15	480	.291

*Minor league/major league players.
†P value calculated by independent *t* test.
‡U indicates untimed; T, timed; Con, contour; Ran, random dot.

minor leagues. The results of near stereoacuity and distance stereoacuity testing are presented in Table 7. In addition to the mean, S.D., minimal value, and maximal value, we present the P values resulting from the independent *t* test. Table 7 shows that the major league players did statistically significantly better on distance untimed contour and random dot stereoacuity testing compared with their minor league counterparts (P = .037 and .047, respectively). Although not reaching statistical significance, the major league players outperformed their minor league counterparts on all tests of stereoacuity (at both distance and near). An additional difference between the two leagues is found in the percentage of players achieving a perfect score on each of the four tests of distance stereoacuity (contour and random dot, both timed and untimed). Seventeen (5.7%) of 300 minor league players achieved a perfect score on all tests, whereas 11 (12.8%) of 86 major league players achieved perfect scores of 15 seconds of arc on all four tests of distance stereoacuity. Finally, although there was no statistically significant difference in visual acuity between the two leagues, 1.0% (6/598) of the minor league players had visual acuity of 20/9.2 or better whereas nearly two and one half times more major league players (2.3%; 4/172) achieved this level of visual acuity.

The results of contrast sensitivity testing for players in the two leagues demonstrated only small differences. Table 8 displays the mean, S.D., and minimal and maximal values of each test of contrast sensitivity by league. In addition, the P values resulting from independent *t* test analysis are included. We found statistically significant differences in contrast sensitivity with the Contrast Sensitivity Viewer at 3.0 and 6.0 cpd. There was no statistically significant difference between the two leagues on any of the other tests of contrast sensitivity. The significant difference between the two leagues on the Contrast Sensitivity Viewer at 3.0 and 6.0 cpd can be further highlighted by examining the percentage of players in each league achieving maximal scores. On the Contrast Sensitivity Viewer at 3.0 cpd, 52% (24/46) of the major league players achieved a maximal score, whereas only 33% (76/227) of the minor league players achieved the same score. At the 6.0-cpd level, 61% (28/46) of the major league players and 41% (94/227) of the minor league players achieved maximal contrast sensitivity scores.

DISCUSSION

IT IS COMMONLY ACCEPTED THAT PERSONS IN CERTAIN professions (for example, pilots, marksmen, and athletes) require a high level of visual acuity. Although we expected that professional baseball players had excellent visual acuity, we did not expect to find approximately 81% of the eyes tested in the 1992 season to be at least 20/15. This finding prompted a change in our subsequent testing, with the upper limit of visual acuity increased to 20/7.5.

The normal threshold of acuity is considered to be the ability to resolve targets subtending a visual angle

TABLE 8

RESULTS OF CONTRAST SENSITIVITY TESTING ON MAJOR AND MINOR LEAGUE PROFESSIONAL BASEBALL PLAYERS

TEST*	NO. OF PLAYERS†	MINOR LEAGUE				MAJOR LEAGUE				P‡
		MEAN	S.D.	MIN	MAX	MEAN	S.D.	MIN	MAX	
VCTS 1.5	293/67	102	41	12	170	107	45	12	170	.339
VCTS 3	293/67	168	44	24	220	171	49	15	220	.524
VCTS 6	293/67	202	53	45	260	204	60	5	260	.8
VCTS 12	293/67	132	40	5	170	130	46	8	170	.678
VCTS 18	293/67	61	24	4	90	60	26	4	90	.653
CSV 3	227/46	78	34	10	120	89	35	22	120	.048
CSV 6	227/46	149	45	16	193	165	40	24	193	.024
CSV 12	227/46	80	24	0	99	82	24	12	99	.789
CSV 18	227/46	29	9	0	36	32	7	13	36	.083
BVAT§ 1.5	233/65	2.5	6.5	0.4	98	2.2	2.8	0.5	20	.685
BVAT 3	233/65	0.71	0.59	0.13	6.3	0.64	0.36	0.25	2.5	.386
BVAT 6	233/65	0.71	1.5	0.16	20	0.54	0.36	0.16	2	.372
BVAT 12	233/65	1.9	6.7	0.2	80	1.5	2.3	0.25	16	.653
BVAT 20	233/65	5.3	10	0.5	80	5.6	11	1	80	.833

*VCTS indicates Vision Contrast Test System; CSV, Contrast Sensitivity Viewer; BVAT, Binocular Visual Acuity Tester.
†Minor league/major league players.
‡P values are obtained from independent *t* test.
§BVAT data are presented in original form; to convert to contrast sensitivity values, divide 100 by result.

of 1 minute of arc. The Snellen 20/20 target is composed of elements with a critical dimension of 1 minute of arc. A target of 20/10 would require the ability to resolve critical dimensions of 30 seconds of arc. While the threshold of minimal resolution is considered to be between 30 seconds and 1 minute of arc,[8] the physiologic limit of human visual acuity is believed to be approximately 20/8. The vast majority of professional baseball players in this study had visual acuities better than 20/15, with a large number better than 20/12.5 and several approaching the limit of human vision at 20/8.89.

Although the overall visual acuity of the players was excellent, it is probably even better than our results indicate. The visual acuity testing was performed with the players wearing their usual refractive correction. Following completion of the testing, those players who performed poorly were referred for further evaluation and refraction. The majority of those referred players noted greatly improved visual acuity following refractive correction.

The ability to detect fine differences in depth between two objects using both eyes together is termed stereoacuity. This skill is measured by the smallest amount of detectable horizontal disparity (in seconds of arc). Until recently, a subject's stereoacuity was only routinely measured at a near distance. Now, with the Binocular Visual Acuity Tester, two types of stereoacuity can be measured for distance vision. Excellent stereopsis is important because some authors[9] feel that a batter must determine the ball's position and decide to swing at a pitch when it is still approximately 25 feet away from home plate.

Professional baseball players demonstrated an excellent ability to resolve small stereo disparities. In this study, between one half and three fourths of the players tested were able to resolve stereo disparities of less than 30 seconds of arc. When previously published studies[6] performed on normal binocular subjects are compared with the current data, it becomes clear that professional baseball players possess superior stereoacuity. Table 2 demonstrates that although the mean distance contour stereoacuity is only slightly better in the baseball player group, the mean distance random dot score is much better. This difference becomes even clearer when one compares the percentage of players in each league achieving superior stereoacuity (30 to 15 seconds of arc).

Seventy-eight percent (303/389) of the players vs 68% (34/50) of the reference population had superior stereoacuity on distance contour testing, and a dramatic 58% (225/387) of the players achieved superior stereoacuity on distance random dot testing compared with only 18% (9/50) of the reference population.

We made three different measurements of a player's contrast sensitivity function. Two of the tests (the Vision Contrast Test System and Contrast Sensitivity Viewer) used a fixed-image board, requiring each subject to view identical targets in the same order, whereas the Binocular Visual Acuity Tester uses a video monitor, which allows for a much larger range of possible contrast targets and is thus a more "directed" test of a player's contrast sensitivity. Although significant percentages of the players achieved the maximal contrast sensitivity testable on the Vision Contrast Test System (20% to 44%) and Contrast Sensitivity Viewer (36% to 58%), no player achieved the maximal possible contrast sensitivity on the Binocular Visual Acuity Tester. Thus, it appears that the Vision Contrast Test System and Contrast Sensitivity Viewer did not fully measure the contrast sensitivity of the professional baseball players.

A comparison of the Vision Contrast Test System results obtained from the baseball players to population norms provided by the unit's manufacturer (Keep GF, Vistech Consultants, Inc., unpublished data, written communication, Sept. 1, 1992) reveals a greater contrast sensitivity in the baseball group (Table 4). This difference is largest at the high spatial frequencies (12.0 and 18.0 cpd). Two different reference populations are provided for the Contrast Sensitivity Viewer (Evans DW, written communication, July 16, 1993). The first population is composed of collegiate baseball players and the second is composed of normal 11-year-old children. Table 5 shows that the collegiate baseball players scored midway between the professionals and the normal 11-year-olds. This is probably because of a partial selection process of individuals who excel in baseball and who therefore probably have superior contrast sensitivity.

The Binocular Visual Acuity Tester has the unique ability to test contrast sensitivity over a very large range. This ability, therefore, prevented a large portion of those tested from scoring the maximal possible score on the test. Thus, this test seems to provide a more accurate measure of the contrast sensitivity of the baseball players. A comparison of baseball players' scores with those of the reference population shows once again that the baseball players had a greater contrast sensitivity than those of the population norms[7] (Table 6). As on the previous tests of contrast sensitivity, this difference appears greatest at the high spatial frequencies (confirming the relationship between excellent visual acuity and contrast sensitivity at high spatial frequencies).

After noting better visual acuity, stereoacuity, and contrast sensitivity for baseball players compared with normal populations, we compared the results of the major and minor league players. Because of the relatively small sample size of major league players, a statistically significant difference was noted on only a few tests. Despite this, the major league players scored higher than the minor league players did on almost every visual function test conducted. These differences will probably reach statistical significance as additional athletes are tested. The minor league population is heterogeneous in its composition of players on their way to the major league in addition to those players who will remain at the minor league level. This mixture will create a need for a larger-than-expected sample size to reach a statistically significant difference between the two populations.

Despite the above findings, a distinction between the two leagues was found in the stereoacuity results. Only one half as many minor league players achieved perfect scores on all four tests of distance stereoacuity compared with their major league counterparts (5.7% [17/300] vs 12.8% [11/86], respectively). Stereoacuity appears to be a critical visual function for the baseball player because he is called upon, in both a defensive and an offensive capacity, to make judgments regarding the apparent depth and trajectory of the moving baseball.

This study represents the application of a comprehensive set of visual function tests to both minor and major league professional baseball players. In addition to more standard tests of visual function, we used the new technology of distance stereoacuity testing (both timed and untimed). These data demonstrate that the visual acuity, contrast sensitivity, and distance stereoacuity of professional baseball players are superior to those of the general population and also show differences between major and minor league players.

Excellent visual acuity, stereoacuity, and contrast sensitivity are important to both offensive players (the batters) and defensive players (pitchers, catchers, and fielders).

Bahill and LaRitz[9] studied the ability of a batter to watch a pitch come toward the plate. They found that batters were able to follow a pitch only to within five feet of the plate. This was because of the angular velocity (almost 500 degrees per second) of a pitch as it crossed the plate, whereas the fastest eye movement they found was 150 degrees per second. Solomon, Zinn, and Vacroux,[5] who studied the Chicago Cubs baseball team in 1988, noted that it took approximately 400 milliseconds from the time a pitcher released the ball until it crossed the plate. They also reported that 200 milliseconds was needed from the time a swing was initiated until the bat crossed the plate. Thus, a batter would have to decide within the first 200 milliseconds whether or not to swing at the pitch. Certainly, those players with an increased ability to determine the exact placement of the ball in three-dimensional space (by taking advantage of superior visual acuity and stereoacuity) would have a greater chance of connecting the bat with the ball as it crossed the plate.

Increased contrast sensitivity is useful at all player positions, from that of the outfielder, who must follow a batted ball against the changing background of the spectators in the stands and the blue (or dark) sky, to that of the pitcher, who must detect the precise placement of the catcher's glove against the catcher's and the umpire's uniforms. Our data are in agreement with those of Hoffman, Polan, and Powell,[4] who found that collegiate varsity baseball players had greater contrast sensitivity than controls did. Whether contrast sensitivity is a skill learned by professional baseball players or one for which they are naturally selected has yet to be understood.

A player's performance depends on a multitude of factors, including practice, physical conditioning, motivation, and speed. Visual functions have been examined extensively both in the current study and in previous studies. By highlighting the differences between professional baseball players and the general population, we hope to understand further the level of visual function necessary for a successful career in professional baseball. Further studies are planned to measure a player's visual abilities over several seasons.

ACKNOWLEDGMENTS

The authors would like to thank the Los Angeles Dodgers, who referred all of the patients for this study, and Mentor O & O, Inc., who donated materials for this study.

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