Original Research

Stroboscopic Training Enhances Anticipatory Timing

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ABSTRACT

International Journal of Exercise Science 5(4) : 344-353, 2012. The dynamic aspects of sports often place heavy demands on visual processing. As such, an important goal for sports training should be to enhance visual abilities. Recent research has suggested that training in a stroboscopic environment, where visual experiences alternate between visible and obscured, may provide a means of improving attentional and visual abilities. The current study explored whether stroboscopic training could impact anticipatory timing—the ability to predict where a moving stimulus will be at a specific point in time. Anticipatory timing is a critical skill for both sports and non-sports activities, and thus finding training improvements could have broad impacts. Participants completed a pre-training assessment that used a Bassin Anticipation Timer to measure their abilities to accurately predict the timing of a moving visual stimulus. Immediately after this initial assessment, the participants completed training trials, but in one of two conditions. Those in the Control condition proceeded as before with no change. Those in the Strobe condition completed the training trials while wearing specialized eyewear that had lenses that alternated between transparent and opaque (rate of 100ms visible to 150ms opaque). Post-training assessments were administered immediately after training, 10-minutes after training, and 10-days after training. Compared to the Control group, the Strobe group was significantly more accurate immediately after training, was more likely to respond early than to respond late immediately after training and 10 minutes later, and was more consistent in their timing estimates immediately after training and 10 minutes later.

KEY WORDS: Sports vision training, Nike vapor strobes, anticipatory timing, training retention

INTRODUCTION

Sports often place extreme demands on visual processing. A baseball player at bat must quickly pick up the location and spin of a baseball to make an appropriate swing (18), and a baseball player in the outfield must estimate a fly ball's trajectory to be in position to make a catch (7, 10). Likewise, golfers use vision to judge distance and putting surfaces, and racecar drivers use vision to judge when, and if, they can try to pass a fellow driver. More broadly, many sports (e.g., American football, soccer, basketball, hockey) require players to use vision to track teammates and opponents during fast-paced action. Given the integral role that vision plays in most sports, it is not surprising that previous research has made several important connections between sports performance and visual processing (6).

There are many factors that influence sports performance, and one fundamental area of extreme importance is training. Athletes commonly train their muscles, their understanding of the game, and their strategies to outperform their opponents. But relatively little attention has been dedicated to training visual and attentional abilities within the sports world (6). Might athletes be able to gain a competitive edge by directly training vision and attention? One way to train vision and attention for sports is to practice and train in suboptimal conditions, and this general strategy is often employed; baseball players take warm-up swings with weights on their bats, runners train in high altitudes to perform better in low altitudes, and swimmers practice with weights on their ankles during practice. Moreover, many training regimens are designed on the premise that training in extreme and restrictive conditions can produce enhanced performance (e.g., over speed treadmill training, resistance throwing cord training, and stretch shortening cycle work such as box jumps prior to competition in the long jump). Here we apply this same logic to the training of vision and attention, and do so through the use of intermittent, or stroboscopic, vision.

While somewhat counterintuitive, a useful means of training and testing visual and motor abilities is to present individuals with limited information, and then see how well they are able to adapt. Stroboscopic vision accomplishes this by offering intermittent snapshots of the visual world, forcing observers to perform in suboptimal conditions wherein they must somehow link together temporally separated views of their visual environment. Stroboscopic vision has been used in a variety of ways as a tool, from a means to alleviate motion sickness (13, 14) to a way to determine what visual information is used during driving (17, 20), to a means of increase attentional selectivity (2).

From a research perspective, several questions have been addressed by having participants perform in stroboscopic environments wherein they are presented with intermittent views of the visual world rather than normal, continuous visual experiences (e.g., 1, 2, 4). The basic premise is that individuals forced to perform in suboptimal conditions, where they must act and respond based upon only a fraction of the information they normally experience, may increase their cognitive and physical skills such that they can perform even better when they return to normal visual conditions. Recent work has used stroboscopic visual training to determine what specific attentional mechanisms can be trained and improved. For example, one study (2) had participants complete various attentional assessments before and after completing a stroboscopic training regimen where they engaged in physical activities while wearing stroboscopic eyewear (same tool as used in the current study, see methods section below). Compared to a control group that completed the same experimental paradigm, but with non-stroboscopic eyewear, the participants significantly improved their abilities to detect subtle motion cues and identify briefly presented stimuli (2). In contrast, no benefits were found for a sustained attention task where the participants were to mentally track moving objects over several seconds. In a continuation of this work, it was also found that participants who trained with the stroboscopic eyewear experienced boosts in visual memory abilities, and that this boost could last for at least 24 hours (1).

Most relevant for the current study, there have been several examinations of how intermittent vision interacts with perceptual-motor skills. Intermittent vision has been used with a variety of tasks, including a one-hand catching task (4, 5, 9), dynamic balance (16), and on-ice skills in professional ice hockey players (11). Moreover, differences in performance have been observed between novice and expert athletes (4), and adaptation has been found during intermittent vision (9, 12). Collectively, these prior findings suggest that intermittent, or stroboscopic, visual training offers a powerful tool for improving performance.

Here we explore key, open questions about the nature of stroboscopic training; can a single brief stroboscopic training session improve anticipatory timing abilities, and how long might the effects last? This work serves to complement previous findings (e.g., 1, 2, 4) by filling in important holes in our understanding of stroboscopic training. Repeated training over several weeks was found to produce physical skill learning benefits that lasted for at least 24 hours (11). Specifically, professional hockey players performed on-ice skill assessments (forwards took shots on goal and defensemen made long passes) before and after training. A strobe group performed normal hockey preseason training camp activities, but while wearing stroboscopic eyewear for 10 or more minutes per day, for 16 days in between the pre- and post-training assessments. A control group did everything the same, but never wore specialized eyewear. The post-training assessments were taken 24 hours after the final stroboscopic training session, and the strobe group was found to significantly improve on the skill tests compared to the control group. This suggests that repeated, albeit simple, training can lead to measurable improvements, but what might come from a single and brief training exposure?

Another previous study found perceptual-motor benefits in a one-handed catching task immediately after training in an intermittent visual environment (4). Specifically, participants completed pre-training and post-training assessments of having to make one-handed catches in a difficult stroboscopic visual environment (with an alternation of a visible phase that lasted 20ms and a dark phase of 80ms). Different groups of participants underwent different forms of training; all groups completed the exact same task as the pre- and post-training assessments, but what differed was whether or not they were exposed to a stroboscopic environment or not, and the difficulty of their stroboscopic rate (alternation rates of 20/40, 20/80, and 20/120). Those who underwent stroboscopic training significantly improved from their pre- to post-training assessments, but those who were not exposed to a stroboscopic environment during training did not (4). This work suggests that stroboscopic training can improve perceptual-motor skills that involve predictive timing, but it remains unknown whether training can also affect the ability to predict the time of a moving stimulus when there is no active motor aspect involved. Can stroboscopic training improve perceptual anticipatory timing? Moreover, here we also look to inform how long such improvement might last after a single brief training session.

METHODS

Participants

Thirty members of the Southern Utah University community participated as unpaid volunteers. Participants were recruited by class announcements and word-of-mouth, without bias towards any particular population bias. All members of the community were free to participate and inclusion in the study was based upon a first-come-first-served policy. Enrolled participants were randomly assigned to the Strobe or Control group, with fifteen in each group. Each group was comprised of nine female and six male participants. The Strobe group had an age range of 20 years-old to 27 years-old and the Control group had an age range of 20 years-old to 29 years-old; there was no significant difference in age between the groups (Strobe: M=22.80, SD=2.11; Control: M=23.60, SD=2.82; $t(28)=0.88$, $p=0.387$). Participants were not selectively recruited for athletic ability (athletes were not explicitly recruited to participate), but each individual was administered the Physical Activity Readiness Questionnaire (PAR-Q) (19) prior to their participation to ensure they were fit for physical activity. Informed consent was obtained prior to testing in line with the Southern Utah University Institutional Review Board.

Protocol

Stroboscopic eyewear: To address the current questions we made use of a new sports training item, Nike Vapor Strobe Eyewear®, that has been used before as a research tool (1, 2, 11). The eyewear has liquid crystal display plastic lenses that can alternate between transparent and opaque states. The transparent state is complete visibility and the opaque state is a medium grey that is difficult to see through. The alternation rate between the transparent and opaque states varies along 8 levels (see ref. 2 for details). Here only one level was employed (level 3, 100ms clear:150ms opaque). The Strobe group wore the eyewear during the 5-7 minute training phase (see below) and the Control group never wore nor saw the stroboscopic eyewear.

Anticipatory timing device: A Bassin Anticipation Timer (Lafayette Instrument Co.) was employed to measure anticipation timing. This apparatus has been used in a variety of experiments (e.g., 3, 8, 15) and provides a means to assess reaction times to a controlled temporal sequence. The model employed here was comprised of a 4-meter long track that held 200 red light-emitting diodes (LEDs) that were evenly spaced every 2 cm. The LEDs were synchronized to illuminate successively to create apparent motion in the form of a light sequence moving from the left to the right. Green LEDs were located 2 cm above and below the rightmost red LED, and these would illuminate when (if) the motion sequence reached the end of the track. Participants stood 230 cm from the track so that they were centered along the horizontal length. Participants held two wired response wands, one in each hand, and pressed a button with their left hand to start each trial and pressed a button with their right hand to make their timing response.

Each trial began when the participant pressed a button with their left hand. The leftmost LED would then become illuminated to signal the start of the trial. After a variable delay of .5 to 3 seconds, the light sequence began. The variable delay was included to keep participants from anticipating the timing based upon their button press. The lights illuminated in sequence at a rate of 5 miles/hour (2.25 meters/second) so that a total motion sequence took 1.78 seconds. Participants were to respond by pressing a button with their right hand when the light sequence reached the end of the board. A trial ended immediately upon the participant's response, even if the response came prior to the completion of the light sequence.

After 10 practice trials participants completed 10 *pre-training trials* that served as a measure of their initial performance level. Immediately following the pre-training trials, all participants completed five blocks of 10 *training trials*; those in the Strobe group wore the stroboscopic eyewear during these 5 blocks and those in the Control group participated as normal without specialized eyewear. Participants took approximately five to seven minutes to complete the 5 training blocks. The Strobe group had the stroboscopic eyewear set to the third level, which alternates between a 100 ms visible phase and a 150 ms opaque phase (4 hertz alternation). The training phase constituted the only stroboscopic exposure for the Strobe group, and this stroboscopic exposure is the only experimental difference between the two participant groups. Immediately following the training blocks, all participants completed 3 different post-training test blocks: one immediately after training (*immediate retest*), one 10 minutes after the training phase (*10-minute delay retest*), and one 10 days after the training phase (*10-day delay retest*). Four participants did not return for the final 10-day delay retest (one male and one female participant from each of the Strobe and the Control groups). The stroboscopic eyewear was only employed during the training phase for the Strobe group and the Control group never used any specialized eyewear.

Statistical Analysis

Reaction times for each trial were presented on the Bassin Anticipation Timer's console and these data were recorded for later analysis. All analyses were conducted with Microsoft Excel and SPSS software, and a significance level of 0.05 and two-tailed t-tests were used in all comparisons. The reaction times represented the difference between the timing of the participant's response and the actual time at which the final LED had been illuminated (reaction time error). Three dependent variables of reaction time errors are analyzed in the current study: absolute error, early vs. late responding, and variability error. Absolute error provides a measure of the magnitude of response error, regardless of whether the responses were early or late. This provides a metric of how far performance was from perfect timing. It is also interesting to examine the direction of the errors, and we assess that through an examination of early vs. late responding to determine if the stroboscopic training affects whether participants were responding early or late. Finally, we also assess the variability of the errors to determine if stroboscopic training can influence response consistency. Each dependent variable was compared between groups (Strobe, Control) for each phase of the experiment (pre-training, immediate retest, 10-minute delay retest, 10-day delay retest). These planned comparisons are theoretically independent for each phase (i.e., a possible immediate retest effect may or may not speak to the existence of a possible 10-minute delayed effect) so independent t-tests were administered for each.

RESULTS

Response errors greater than 300ms during any of the test blocks (pre-training, immediate retest, 10-minute delay retest, 10-day delay retest) were removed prior to any additional analyses. This removed 0.52% of the trials (3/580) for the Strobe group and 1.38% for the Control group (8/580). No other data corrections were performed.

Absolute error

As can be seen in figure 1, there was no pre-training difference between groups (Strobe: M=63.77ms, SE=8.96ms; Control: M=62.80ms, SE=14.29ms; $t(28)=0.06$, $p=0.96$) for absolute error. During training (wherein the Strobe group was performing while wearing the stroboscopic eyewear) the Strobe group produced marginally significantly larger errors than the Control group (Strobe: M=102.82ms, SE=12.94ms; Control: M=67.20ms, SE=13.30ms; $t(28)=1.88$, $p=0.07$). The Strobe group had significantly smaller errors at immediate retest (Strobe: M=43.85ms, SE=4.21ms; Control: M=72.65ms, SE=9.94ms; $t(28)=2.88$, $p=0.02$), but the differences were not significant at the 10-minute delay retest (Strobe: M=54.31ms, SE=6.82ms; Control: M=75.67ms, SE=13.90ms; $t(28)=1.72$, $p=0.19$) or the 10-day delay (Strobe: M=60.70ms, SE=9.01ms; Control: M=71.63ms, SE=12.80ms; $t(24)=1.18$, $p=0.50$).

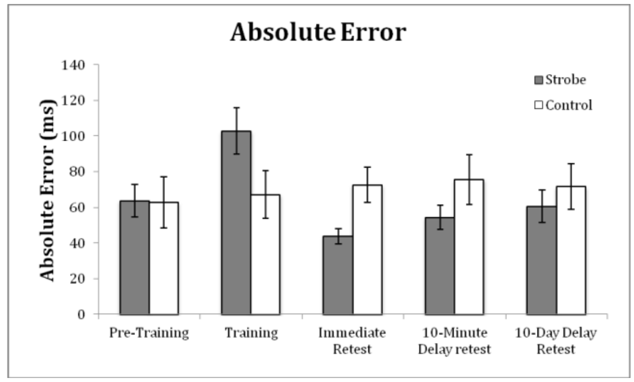

Figure 1. Absolute error in response timing for the Strobe (gray) and Control (white) groups for each phase of the experiment. The training data represent the average of the five training blocks, and the Strobe participants wore the stroboscopic eyewear during this phase. Error bars represent standard error.

Early vs. Late responding

As can be seen in figure 2, the Strobe group started pre-training with a slightly stronger bias to respond early (Strobe: M=87.33%, SE=3.00%; Control: 75.33%, SE=4.96%; $t(28)=2.07$, $p=0.05$), and this bias held after training for the immediate retest (Strobe: M=86.67%, SE=2.87%; Control: 64.00%, SE=4.00%; $t(28)=4.60$, $p<0.001$) and the 10-minute delay retest (Strobe: M=90.67%, SE=2.28%; Control: 56.00%, SE=5.84%; $t(28)=5.53$, $p<0.001$). During training the Strobe group was less likely to respond early (Strobe: M=65.73%, SE=3.88%; Control: 79.87%, SE=4.05%; $t(28)=2.52$, $p=0.02$). At the 10-day delay retest the groups did not differ and both were responding equally early and late (Strobe: M=59.23%, SE=8.58%; Control: 52.31%, SE=10.75%; $t(28)=0.50$, $p=0.62$).

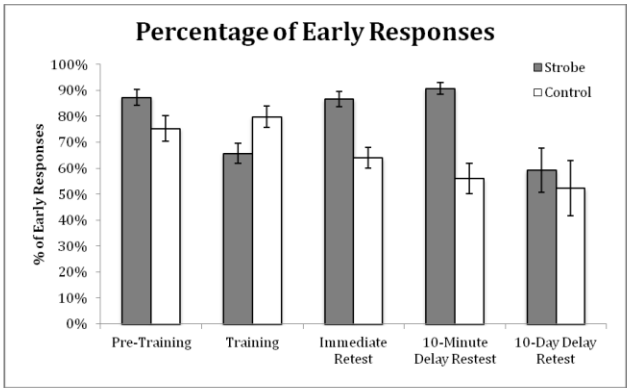

Figure 2. Percentage of responses made prior to the end of the light sequence for the Strobe (gray) and Control (white) groups for each phase of the experiment. The training data represent the average of the five training blocks, and the Strobe participants wore the stroboscopic eyewear during this phase. Error bars represent standard error.

Variable Error

The previous analyses suggest that the Strobe group responds with smaller errors and earlier for immediate retest and earlier at the 10-minute delay retest, but are they also more consistent in their responses? For each test phase of the experiment we calculated each participant's standard error around his or her mean performance. The values below and in figure 3 represent the mean values for the Strobe and Control groups. There was no significant difference in consistency at the pre-training assessment (Strobe: M=17.06ms, SE=2.95ms; Control: M=22.26ms, SE=5.09ms; $t(28)=0.95$, $p=0.35$), but the Strobe group was significantly more consistent in their response errors at the immediate retest (Strobe: M=14.15ms, SE=1.82ms; Control: M=24.54ms, SE=3.53ms; $t(28)=2.63$, $p=0.01$) and at the 10-minute delay retest (Strobe: M=12.99ms, SE=1.39ms; Control: M=22.34ms, SE=2.91ms; $t(28)=2.90$, $p=0.01$). There were no differences at the 10-day delay (Strobe: M=17.89ms, SE=1.49ms; Control: M=17.31ms, SE=2.34ms; $t(24)=0.21$, $p=0.84$).

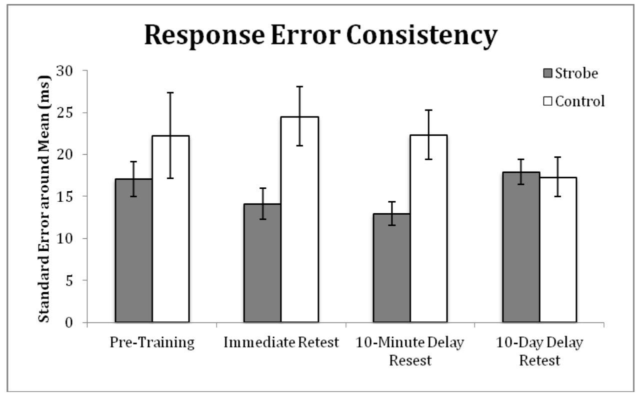

Figure 3. Mean of the standard error around each participant's mean for the Strobe (gray) and Control (white) groups for each test phase of the experiment. These values represent the consistency of responses within an experimental phase (smaller values signify higher degrees of consistency). Error bars represent standard error.

DISCUSSION

The current study found that a single 5-7 minute stroboscopic training session could produce significant benefits for an anticipatory timing task. Participants performed a simple task in which they were to predict the timing of a moving visual stimulus, and they did so before and after training. The training session involved the exact same task; the Strobe group wore eyewear that produced stroboscopic vision (the lenses alternated between transparent and opaque) and the Control group did not have any specialized eyewear. Compared to the Control group, the Strobe group was significantly more accurate at the timing task immediately after training, was more likely to respond early than to respond late immediately after training and 10 minutes later, and was more consistent in their timing estimates immediately after training and 10 minutes later.

Stroboscopic training reduces errors in anticipatory timing

The stroboscopic training employed here reduced both the magnitude and variability of timing errors when participants were to predict when a moving visual stimulus would reach a specific location. As can be seen in Figures 1 and 3, the differences between the Strobe and Control groups are relative large. Such differences could have broad impact for sports, or any activity that requires being at the right place at the right time given that being significantly better able to anticipate when an object will be at a specific time and place is an important sports skill (e.g., hitting a baseball, kicking a ball, tackling an American Football player) and general skill (e.g., knowing when it is safe to cross a busy street, keeping a newly-mobile toddler safe).

Stroboscopic training speeds anticipatory timing

Not only did the training reduce overall error, but it also affected the participants' timing biases. The Control group began the experiment with a bias to respond early and slowly shifted to an equal likelihood to respond early or late. Note that this does not represent an improvement in performance as they were still making relatively larger errors and were relatively inconsistent in their timing; they were just equally likely to be early and error-prone as they were to be late and error-prone. The Strobe group, in contrast, maintained a strong bias to respond early while simultaneously benefitting from reduced absolute and relative error. This finding is consistent with subjective reports from athletes who have trained with this particular eyewear that the stroboscopic exposure appears to 'make the world slow down.' While athletes generally strive for accuracy more so than for a general bias to be early or late, this effect may have several benefits for athletic training purposes. In conjunction with being more accurate, being consistently early can help athletes be at the right place and prepared to act. More broadly, this bias to respond early may represent a shift in perceptual abilities where more information can be processed (e.g., 2). For example, Appelbaum et al. (2012) found that stroboscopic training produced an increase in visual memory capacity.

Retention of stroboscopic training

An important question for any training effect is how long do the benefits last. To date, only limited data exists for stroboscopic training and most studies have assessed performance immediately after training (e.g., 2, 4), and two studies have used a 24-hour delay (1, 11). Here we employed three different test delays: immediate, 10 minutes later, and 10 days later. With just a single 5-7 minute training session, significant effects were found with immediate testing (akin to ref. 4). Significant effects were still observed after a 10-minute delay, but the effects were notably weaker than after the immediate retest. By 10 days later, there were no longer any differences between the groups. It is important to emphasize that these retention effects are coming from a single testing session that was extremely brief. The participants did not use the stroboscopic eyewear before or after this single training session, yet performance was nevertheless improved.

The current study has demonstrated that stroboscopic training can improve various aspects of anticipatory timing, but more work will be needed to fully understand this process. For example, since the current study only included a single 5-7 minute training session, we do not know if more extensive training (more sessions and/or more time per session) can lead to larger effects. Likewise, a 10-day delay represents an extreme retention delay given this single, brief training session. Future work can assess learning after shorter delays. Finally, the current study only examined a single population, members of a university community. It would be interesting to determine if the effects are stronger or weaker across various populations (athletes, children, elderly, etc.).

These results complement and extend the existing stroboscopic training literature. Previous research has found that repeated stroboscopic training over a few weeks produced benefits lasting at least 24 hours (11), and that a single stroboscopic training session could produce immediate benefits (4). Here, we see benefits after a single brief training session that can be seen at least 10 minutes later. Moreover, these benefits are found for anticipatory timing abilities at a perceptual level without a direct motor component. For athletic training purposes, the current study suggests that a brief exposure to stroboscopic training may serve as a means to gain a quick increase in performance.

Combined with the previous work conducted with professional ice hockey players (11), a potential training regimen may be best served by including routine stroboscopic training during normal practices and then targeted stroboscopic training immediately before the need to perform. This relationship is analogous to how a baseball player prepares for an at bat. The player will undergo repeated practice with swinging a bat, with or without added weights to gain long-term improvements in their swing. This sustained training serves to increase strength and skill that can be observed days and weeks later. To complement this regular training regimen, players will also engage in targeted practice with swinging a bat immediately before getting into the batter's box. This training (often done with extra weights on the bat) can help in that moment, but will not produce lasting effects days later. Stroboscopic training appears to behave the same way; repeated training over a few weeks can lead to longer lasting benefits (11), and specific training in a single session can lead to immediate benefits. More broadly, stroboscopic training may be most effective in a dual-phase process; extended training to build up long-term skill combined with targeted training immediately before performance for an extra increase.

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REFERENCES

1. Appelbaum LG, Cain MS, Schroeder JE, Darling EF, Mitroff SR. Stroboscopic visual training improves information encoding in short-term memory. Atten Percept Psychophys 2012. DOI 10.3758/s13414-012-0344-6

2. Appelbaum LG, Schroeder JE, Cain MS, Mitroff SR. Improved visual cognition through stroboscopic training. Front Psychol 2:276, 2011.

3. Benguigui N, Ripoll H, Broderick MP. Time-to-contact estimation of accelerated stimuli is based on first-order information. J Exp Psychol Hum Percept Perform 29: 1083-1101, 2003.

4. Bennett S, Ashford D, Rioja N, Elliott D. Intermittent vision and one-hand catching: The effect of general and specific task experience. J Motor Behav 36: 442-449, 2004.

5. Bennett S, Ashford D, Rioja N, Coull J, Elliott D. Integration of intermittent visual samples over time and between the eyes. J Motor Behav 38: 439-450, 2006.

6. Erickson GB. Sports vision: vision care for the enhancement of sports performance. Butterworth-Heinemann, Oxford UK, 2007.

7. Fink PW, Foo PS, Warren WH. Catching fly balls in virtual reality: A critical test of the outfielder problem. J Vis 9(13): 1-8, 2009.

8. Hart MA. Transfer of participation in fast-pitch softball to the performance of a coincidence anticipation task. J Hum Mov Stud 46: 359-371, 2004.

9. Lyons J, Fontaine R, Elliott D. I lost it in the lights: The effects of predictable and variable intermittent vision on unimanual catching. J Motor Behav 29: 113-118, 1997.

10. McBeath MK, Shaffer DM, Kaiser MK. How baseball outfielders determine where to run to catch fly balls. Science 28 (268): 569-573, 1995.

11. Mitroff SR, Friesen P, Bennett D, Yoo H, Reichow A. Enhancing ice hockey skills through stroboscopic visual training. Unpublished manuscript, Duke University, Durham, NC.

12. Olivier I, Weeks DJ, Lyons J, Ricker KL, Elliott D. Monocular and binocular vision in one-hand ball catching: Interocular integration. J Motor Behav 30: 343–351, 1998.

13. Reschke MF, Krnavek JM, Somers JT, Ford G, Hwang EJ, Leigh RJ, Estrada A. Stroboscopic vision as a treatment for retinal slip induced motion sickness. Proc Int Symp Vis Induced Motion Sickness, Fatigue, Photosensitive Epileptic Seizures 1: 51-58, 2007.

14. Reschke MF, Somers JT, Ford G. Stroboscopic vision as a treatment for motion sickness: strobe lighting vs. shutter glasses. Aviat Space Environ Med 77: 2-7, 2006.

15. Ripoll H, Latiri I. Effect of expertise on coincident-timing accuracy in a fast ball game. J Sports Sci 15: 573-580, 1997.

16. Robertson S, Collins J, Elliott D, Starkes JL. The influence of skill and intermittent vision on dynamic balance. J Motor Behav 26: 333-339, 1996.

17. Senders JW, Kristofferson AB, Levison WH, Dietrich CW, Ward JL. The attentional demand of automobile driving. Highway Res Record 15-33, 1967.

18. Shapiro A, Lu Z-L, Huang C-B, Knight E, Ennis R. Transitions between central and peripheral vision create spatial/temporal distortions: A hypothesis concerning the perceived break of the curveball. PLoS ONE 5(10): e13296, 2010. doi:10.1371/journal.pone.0013296

19. Thomas S, Reading J, Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Can J Sports Sci 17(4): 338-345, 1992.

20. Tsimhoni O, Yoo H, Green P. Effects of visual demand and in-vehicle task complexity on driving and task performance as assessed by visual occlusion. The University of Michigan Transportation Research Institute (UMTRI); Mitsubishi Motors Corporation, Ann Arbor, MI, 1999. www.umich.edu/~driving/publications/ UMTRI- 99-37.pdf