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Improved vision and on field performance in baseball through perceptual learning

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Our visual abilities profoundly impact performance on an enormous range of tasks. Numerous studies examine mechanisms that can improve vision [1]. One limitation of published studies is that learning effects often fail to transfer beyond the trained task or to real world conditions. Here we report the results of a novel integrative perceptual learning program that combines multiple perceptual learning approaches: training with a diverse set of stimuli [2], optimized stimulus presentation [3], multisensory facilitation [4], and consistently reinforcing training stimuli [5], with the goal to generalize benefits to real world tasks. We applied this training program to the University of California Riverside (UCR) Baseball Team and assessed benefits using standard eye-charts and batting statistics. Trained players showed improved vision after training, had decreased strike-outs, and created more runs; and even accounting for maturational gains, these additional runs may have led to an additional four to five team wins. These results demonstrate real world transferable benefits of a vision-training program based on perceptual learning principles.

Nineteen players completed 30, 25-minute sessions, each on a different day, of the integrated training program and served as the Trained group. Briefly, the training program consisted of targeting Gabor patches (game ‘targets’) of varying spatial frequency and orientation that were presented at threshold (see Supplemental Information for methods). Eighteen pitchers served as an Untrained control group. Both before and after the training phase, visual acuity (using Snellen charts) was measured in both the Trained and Untrained groups.

Players in the Trained group, showed impressive improvements in visual acuity (measured at 20 feet; 6.1 meters), with an average of 31% improvement in binocular acuity (pre-training mean of 20/13 ± 0.69 SE vs post-training mean of 20/10 ± 0.59; Figure 1A). These changes were significantly ($F = 31.13$, $p < 0.0001$) greater than those of the players in the Untrained group (20/16 ± 1.4 vs 20/16 ± 1.2). The pre-training differences were not significant between Trained and Untrained players ($t = 0.8774$, $p = 0.39$ t-test). Notably, 15 of 19 Trained players showed improved binocular acuity, the four Trained players without binocular improvements, improved in one or both of the eyes individually; and seven of the Trained players reached 20/7.5 Snellen acuity in far binocular acuity after training. Similar

Supplemental Information
Supplemental Information includes experimental procedures, two figures and three tables and can be found with this article online at *bxs.

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improvements were also found in near vision for the Trained, but not Untrained, players (see Figure S1 in the Supplemental Information). For Trained players we also measured contrast sensitivity functions, where we found significant ($F = 25.4$, $p = 0.0001$) improvement (Figure 1B), demonstrating that contrast sensitivity as well as acuity benefitted from integrated training.

The vision tests demonstrate training based benefits transfer outside the context of the computerized training program to standard eye-charts. Notably, players reported, "seeing the ball much better", "greater peripheral vision", "easy to see further", "able to distinguish lower contrasting things", "eyes feel stronger, they don't get tired as much", and so on. These results suggest that the improved vision translates to real world benefits for the Trained players. To quantitatively assess this, we measured their on-field performance in the game of baseball (see Supplemental Information for explanation of the game and related terminology).

We analyzed batting statistics from the 2012 Big West Baseball season (ending four months prior to training), and the 2013 season (beginning two months after training), a comparison used in previous research [6]. Eleven of the 19 Trained players played in both the 2012 and 2013 seasons and subsequent analyses focus on these players. College players typically do improve from year to year; and this improvement needs to be incorporated into our estimation of treatment effect. We identified 78 non-UCR players in the Big West who played in both seasons and used their data as a baseline for the typical year-to-year improvements expected in this population of players.

As a first metric of batting performance we examined strike-outs (SOs). Improved vision should decrease the number of SOs. The SOs of Trained players decreased from 22.1% to 17.7% of plate appearances, a reduction of 4.4% ± 2.0 SE, with 10 (11) players showing a reduction in SOs. This was significantly greater than that of the rest of league ($p = 0.029$, permutation test, see Supplemental Information for details), whose SOs decreased from 16.0% to 15.4% of plate appearances, a reduction in SOs of 0.4% ± 0.71 SE with only about half the league, 42 (78), showing improvement. While there exist baseline differences in SOs between the UCR and the rest of the league, these cannot explain the observed year-to-year changes in SOs and this is the only example over the last five years of a Big West Baseball team showing a significantly greater improvement in strike-outs than the rest of the league.

Next, we examined Runs Created (RC), a statistic that includes key components of both on base and slugging percentage [7] as a measure of overall batting performance (see Table S1). The 11 Trained UCR players averaged 0.188 RC per out in 2013 compared to only 0.140 RC/Out in 2012. This year-to-year improvement of 0.048 RC/Out favorably compared to a league average improvement of 0.011 RC/Out. Had UCR players improved at the league rate, their expected RC/Out would have been 0.151 (0.140 + 0.011). Projecting the 0.151 RC/Out into the UCR players' performance over the course of their 2013 season, we estimate that the UCR team scored 41.71 extra runs in 2013 than would be projected based upon typical league maturational gains. To evaluate the impact of these extra runs scored, we considered how team wins and losses may have been affected.

We applied Bill James' so-called 'Pythagorean Theory of Baseball' to estimate the number of wins and losses expected based upon the estimates of Runs Created (see Table S2). Using the actual 2013 performance, the Pythagorean theorem predicts a record of 21.2 wins and 32.8 losses, which closely matches UCR's actual record of 22 wins and 32 loses. However, the same calculations based upon augmenting the 2012 UCR performance by the league's average year-to-year improvement would predict a record of 16.5 wins and 37.5 losses.

Thus, we estimate that treating the 11 UCR players may have gained the team four or five (21.2 versus 16.5) wins in the 2013 season.

Elite baseball batters use various kinds of sensory information to be successful batters, but most weight is given to visual feedback [8]. This has motivated other vision training approaches to focus on exercising the ocular muscles, producing mixed results [6,9]. Our integrated training program is unique in that we examined both standard measures of vision as well as real world performance in elite players. While it is difficult to make a conclusive causal inference that the improvements in vision are solely responsible for the improved offensive performance shown by the trained players, the observed improvements are substantial and significantly greater than that experienced by players in the rest of the league in the same year. For example looking at other standard measures of offensive performance (Batting Average, Slugging Percentage, On Base Percentage, Walks, and Strike Outs), in each and every case UCR's year-over-year improvements are substantially greater (at least 3X) than the rest of the league (see Table S3). A permutation test incorporating the set of examined baseball statistics for Trained versus Baseline players shows a probability of 0.0017 of getting such an improvement in offensive statistics by a chance draw of any random 11 players from the league (including the UCR players). Still the extent of improvements observed are surprising and it is premature to conclude that all year-over-year improvements are simply due to changes in vision. Our training intervention may have combined with any number of unmeasured factors to improve UCR's batting performance.

The integrated perceptual learning training program created broad based visual benefits in UCR baseball players. Unlike typical perceptual learning approaches, which are known to produce limited transfer, the improvements transferred both to tests of basic vision and arguably resulted improved offensive performance on the baseball field. These results suggest curse of specificity in perceptual learning studies may be overcome by moving beyond traditional approaches that target single mechanisms of learning to instead integrate multiple mechanisms with the goal of maximizing learning outcomes. Additional research will be required to better understand how these mechanisms interact and to understand the extent to which they are independent, synergistic, or some may interfere with each other. Furthermore, we have identified benefits of such training, but it will be important also to understand what costs could arise from such specialized vision training[10]. Still, we suggest that this approach has great potential to aid many individuals that rely on vision including not only athletes looking to optimize their visual skills but also individuals with low vision engaged in everyday tasks.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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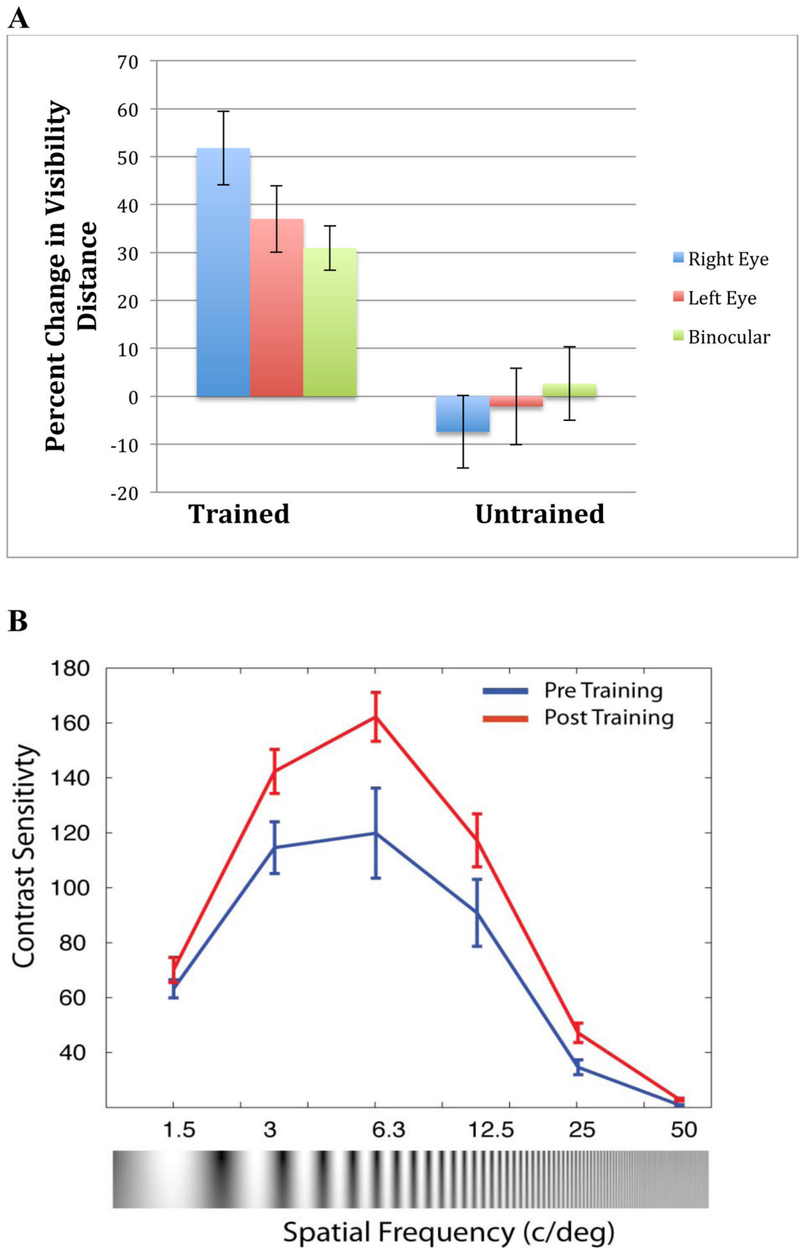

Figure 1. Changes in Acuity and Contrast Sensitivity

(A) change in distance the same text can be read from the pre-test to the post-test in the Trained and Untrained UCR players. (B) change in Contrast Sensitivity Function assessed using a computer program that staircased contrast in an orientation matching task for centrally presented Gabor patches of six different spatial frequencies (1.5, 3, 6, 12.5, 25 and 50 cpd). Y-axis, contrast sensitivity; higher score represents better ability to see low contrasts. X-axis, the spatial frequency. Error bars represent within subject standard error.