The Hand-eye Coordination of Professional Baseball Players: The Relationship to Batting

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SIGNIFICANCE: A visuomotor skill (eye-hand visual-motor reaction time [EH-VMRT]) important for baseball performance is described. Eye-hand visual-motor reaction time represents the integration of visual information, perceptually based decisions, and motor movements to accomplish a specific task. The speed at which this occurs depends on many factors, some visual, some perceptual, and some motor related.

PURPOSE: The purpose of this study was to describe the EH-VMRT ability and evaluate its relationship to the baseball batting performance of professional baseball players.

METHODS: A commercially available EH-VMRT system was used on 450 professional baseball players. Results were retrospectively compared with standard, career, plate discipline metrics.

RESULTS: Statistically significant correlations were found between the EH-VMRT metrics and plate discipline batting metrics. Better EH-VMRT ability also correlated with longer service in, and likelihood to achieve, the major-league level. The better (top 20%) EH-VMRT group had three fewer at bats before gaining a walk (22% decrease), as well as swinging 10 to 12% less often at pitches outside the strike zone and 6 to 7% less often at pitches in the strike zone as compared with the bottom 20% group. In addition, EH-VMRT displays a threshold-like relationship with the ability to gain a walk.

CONCLUSIONS: These results describe the EH-VMRT ability of professional baseball players and show a significant relationship between the EH-VMRT ability and batting performance. These results may suggest a possible role in player selection, indicating that batters with better EH-VMRT may be more likely to reach the major-league level and be more productive for their team. Further studies will be needed to demonstrate whether training better EH-VMRT results in improved batting performance.

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The synchrony between the visual system and the motor system is a critical component to human action. The skill of coordinating eye and body movements, sometimes called eye-hand visual-motor reaction time and defined as the elapsed time between the presentation of a visual stimulus and the completion of a motor response with the hand,[1] is particularly important in high-speed sport movements such as hitting a pitch in baseball.

Many authors[2,3] have described eye-hand visual-motor reaction time as a series of decisions and resulting motor movements to accomplish a specific task. In fact, eye-hand visual-motor reaction time represents the integration of visual information, perceptually based decisions, and motor movements to accomplish a specific task. The speed at which this occurs depends on many factors, some visual, some perceptual, and some motor related. It is possible that eye-hand visual-motor reaction time encompasses several different tasks that are not identical. For example, it is possible that a pointing or reaching movement is different from estimating when or where a moving target will arrive and be intercepted, as required to hit a pitched baseball. It is unclear if the motor components and/or the perceptual components of each task are related.

In terms of vision, the literature[4] describes the average static Snellen visual acuity of professional baseball players as 20/12. Description of the average refractive error and optical aberration of the eyes of professional baseball players has shown that the visual system is driven by low-order optical aberrations, with no significant high-order aberrations present.[5] Similarly, the stereo acuity as well as the contrast sensitivity of this population appears to be superior to that found in the general population.[3]

Several authors[6] have described the perceptual tools used by athletes to optimize eye-hand visual-motor reaction time ability, including the construction of a series of programmed responses to specific visual information. These models, based on previous experience, enable the elite athlete to select a pre-programmed motor action, allowing them to appear able to "predict" future events as opposed to simply reacting.

In addition, the literature reveals that eye-hand visual-motor reaction time has been tested using several devices in many different sports over the past decades. In 1983, Sherman[7] described the use of the Wayne Saccadic Fixator to evaluate eye-hand visual-motor reaction time in athletes. Sherman[7] described that, of the 16 collegiate sports populations he tested (both amateur and collegiate), the collegiate baseball players had among the best eye-hand visual-motor reaction time in his collegiate cohort. Detail as to the level of the collegiate and professional players was not provided in the report.

Ellison et al.[8] described their use of another eye-hand visual-motor reaction time testing system, the Sports Vision Trainer. In this report, the authors found using limits of agreement analysis that the system had a high retest reliability ($r = 0.82$ to 0.89). Wells et al.[9] described their experience using the Dynavision D2 eye-hand visual-motor reaction time testing system. The authors found the Dynavision D2 system to be a reliable device given that "adequate practice is provided," consisting of one to three familiarization trials before testing. As described previously, many systems are available to assess a subject's eye-hand visual-motor reaction time with none considered to be the criterion-standard measure.

Zupan et al.[10] found that users of eye-hand visual-motor reaction time systems could be trained to improve eye-hand visual-motor reaction time results. In their study, trained athletes using the Sports Vision Trainer device showed a 25% improvement after training. The potential for improved eye-hand visual-motor reaction time suggests the possibility that training could result in improved on-field performance, if eye-hand visual-motor reaction time is in fact related to baseball performance.

In this report, we describe the normal levels of eye-hand visual-motor reaction time for professional baseball players, using a commercially available test system. In addition, we hypothesize that eye-hand visual-motor reaction time is related to batting performance, and this report describes the relationship between eye-hand visual-motor reaction time and batting ability in a large cohort of professional baseball players.

METHODS

Participants

Four hundred fifty professional baseball players were included in this analysis. Athletes were evaluated during the 2012 to 2013 and 2015 Major League Baseball spring training seasons. In the event that any single player was tested more than once during that period, only their most recent results were included in the analysis. Thus, each member of the cohort represented a single professional baseball player. One hundred five athletes were major league players, whereas 345 were minor league players. The average length of major league service for the major league players was (mean ± SD) 3.9 ± 3.6 years and was 0.14 ± 0.17 years for the predominantly minor league players, who may have had a brief assignment in some cases to the major league. Assignment to the major or minor league was by the individual teams; we did not use league assignment in our analysis. The major league players had, on average, 3563 ± 1719 individual at bats per player, whereas the minor league players had an average of 1134 ± 920 at bats per player. All athletes were male and represented a total of six professional (Major League Baseball) baseball clubs and their affiliated minor league teams. This retrospective review was approved by the State University of New York, College of Optometry, Institutional Review Board and conformed to tenets of the Declaration of Helsinki.

Materials and Design

The Sports Vision Trainer system (Sports Vision PTY Ltd., Sydney, Australia) is a 32 sensor-pad touch board, arranged in an 8×4 linear pattern, which is portable and was carried from team to team each spring. The board was always used in the landscape orientation with the subject facing the board at arm's length. In general, the task involves pressing each lit circle as quickly as possible. Each light is covered, and surrounded, by a pressure-sensitive touchpad, which registers the subject's touch. Lights may be either green or red depending on the task as described below and are randomly presented for each trial, with no light lit more than once per trial.

Testing Procedure

The first of the two testing modes is termed *Proactive* (ProMean). In this configuration, a small red LED on the board illuminates, and the player is asked to press/strike the lighted target as quickly as possible. Once the light is pressed, the light turns off, and another red LED positioned randomly (some centrally and some peripherally) on the board immediately illuminates, and the player once again must press that light as quickly as possible. The Sports Vision Trainer records, in milliseconds, the total time it takes the player to hit the 20 randomly positioned targets. The aim in this mode is to strike the 20 lights as quickly as possible to obtain the shortest total overall elapsed time for all lights presented. Consistent with the published literature[11] and to ensure adequate training and thus a reliable result, each subject was tested five times, with the final three results averaged for a recorded Proactive (ProMean) score recorded in milliseconds. This accounted for any possible effect of learning. No subject used the board, or underwent testing, more than once in a 12-month period.

The second mode is called *Reactive*. In this mode, the randomly displayed 20 red lights are turned on and off at a given pre-set interval. Thus, the athlete's task is to strike the red light before it turns off to achieve success and receive credit for that particular target. This mode is run twice. Initially, the red lights are illuminated for 600 milliseconds each (Reactive 0.6), whereas for the second run they remain illuminated for 400 milliseconds each (Reactive 0.4). The subject's score is determined by the percentage of successfully hit targets on each of the two runs.

The reactive mode has an additional protocol that is termed *Go-NoGo* (GNoG). In this configuration, the 20 randomly chosen green or red lights are illuminated initially for 600 milliseconds, and then the 20 targets are repeated for 400 milliseconds each. The athlete is instructed to only hit the green lights and to let the red lights turn off on their own without being struck. The system records the percentage of red lights (NoGo) hit and percentage of green (Go) lights struck, respectively (GNoG Red or GNoG Green). Of the 20 randomly placed lights in this mode, 80% are green and 20% are red. Ideally, a subject should hit all of the *Go* green lights and none of the *NoGo* red lights in this protocol.

The lights are presented both centrally and peripherally in the subject's visual field and are presented in a random order for each trial, of each mode.

Plate Discipline Metrics

Baseball batting metrics, which are more exclusively dependent on a batter's own ability with minimal, if any, influence by the abilities of the defensive players, have been developed. These measurements have been termed *plate discipline* because they reflect the batter's ability to swing at pitches he feels he can hit successfully while not swinging at balls outside the strike zone or ones within the strike zone that he is not able to successfully put into play.

The decision to swing at a pitch that is in or out of the strike zone and deciding to swing at a pitch that is a fastball and not swing at other types of off-speed pitches are all related to a batter's visual ability and hand-eye coordination. Therefore, five measures of batting ability that appeared to be most related to visual ability were chosen (see below). In addition, we looked at two additional metrics (highest level obtained and years of major league service) to gauge the effect of experience (or age) on the visual metrics.

Plate discipline metrics:

1. Out-of-zone chase percentage is the percentage of swings on all pitches deemed outside strike zone. Lower value is preferred.
2. Fastball chase percentage is the percentage of swings on only fastballs outside the strike zone. Lower value is preferred.
3. In-zone swing percentage is the overall swing percentage of all pitches in the strike zone. Lower value indicates a more discerning batter.
4. In-zone fastball swing percentage is the overall swing percentage of fastballs in the strike zone. Lower value indicates a more discerning batter.
5. At bats per base on ball is the number of at bats before a walk is gained. Lower value is preferred. It is also known as *walk rate* or *base on balls*.

Additional metrics:

1. Highest level is the measure of how a player has progressed through the different levels of Major League Baseball. Level 1 represents the major league (expert) level, and level 5 represents the A (novice) level.
2. Major league service is the total number of years at the major league level in professional baseball.

Additional detail regarding plate discipline statistics can be found at https://www.fangraphs.com/library/offense/plate-discipline/ or https://www.fangraphs.com/tht/introducing-plate-discipline-stats/.

Although the plate discipline values for this study were provided by the Major League Baseball teams, they are also available publicly, online, at various Web sites such as www.baseballprospectus.com or www.fangraphs.com.

Statistical Method

The results were tabulated on a Microsoft Excel spreadsheet. Career plate discipline statistics, for each athlete, were then combined with the eye-hand visual-motor reaction time data. These statistics were used for analysis, as they provided the best overall measure of a batter's skill, minimizing the effect of any seasonal fluctuations. Descriptive statistics, Fisher skewness, and Fisher kurtosis as well as histograms describing the data distribution were calculated for each eye-hand visual-motor reaction time metric as well as for each plate discipline metric. In addition, the Student *t* test was used to compare the different eye-hand visual-motor reaction time results to each other. Pearson correlation coefficients were then calculated between each of the eye-hand visual-motor reaction time results (AnalystSoft Inc., Walnut, CA, StatPlus: mac, statistical analysis program for Mac OS version 5 and SAS version 9.4). Microsoft Excel was used to graphically plot the Proactive score (ProMean) against Reactive 0.4 and GNoG 0.4 Green. Best fit linear regression lines were placed on the plot along with the line's formula.

Pearson correlation coefficients were then calculated between the ProMean result and each of the plate discipline metrics. There are a total of five performance related plate discipline metrics and two descriptive metrics (highest level and major league service). In an effort to avoid type I error, the Bonferroni correction was calculated. We performed 25 correlation calculations (five eye-hand visual-motor reaction time tests × five plate discipline metrics) in this portion of the analysis, resulting in an adjusted *P* value for statistical significance at the 95% confidence limit of .002 (0.05 divided by 25).

To calculate the top and bottom 20% quintiles for each of the plate discipline metrics based on ProMean ability, we sorted the complete database by ProMean score. After the sorting, we separated the database into five equal groups (quintiles) and calculated descriptive statistics for each quintile. This process was repeated to determine the effect of major league experience and highest level.

The Student *t* test was used to evaluate the differences between the top and bottom 20% groups for each of the five plate discipline metrics as determined by ProMean score as well as by major league experience. Once again, in an effort to avoid type I error, the Bonferroni correction was calculated. In this case, we performed five correlation calculations. Thus, in this portion of the analysis, the adjusted *P* value for statistical significance at the 95% confidence limit is .01 (0.05 divided by 5).

The percent difference between the top and bottom 20% groups for each plate discipline metric, when sorted by Proactive score, was calculated by subtracting the top 20% score from the bottom 20% score then dividing that result by the bottom 20% score and expressing the quotient as a percentage. Positive values indicate that the top 20% result was better compared with the bottom 20% value. The opposite was true for negative values.

In addition, each plate discipline metric was fully studied in relation to the ProMean results. For this evaluation, a plot of each plate discipline metric (e.g., at bats per base on balls) versus each quintile was created as well as a calculation of mean and SD, and finally, a comparison, using the two-sample *t* test (two-tailed) between each possible quintile combination of each plate discipline metric, was performed.

Once again, in an effort to avoid type I error, the Bonferroni correction was calculated. In this case, we performed 30 correlation calculations. Thus, in this portion of the analysis, the adjusted *P* value for statistical significance at the 95% confidence limit is .002 (0.05 divided by 30).

RESULTS

Normative Values for Professional Baseball Players

Descriptive statistics for each of the eye-hand visual-motor reaction time variables are shown in Table 1. For both the GNoG Red 0.6 and the GNoG Red 0.4, the average result was close to zero. In fact, despite the 200-millisecond difference in presentation time, two-sample *t* test analysis showed no significant difference between the GNoG Red 0.6 and 0.4 tests. In addition, statistically significant differences ($P < .0001$) between each of the other eye-hand visual-motor reaction time tests were found. Therefore, it was determined that the GNoG Red results do not play a role in understanding the relationship between plate discipline ability and eye-hand visual-motor reaction time and would not be considered in further analysis moving forward.

TABLE 1. Descriptive statistics of Sports Vision Trainer scores for each testing protocol with SD as well as minimum and maximum value for 450 professional baseball players (GNoG = Go/NoGo)

	Proactive (ms)	Reactive 0.6 (%)	Reactive 0.4 (%)	GNoG Green 0.6 (%)	GNoG Red 0.6 (%)	GNoG Green 0.4 (%)	GNoG Red 0.4 (%)
Average	9275	92	58	87	3	42	2
SD	1333	8	23	11	8	21	7
Minimum	5841	55	0	5	0	0	0
Maximum	15,757	100	100	100	40	93	60

Figs. 1 and 2 demonstrate the distribution of results for each of the eye-hand visual-motor reaction time tests. The histograms for Proactive, Reactive 0.4, and GNoG Green 0.4 demonstrate an approximate normal distribution of the results as determined by evaluation of skewness and kurtosis, whereas the Reactive 0.6 and the GNoG Green 0.6 data show a large negative skew to the right, indicating an uneven data distribution and ceiling effect. This grouping of results at the high-end suggests that the task was not sufficiently difficult for this cohort (i.e., ceiling effect).

The results of Pearson correlation analysis for the eye-hand visual-motor reaction time tests are presented in Table 2. Statistically significant correlations ranged from 0.71, between Reactive 0.4 and GNoG Green 0.4, to 0.20, between Reactive 0.6 and GNoG Green 0.4. There is a relatively high correlation between the Proactive score with Reactive 0.4 (r = –0.67) and with GNoG Green 0.4 (r = –0.56). The Reactive 0.6 and GNoG Green 0.6 data are not included in additional analyses, as they were either identical or not sufficiently difficult and thus not helpful in differentiating subject's eye-hand visual-motor reaction time ability.

In light of the correlations noted previously between the Proactive score and the Reactive 0.4 and GNoG Green 0.4 scores, we plotted the Proactive score versus both the Reactive 0.4 and GNoG Green 0.4 scores and found that both best fit lines had similar slopes (Fig. 3). This suggests that they are equivalent in so much, as athletes who performed well on one test also performed well on the other. The correlations were relatively high, suggesting that only one of these tests was necessary to differentiate athletes in terms of eye-hand visual-motor reaction time. Thus, Proactive score (ProMean) was chosen as the best single descriptor of eye-hand visual-motor reaction time in this population.

The Relationship between Eye-hand Visual-motor Reaction Time and On-field Performance

Pearson correlation coefficients were calculated for the Proactive score (ProMean) and each of the five plate discipline metrics along with the two descriptive measures of highest level and years of major league service. Statistically significant correlations at the $P < .05$ level were noted for all analyses. Proactive ability demonstrated a correlation coefficient of 0.20 with highest level and –0.10 with major league service, indicating that players who had better eye-hand visual-motor reaction time had longer major league careers and obtained a higher level of play (i.e., major league instead of minor league). When compared with the plate discipline metrics, the correlation coefficient (r) as well as r^2 values for Proactive ability with out-of-zone chase percentage was $r = 0.17$ and $r^2 = 0.03$, $r = 0.21$ and $r^2 = 0.04$ with fastball chase percentage, $r = 0.25$ and $r^2 = 0.06$ with in-zone swing percentage, $r = 0.18$ and $r^2 = 0.03$ with in-zone fastball swing percentage, and $r = 0.24$ and $r^2 = 0.06$ with at bats per base on ball. All correlations between Proactive ability and the five plate discipline metrics were $P < .0001$.

Although the correlations are considered small to moderate in size, likely due to the many factors that are necessary for successful batting in baseball, they are highly unlikely to be due to chance, indicating that eye-hand visual-motor reaction time likely accounts for a portion of the variability in plate discipline.

When multiple correlations are performed, the Bonferroni correction may be considered in an effort to reduce type I error. In the previous correlation analysis, we performed seven correlation calculations. Thus, only P values less than .05/7 or .007 may be considered statistically significant. At this stricter definition, all of the Proactive correlations remain statistically significant with all the plate discipline metrics, although one of the descriptive measures, major league service, is no longer significant.

In addition, we compared the plate discipline ability of the baseball players with the best eye-hand visual-motor reaction time ability (top 20% of Proactive scores) with those with the worst eye-hand visual-motor reaction time ability (bottom 20% of Proactive scores). Table 3 details this comparison. For each plate discipline metric, the average, SD, and 95% confidence ranges of the two groups are compared (Student t test), and a measure of statistical significance is listed (P value). A statistically significant difference was found between the players with excellent eye-hand visual-motor reaction time and those with poor eye-hand visual-motor reaction time at the $P < .05$ level. Differences ranged from 6 to 22%, with the difference in at bats per base on ball (walk rate) being the largest with a 22% decrease in the number of at bats before a walk occurred in those players with excellent eye-hand visual-motor reaction time. For example, the number of at bats occurring before a walk was lower in the athletes who scored in the top 20% of Proactive ability (10.2; 95% confidence interval, 9.5 to 10.9) as compared with the number of at bats required for a walk in the bottom 20% (13.1; 95% confidence interval, 12.0 to 14.2) Proactive ability group (two-sample $t_{90} = -4.20$; $P = .0001$).

Having performed five statistical evaluations in regard to plate discipline (top vs. bottom 20% for each of the five plate discipline metrics), a Bonferroni correction may be applied. In this case, only P values less than .05/5 (.01) can be considered statistically significant. At this stricter definition, all comparisons between Proactive score and the five plate discipline metrics remained statistically significant (Table 4).

To address the possibility that the difference in plate discipline was related in fact to experience, and not Proactive ability, we sorted the data set by major league experience and evaluated the plate discipline ability of the most experienced 20% against the same abilities in the least experienced 20% group. This evaluation showed an average Proactive score in the most experienced players of 9024 milliseconds, whereas a score of 7961 milliseconds was

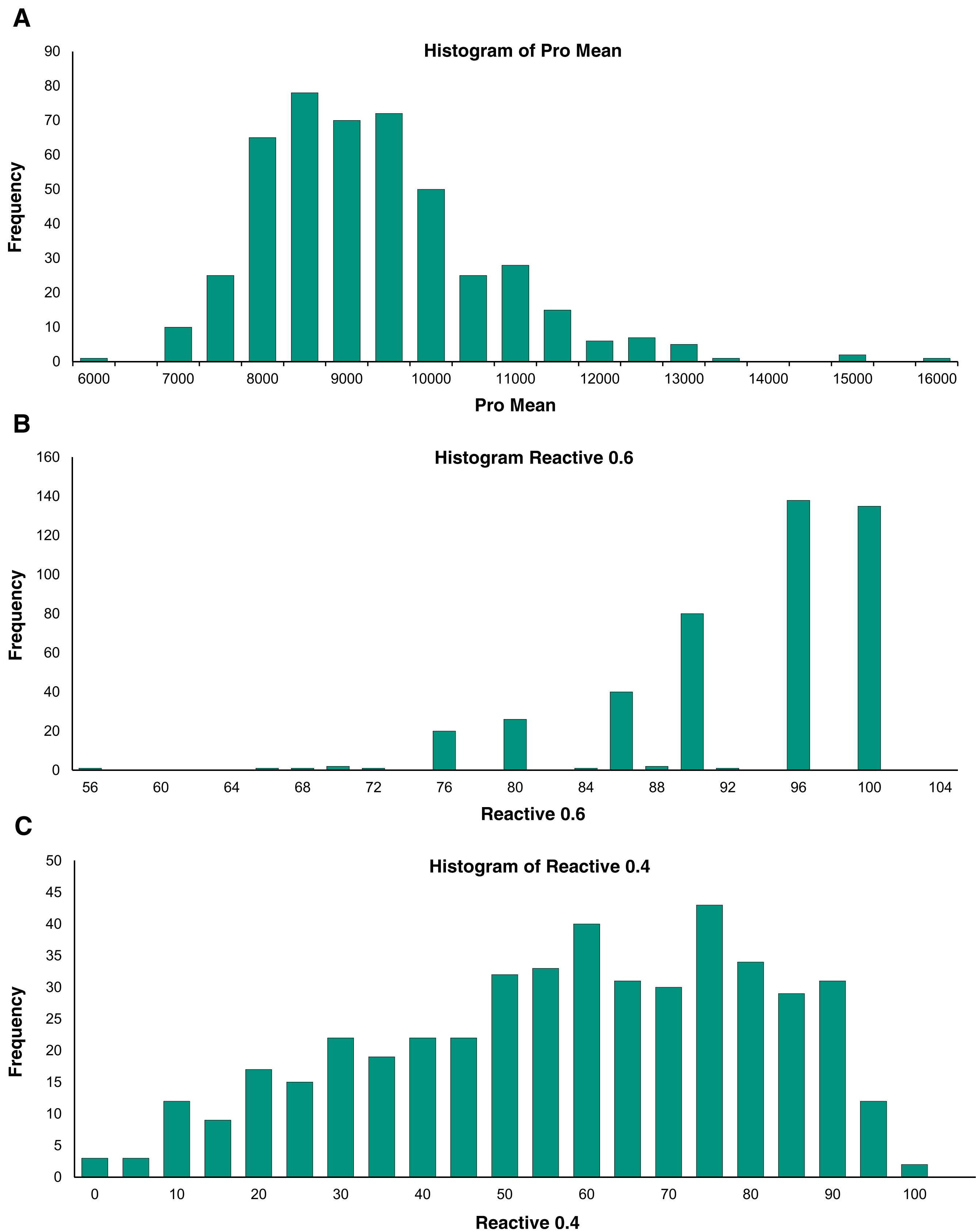

FIGURE 1. Histogram for three of the test protocols used, demonstrating Proactive, Reactive 0.6, and Reactive 0.4 scores. Note that the Reactive 0.6 test results are bunched to the right, indicating a ceiling effect resulting in poor ability to differentiate players.

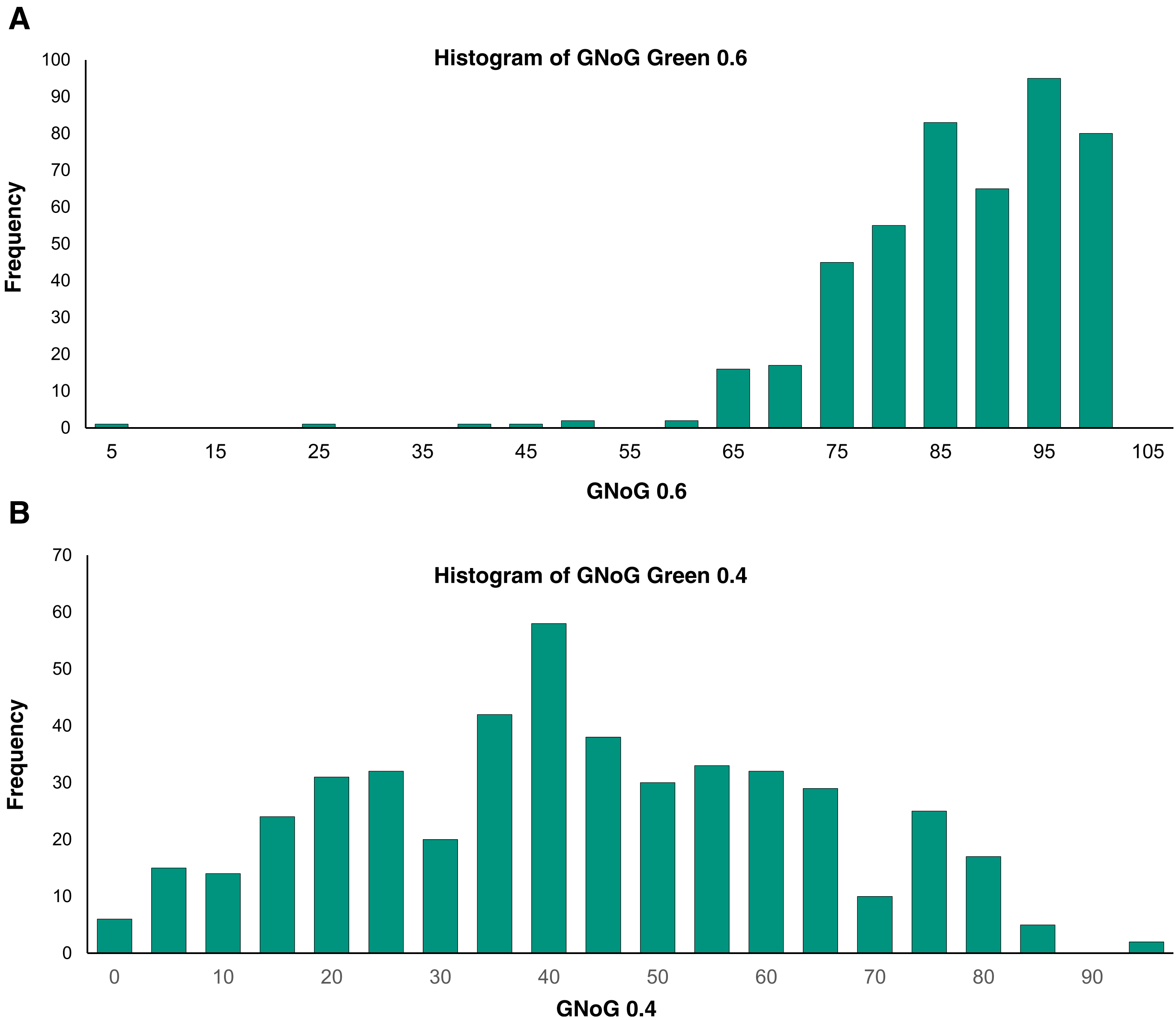

FIGURE 2. Histogram for the Go/NoGo protocols, including GNoG 0.6 Green and GNoG 0.4 Green. Note, as above, that the GNoG 0.6 Green test results are also bunched to the right, indicating that a high percentage of the players scored very well on these tests, resulting in poor ability to differentiate.

noted in the least experienced group ($P < .0001$). In addition, out-of-zone chase percentage was 0.290 versus 0.255 ($P < .0001$), fastball chase percentage was 0.130 versus 0.142, in-zone swing percentage was 0.631 versus 0.642, in-zone fastball swing percentage was 0.629 versus 0.652, and at bats per base on ball was 11.390 versus 10.353 in the least experienced batters. All *t* tests showed nonsignificance, except where noted.

Figs. 4 and 5 contain interval plots of the plate discipline measures versus Proactive scores by Proactive quintile (20%). For at bats per base on ball, the best four quintiles were relatively equal in their mean at bats per base on ball, with the fifth (worst) quintile being different. This accounts for the statistical difference between the top 20% and bottom 20% of eye-hand visual-motor reaction time ability in at bats per base on ball result. In addition, only the worst quintile group (bottom 20%) had a poor walk rate (at bats per base on ball), whereas the other quintiles had essentially the same better walk rate.

In terms of in-zone swing percentage and in-zone fastball swing percentage, a more linear relationship is evident from the graphical figure. In this case, though, despite a statistically significant difference between quintiles one and five and one and four, there was no difference noted between the other quintile comparisons (Table 5). In addition, a large amount of overlap of the 95% confidence intervals was noted, especially in quintiles two, three, and four, suggesting that these are not actually different.

Review of the out-of-zone chase percentage and fastball chase percentage figures (Fig. 5) suggests a similar relationship as noted directly previously. Specifically, a significant difference between the best and worst quintile was noted, with no real difference noted between the middle 60% group. Again, the data demonstrate that

TABLE 2. Correlation coefficient (*r*) with level of statistical significance (*P*) below, for each pair of Sports Vision Trainer tests (GNoG = Go/NoGo)

	Proactive	Reactive 0.6	Reactive 0.4	GNoG Green 0.6	GNoG Red 0.6	GNoG Green 0.4
Reactive 0.6	–0.46					
	<.0001					
Reactive 0.4	–0.67	0.30				
	<.0001	<.0001				
GNoG Green 0.6	–0.34	0.32	0.31			
	<.0001	<.0001	<.0001			
GNoG Red 0.6	–0.02	–0.01	0	–0.15		
	.75	.89	.98	.002		
GNoG Green 0.4	–0.57	0.21	0.71	0.35	–0.09	
	<.0001	<.0001	<.0001	<.0001	.048	
GNoG Red 0.4	0.01	0.02	0.06	–0.01	0.30	–0.06
	.88	.67	.18	.76	<.0001	.23

athletes with poorer eye-hand visual-motor reaction time have poorer plate discipline ability in this plate discipline metric as compared with players with the top 20% eye-hand visual-motor reaction time ability.

DISCUSSION

The ability to successfully hit a pitched baseball depends on many factors. Clearly, visual ability is important but is certainly only part of what is needed. Previous research[4] has noted that the visual ability, measured through visual acuity, of the average professional baseball player is approximately 20/12. This report describes another different aspect of visually related ability, specifically hand-eye coordination (eye-hand visual-motor reaction time), and its relationship to batting ability. Our hypothesis was that the Sports Vision Trainer test was a proxy for batting proficiency as measured by several plate discipline metrics despite the fact that the Sports Vision Trainer task and batting are different. By evaluating a batter's visual function as it relates to the decision to swing at a pitch (plate discipline), we gain insight regarding the many visual functions required for elite batting performance as well as create visual criteria that may be useful in predicting which batters will be more successful.

Review of the basic Sports Vision Trainer results indicates that the average Proactive score for this cohort of professional baseball

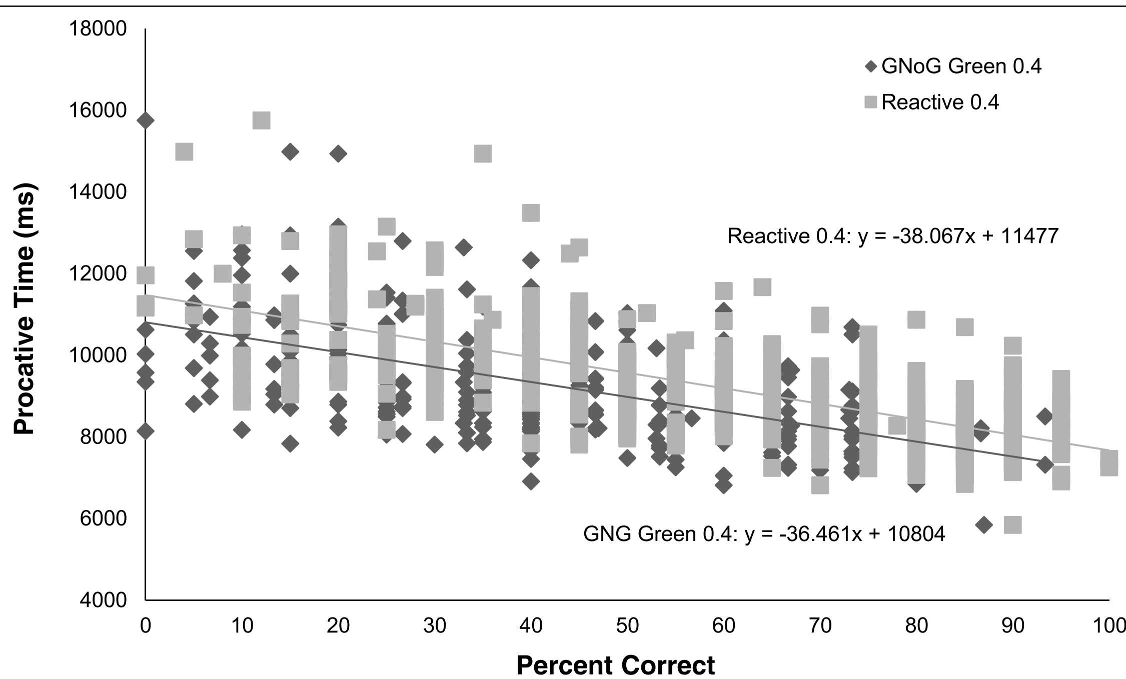

FIGURE 3. Proactive score plotted against both Reactive 0.4 and GNoG 0.4 Green percent correct scores. Best fit linear regression line, with its equation, is included. The slopes of each of the two best fit lines are similar, indicating a parallel relationship to Proactive ability.

TABLE 3. Plate discipline metrics when sorted by Proactive score for all athletes

	Mean Top 20%	SD Top 20%	95% CI Top 20%	Mean Bottom 20%	SD Bottom 20%	95% CI Bottom 20%	*P*	Pct top 20% better than bottom 20%
Highest level	1.59	1.449	1.291–1.890	2.26	1.444	1.962–2.559	.004	30
MjService	1.429	2.861	0.838–2.020	0.595	1.881	0.207–0.984	.02	140
OvChasePct	0.264	0.063	0.251–0.278	0.293	0.075	0.278–0.309	.01	−10
fbChasePct	0.134	0.036	0.127–0.142	0.152	0.049	0.142–0.162	.01	−12
inZSwPct	0.625	0.052	0.614–0.635	0.672	0.064	0.659–0.685	<.001	−7
inZfbSwPct	0.629	0.062	0.616–0.642	0.67	0.066	0.656–0.684	<.001	−6
abbb	10.2	3.5	9.477–10.939	13.1	5.5	11.972–14.249	<.001	22

abbb = walk rate or at bats per base on ball; CI = confidence interval; fbChasePct = fastball chase percentage; inZSwPct = in-zone swing percentage; inZfbSwPct = in-zone fastball swing percentage; MjService = Major League Service; OvChasePct = out-of-zone chase percentage; Pct = percentage.

players was 9275 milliseconds with a fairly wide range of values spanning from a speedy 5841 milliseconds to a rather slow 15,757 milliseconds. In general, the Reactive tests (both Reactive and GNoG) performed at 600-millisecond display times were too easy for this group, with the 400-millisecond display times providing a more challenging test environment leading to a more normal distribution of the results. In addition, for this cohort of professional baseball players, the GNoG Red 0.6 and 0.4 results were not meaningful owing to the fact that the overwhelming majority of subjects did not strike any of the red lights when tested (as desired), resulting in near zero means for each. Although very few red lights were struck, they apparently serve to make the test more difficult as noted in the reduced correct percentage between the Reactive scores and the GNoG scores (92% reduced to 87% for the Reactive 600 vs. GNoG Green 600 and 58% reduced to 42% for the Reactive 400 vs. the GNoG Green 400 correct scores).

Correlation (*r*) values for the Sports Vision Trainer test showed significance in the Proactive, Reactive 0.4, and GNoG Green 0.4 results with most of the plate discipline metrics. The low magnitude of the correlations themselves is not surprising when one considers the multiple visual, as well as physical, abilities that are critical to batting performance. It would not be expected that hand-eye coordination alone would be highly correlated to batting performance, as many additional visual factors such as visual acuity, anticipation, and visual concentration, to name only a few, likely play a role in batting performance as well as the obvious physical factors such as strength, timing, and experience. In addition, as shown in Fig. 4 in regard to the Proactive ability and walk rate (at bats per base on ball), there appears to be a threshold relationship as opposed to a linear relationship between eye-hand visual-motor reaction time and plate discipline ability. In a threshold type of relationship, one would expect a lower correlation than would be seen in a linear relationship between two variables. Thus, it is reasonable that hand-eye coordination accounts for a maximum of 6% ($r = 0.25$, $r^2 = 0.06$) of the variability in the plate discipline metrics.

Another method of evaluating the role of eye-hand visual-motor reaction time in plate discipline is to compare the plate discipline ability of the players with the best (top 20%) hand-eye coordination with those of the worst (bottom 20%) hand-eye coordination. We noted that statistically significant differences were found in the plate discipline metrics considered. Specifically, a 22% difference in the ability to walk (at bats per base on ball) and a 10 to 12% difference in swinging at pitches outside the strike zone (out-of-zone chase percentage and fastball chase percentage) were noted between the two groups of eye-hand visual-motor reaction time ability. Other trends included the finding that players with more major league experience had better Proactive scores and players

TABLE 4. Mean and SD for plate discipline metrics when sorted by quintiles for all athletes

	Q1		Q2		Q3		Q4		Q5	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ProMean	7740	412	8482	169	9091	190	9743	209	11,319	1090
abbb	10.208	3.538	10.46	4.052	10.281	3.817	11.289	4.105	13.11	5.512
inZSwPct	0.625	0.052	0.642	0.06	0.649	0.069	0.653	0.059	0.672	0.064
inZfbSwPct	0.629	0.062	0.648	0.065	0.657	0.079	0.661	0.061	0.67	0.066
OvChasePct	0.264	0.063	0.258	0.06	0.254	0.063	0.281	0.065	0.293	0.075
fbChasePct	0.136	0.033	0.134	0.031	0.13	0.034	0.144	0.038	0.156	0.044

abbb = number of at bats before a walk is gained (lower value preferred); fbChasePct = percentage of swings on only fastballs outside the strike zone (lower value preferred); inZfbSwPct = overall swing percentage of fastballs in the strike zone (lower value indicates a more discerning batter); inZSwPct = overall swing percentage of all pitches in the strike zone (lower value indicates a more discerning batter); OvChasePct = percentage of swings on all pitches deemed outside strike zone (lower value preferred); Q = quintile.

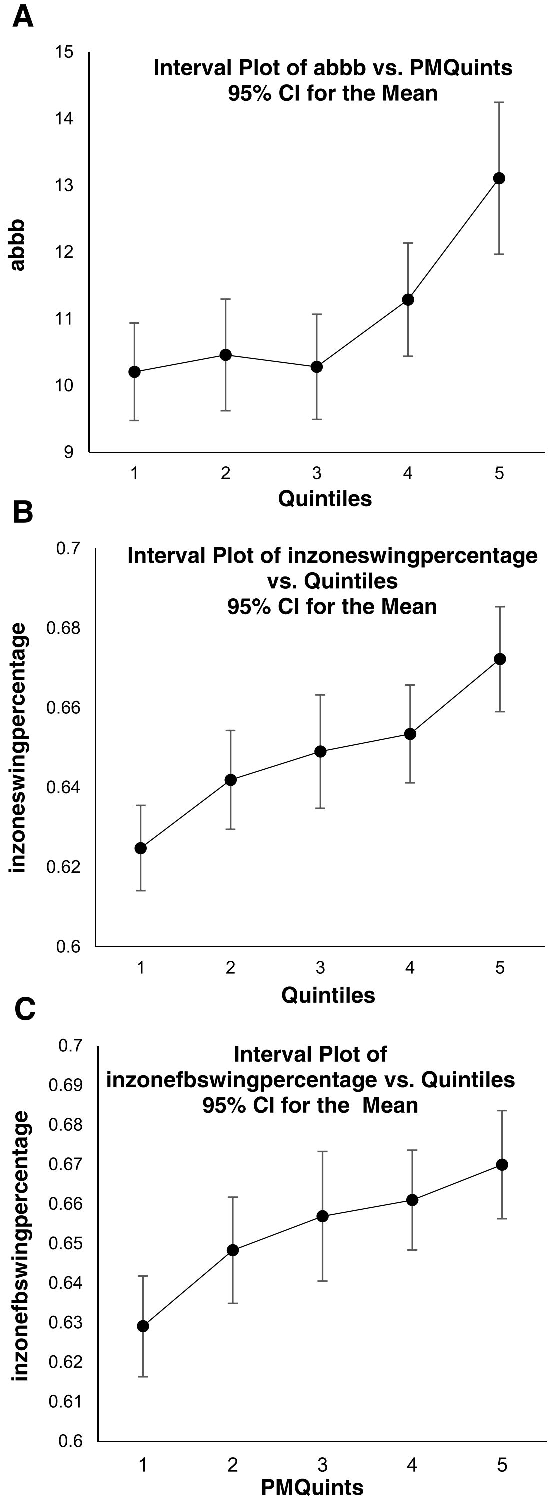

FIGURE 4. Interval plot of Proactive versus abbb, Proactive versus inzoneswingpercentage, and Proactive versus inzonefbswingpercentage results divided by quintile (PMQuints). Note that only in the fifth quintile (worst Proactive scoring group) is there a significant difference in abbb, as compared with the other 80% of the cohort. The intervals represent 95% confidence intervals. abbb = at bats per base on ball; inzonefbswingpercentage = in-zone fastball swing percentage; inzoneswingpercentage = in-zone swing percentage.

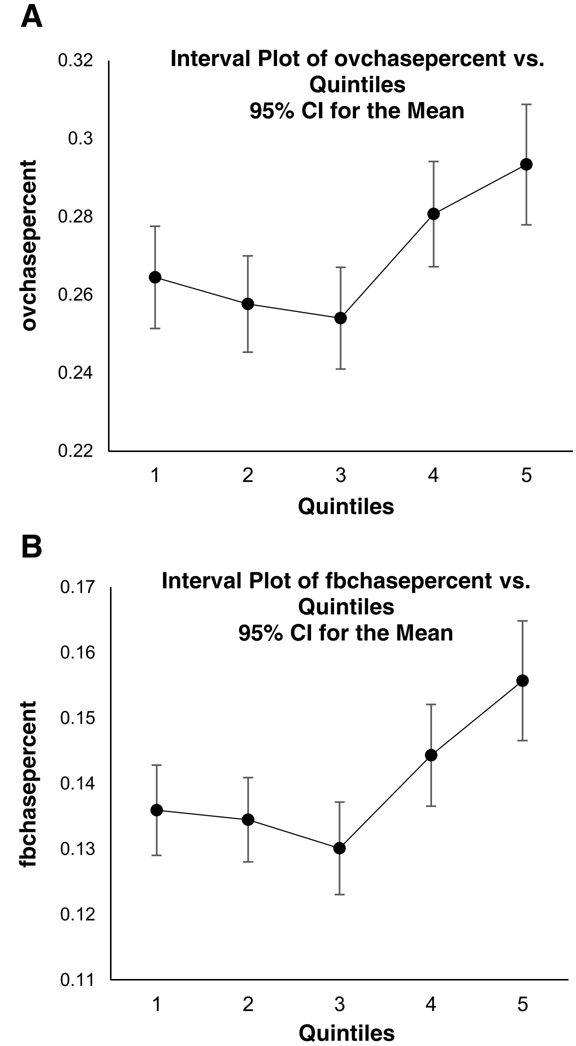

FIGURE 5. Interval plot of Proactive versus ovchasepercent and Proactive versus fbchasepercent results divided by quintile (PMQuints). Note that the top three quintiles appear very similar with the fourth and especially the bottom quintile being different. A statistically significant difference was noted between the top and bottom 20% groups for fbchasepercent. The intervals represent 95% confidence intervals. fbchasepercent = fastball chase percentage; ovchasepercent = out-of-zone chase percentage.

closer to the major leagues had better Proactive scores as well. The correlation between Proactive time and Major League Baseball experience may suggest that individuals with better eye-hand visual-motor reaction time may have a better chance of progressing to a higher level of baseball than someone with worse eye-hand visual-motor reaction time performance.

As noted, these differences between the top and bottom 20% of eye-hand visual-motor reaction time abilities resulted in a 22% increase in ability to gain a walk (at bats per base on ball of 10.2 vs. 13.1), chasing 10 to 12% fewer pitches outside the strike zone and swinging at 6 to 7% fewer pitches in the strike zone as compared with the poor hand-eye coordination group. Thus, batters with better eye-hand visual-motor reaction time appear to be more discerning in deciding to swing at pitches as compared with the poorer eye-hand visual-motor reaction time group. In addition,

TABLE 5. *P* values for each possible comparison for each plate discipline metric

	ProMean	abbb	inZSwPct	inZfbSwPct	OvChasePct	fbChasePct
Q1 vs. Q2	**<.0001**	.66	.04	.04	.46	.76
Q1 vs. Q3	**<.0001**	.89	.008	.009	.27	.25
Q1 vs. Q4	**<.0001**	.06	**.001**	**.001**	.09	.11
Q1 vs. Q5	**<.0001**	**.00**	**.00**	**.00**	.006	**.001**
Q2 vs. Q3	**<.0001**	.76	.46	.43	.69	.38
Q2 vs. Q4	**<.0001**	.68	.71	.59	.55	.28
Q2 vs. Q5	**<.0001**	.77	.59	.51	.71	.28
Q3 vs. Q4	**<.0001**	.91	.46	.42	.77	.29
Q3 vs. Q5	**<.0001**	.98	.5	.46	.83	.33
Q4 vs. Q5	**<.0001**	.95	.65	.57	.78	.29

Bolded values are significant with Bonferroni. abbb = number of at bats before a walk is gained (lower value preferred); fbChasePct = percentage of swings on only fastballs outside the strike zone (lower value preferred); inZfbSwPct = overall swing percentage of fastballs in the strike zone (lower value indicates a more discerning batter); inZSwPct = overall swing percentage of all pitches in the strike zone (lower value indicates a more discerning batter); OvChasePct = percentage of swings on all pitches deemed outside strike zone (lower value preferred); Q = quintile.

the testing of eye-hand visual-motor reaction time appears to be most useful in identifying those athletes who are in the bottom 20% of Proactive times, as they will tend to have worse plate discipline ability as compared with the remaining 80% of athletes. Conversely, Proactive ability appears less useful in directly identifying players who have superior plate discipline ability, as the top four quintiles of players on Proactive testing all had about equal scores on at bats per base on ball.

In addition to the differences in plate discipline ability between the top and bottom 20% groups when sorted by Proactive score, it was apparent that there was also a large difference in baseball experience between these same groups. Table 3 shows a 140% difference in major league experience between these top and bottom groups. To address the possibility that this difference in plate discipline was related in fact to experience, and not Proactive ability, we sorted the data set by major league experience and evaluated the plate discipline ability of the most experienced 20% against the same abilities in the least experienced 20% group. This evaluation showed that not only the average Proactive score was better in the least experienced group, but also there was no statistically significant difference in any of the plate discipline metrics (except out-of-zone chase percentage) when the two groups are compared. Thus, it was concluded that plate discipline ability was not related to major league experience but instead to eye-hand visual-motor reaction time ability.

Review of Figs. 4 and 5 indicates that only the bottom 20% groups are significantly different from the other quintiles. Thus, an attempt to improve a batter who is in the third quintile to the first quintile would not be expected to result in improved plate discipline ability. However, improving a batter in the fifth (worst) quintile may in fact lead to improved batting performance. Additional data will be needed to evaluate the possible effect of correction/training of eye-hand visual-motor reaction time ability and any resulting transfer to better batting performance.

The possibility that training eye-hand visual-motor reaction time may lead to improved batting ability is certainly important for those batters in the bottom 20% group. Several reports in the literature have addressed the ability to train eye-hand visual-motor reaction time,[12] the lasting effect of training,[13,14] and its possible effect on baseball performance.[15]

Kida et al.[12] described the improvement in reaction time as related to experience. In their report, they tested several different groups, including both professional and amateur baseball players over a 3-year period. Their results show a statistically significant decrease in Go/NoGo reaction time from year to year as well as a reduced, but not statistically significant, decrease in simple reaction time in the baseball population tested. In addition, they demonstrated a very strong correlation between the simple and the Go/NoGo reaction times in the professional baseball players.

Ciuffreda,[14] reviewing the findings of Ando et al.,[13] noted that eye-hand visual-motor reaction time can be trained with a few hours of practice, the training effect is transferable between the central and peripheral visual field, and the effect of training lasted at least for the period of the study (3 weeks).

Clark et al.[15] used this knowledge in their work with the University of Cincinnati baseball team. In addition to several other types of vision training, they used eye-hand visual-motor reaction time training both before and during the baseball season. They noted an improvement in batting average and slugging percentage when comparing the year trained with the previous year in which no training occurred. Although it is impossible to separate the effect, if any, of each training technique on batting performance, and the batting metrics used are not fully reflective of an individual's batting ability, the possibility that eye-hand visual-motor reaction time can be improved with training and that improved eye-hand visual-motor reaction time may lead to improved batting is intriguing and should be studied further.

One could hypothesize that faster eye-hand visual-motor reaction time allows the batter an opportunity to be selective in which pitches he ultimately decides to swing at. Our data demonstrate that the batters with better eye-hand visual-motor reaction time gain walks (base on balls) more frequently and swing at fewer pitches both inside and outside the strike zone. Perhaps, the faster ability to react allows the batter to observe the pitch trajectory for a longer period of time and thus gain a better understanding of where the pitch will ultimately cross the plate while still allowing them sufficient time to initiate a swing, whereas those batters with worse eye-hand visual-motor reaction time must initiate their swing earlier and are thus less certain how the pitch thrown will cross the plate and if it is one that they wish to attempt to hit. These timing differences may result in higher rates of swinging at pitches and a lower likelihood to gain a base on balls.

What Does This Report Add?

These data demonstrate the relationship between eye-hand visual-motor reaction time and on-field batting performance in a large cohort of professional baseball players. Commonly used baseball performance metrics such as batting average, on-base percentage, and slugging percentage are confounded by the effects of the defense and thus are not useful in evaluating the ability of an individual player. In this report, we use well-known plate discipline metrics, which are almost solely dependent on a batter's ability alone, to demonstrate the relationship between eye-hand visual-motor reaction time and batting success. The correlations between the various plate discipline metrics are low, likely owing to the fact that many factors contribute to batting success in addition to eye-hand visual-motor reaction time. Despite this, of note is the very large and statistically significant difference between the top and bottom 20% eye-hand visual-motor reaction time groups and their respective plate discipline abilities, highlighting the importance of this physiologic metric. These findings may be important in player selection as well as identification of players who may possibly benefit from an intervention to improve eye-hand visual-motor reaction time. Whether improvement in an individual's initially poor eye-hand visual-motor reaction time leads to improved on-field performance will need to be studied in the future.

Although this study represents a large group of professional baseball players, several limitations exist. Likely, the largest limitation of this study lies in the heterogeneity of the population. The professional baseball population is composed of major and minor league players. An unknown subset of minor league players will eventually rise to the major league, but they are included in the minor league population at this time. In addition, the remainder of minor league players will never make the major leagues and will not possess the baseball skills required for that level. Also, batters facing minor league pitchers will have a different experience than those batters who face major league pitchers, possibly affecting their ability to identify pitches and make the appropriate decision to swing or not. In addition, the study is limited by its retrospective nature and the fact that eye-hand visual-motor reaction time results were measured in different Major League Baseball training camps at different times (although by the same examiner).

Much remains to be done in understanding the role of vision in sports, and specifically in baseball hitting ability. This report begins to explain the role of one skill, eye-hand visual-motor reaction time, in batting ability as measured through standard plate discipline metrics.

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