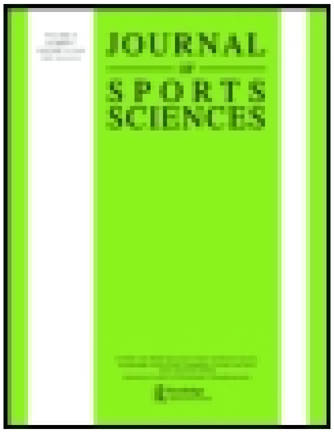

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The role of visual perception measures used in sports vision programmes in predicting actual game performance in Division I collegiate hockey players

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Abstract

In the growing field of sports vision little is still known about unique attributes of visual processing in ice hockey and what role visual processing plays in the overall athlete's performance. In the present study we evaluated whether visual, perceptual and cognitive/motor variables collected using the Nike SPARQ Sensory Training Station have significant relevance to the real game statistics of 38 Division I collegiate male and female hockey players. The results demonstrated that 69% of variance in the goals made by forwards in 2011–2013 could be predicted by their faster reaction time to a visual stimulus, better visual memory, better visual discrimination and a faster ability to shift focus between near and far objects. Approximately 33% of variance in game points was significantly related to better discrimination among competing visual stimuli. In addition, reaction time to a visual stimulus as well as stereoptic quickness significantly accounted for 24% of variance in the mean duration of the player's penalty time. This is one of the first studies to show that some of the visual skills that state-of-the-art generalised sports vision programmes are purported to target may indeed be important for hockey players' actual performance on the ice.

Keywords: *sports vision, ice hockey, the Nike SPARQ Sensory Training Station, sport performance, visual perception*

The role of visual perception measures used in sports vision programmes in predicting actual game performance in Division I collegiate hockey players.

There has been considerable debate in the literature about whether generalised visual processing is better developed in athletes compared to non-athletes, and in expert athletes compared to novices. Some of the positive findings encompass the range of sensory, motor and perceptual aspects of basic vision and information processing. These include measures of visual resolution (dynamic visual acuity (Millslagle, 2000), static visual acuity (Coffey & Reichow, 1989) and contrast sensitivity (Kluka et al., 1995)), depth perception (stereopsis; Laby et al., 1996), visual tracking (vergence, pursuit, saccades and fixation), visuomotor integration (eye–hand coordination, visual reaction time; Hughes, Bhundell, & Waken, 1993) and visual information processing: visual field (Berg & Killian, 1995), speed discrimination and temporal processing (Overney, Blanke, Herzog, & Burr, 2008), peripheral awareness (Zwierko, 2008) and speed of recognition (Isaacs & Finch, 1983).

On the other hand Bulson, Ciuffreda, and Hung (2008) did not find a significant effect of degraded static acuity on athletic performance, while Ward and Williams (2003) failed to report significant differences in performance on a dynamic visual acuity test between elite and subelite youth soccer players. Similarly, Milne and Lewis (1993) did not find any differences between athletes and non-athletes in either speed or span of recognition by evaluating the ability to recall a sequence of numbers presented tachistoscopically for 1/50 of a second. Additionally, Classe et al. (1997) failed to find any differences in visual reaction time between elite and novice baseball players.

Mixed findings have also been reported in evaluation of results of specialised training programmes intended to enhance basic visual perceptual processes (e.g. visual acuity, combined saccadic/accommodative tracking and visual search) in athletes. For example, Junyent and Sole (1995) reported that specialised training of the above basic visual skills improved precision shooting

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scores of elite shooters compared to baseline. In a basketball study, Kofsky and Starfield (1989) reported improvements in both visual function and actual game performance following 5 weeks of general vision training (static and dynamic visual acuity, visual reaction time, peripheral awareness, eye–hand coordination and visualisation/visual imagery).

McLeod (1991) tested the effects of a 12-session visual skill training programme Eyerobics in nine female varsity soccer players. The programme incorporated basic versional, vergence, accommodative and visualisation skills. Compared to the control group (n = 9), athletes receiving generalised visual training showed significantly better performance following the programme on a general test of eye–hand coordination, balance, as well as on a sport-specific dribble test, that involved dribbling a soccer ball around four cones, 9 feet apart, in a figure-eight fashion.

Negative findings associated with generalised vision training programmes were primarily reported by the Abernethy group (Abernethy, 1986; Abernethy, Wann, & Parks, 1998; Abernethy & Wood, 2001; Wood & Abernethy, 1997), who evaluated the effects of visual training in sport-specific performance in tennis players. The researchers found no programme benefits on either sport-specific perceptual tests (i.e. coincidence timing, rapid ball detection and anticipation) or sport-specific motor tasks (i.e. tennis forehand drive accuracy) in the experimental group receiving vision training compared either to the placebo group (read tennis instructional manuals and watched instructional tennis videos) or to the control group (practiced weekly motor tasks).

Erickson et al. (2011) explained the negative findings in basic visual skills and vision training programmes of athletes on the basis of a lack of standardisation of many assessment techniques, inconsistent ambient testing conditions, outdated instrumentation and inappropriate assessment protocols (e.g. assessment of static stereopsis vs. dynamic stereopsis; use of numeric stimuli in assessment of athletes' perception span). In their meta-analysis Ciuffreda and Wang (2004) also underscored the importance of higher information processing skills (i.e. as prediction/anticipation, recall, cognitive strategy and decision-making) in athletic performance and the ability of current sport vision programmes to specifically target these skills.

Studies examining decision-making ability in relation to athletic performance within specific sports also provide evidence of better decision-making in experts compared to novices. In their meta-analysis of 42 studies Mann, Williams, Ward, and Janelle (2007) concluded that experts were more accurate in their decision-making relative to their lesser skilled counterparts and anticipated their opponents' intentions significantly quicker than less-skilled participants suggesting that the use of advanced perceptual cues facilitates sport performance by means of aiding in the anticipation of opponent's actions and decreasing overall response time. In another meta-analysis of 20 studies Voss, Kramer, Basak, Prakash, and Roberts (2010) also found a small-to-moderate effect size for the difference between experts versus non-experts in multiple sports on basic cognitive measures of visual attention and processing speed.

As a result state-of-the-art sports vision programmes now employ integrated visual assessment systems such as the Nike SPARQ Sensory Training Station, designed to test a broad range of basic visual and information processing skills that previously have been identified as important for sports. As discussed above these skills include static visual acuity, dynamic visual acuity, contrast sensitivity, distance stereopsis, accommodative–vergence facility, central eye–hand reaction and response speeds, peripheral eye–hand proaction (speed and precision of self-generated target changes), span of perception and stimulus discrimination (a form of eye–hand recognition reaction time and precision).

The system was developed to provide a customised "sensory performance profile" that graphically represents the athlete's visual strengths and weaknesses by comparing performance (using percentile scores) to a database of peers within a given sport (total of 24 sports), and has been recently found a reliable computer-based assessment system showing no learning effect over multiple testing sessions (test–retest reliability, Erickson et al., 2011).

While relative contributions (weights) of various aspects of generalised visual processing to overall performance in a sport have been suggested for golf, football, baseball, basketball, tennis and soccer (see Ciuffreda & Wang, 2004; Gardner & Sherman, 1995; Seiderman & Schneider, 1983), little is known about unique attributes of visual processing in ice hockey and what role visual processing plays in the overall athlete's performance. Such understanding could help develop better sport-specific visual training programmes that would emphasise specific visual skills and elements of information processing that could benefit ice hockey players to a greater extent than the currently available "one-size-fits-all" visual training protocols.

In the present study we evaluated whether visual, perceptual and cognitive/motor variables collected using the Nike SPARQ Sensory Training Station have a significant association with actual athletic performance of elite ice hockey players. We hypothesised that a number of dynamic components of visual perception and visuomotor control would be more important for prediction of game statistics than measures of static visual processing and nearpoint visual skills. Specifically, our research hypothesis was based on the ratings of relative importance of selected visual functions provided by Ciuffreda and Wang (2004) in reference to some fast-played common sports in the US, such as football, baseball, basketball, tennis and soccer. In all of these sports the highest importance rating (4 or 5 on a 5-point Likert scale) was attributed to dynamic visual acuity, dynamic stereopsis and eye–hand coordination.

In addition, modulation of attention is presumably important for the majority of competitive sports (Di Russo, Pitzalis, & Spinelli, 2003), as most sports are not exclusively played at a fixed distance but involve rapid target shifts between far, intermediate and near distances requiring rapid accommodative–vergence responses (Erickson et al., 2011). Ciuffreda and Wang (2004) went further to suggest that visual attentional training (e.g. dynamically shifting or weighting one's visual attentional focus from one region of the visual field to another) should be incorporated into any sports vision training paradigm irrespective of a given sport. Rapid target changes (e.g. a moving puck) are certainly true for ice hockey. For this reason we hypothesised that the Nike SPARQ measure of near–far quickness (accommodative–vergence facility) would be significantly related to the measures of actual performance of ice hockey players.

Finally as a measure of quick decision-making the SPARQ Go/No-Go measure requires rapid recognition of a target from distractors and a production of an appropriate, rapid and accurate eye–hand motor response. As superior decision-making skills have been consistently reported to separate elite from subelite athletes in multiple sports (Mann et al., 2007; Voss et al., 2010), we hypothesised that higher scores on the Go/No-Go measures (more targets identified within a specified time period with few non-target responses) in elite ice hockey players would also predict better performance on some of the ice hockey performance measures.

Method

Participants

A total of thirty-eight student athletes from the University of North Dakota's NCAA Division I Men's (19) and Women's (19) Hockey teams, ranging in the age from 18–23, with a mean age of 20.52 participated in the study. The sample consisted of 14 defensemen and 24 forwards. The University of North Dakota Institutional Review Board (IRB) reviewed and approved the study protocol and the informed consent document. Written informed consent was obtained from each participant prior to the examination.

Instruments

Sports vision station. The sports vision skills assessment included 10 tests of the Nike SPARQ Sensory Performance System (Nike SST). The Nike SST is a computer-based vision assessment station that evaluates athletes on 10 sport-relevant visual and sensory performance skills. It consists of a single computer controlling two high-resolution liquid crystal display monitors (both 0.2 mm dot pitch): one 22-inch diagonal display and one 42-inch diagonal touch-sensitive display. Custom software controls the displays, input acquisition and test procedures based on participant responses. It then analyses the raw data and converts it into normative data in order to compare the athlete's visual performance to other athletes of the same sport, position and skill level (normative data was not available for ice hockey players at the time of assessment). Five of the tests are performed 16 feet (4.9 m) from the 22-inch display screen. The participant uses a hand-held Apple iPod touch (Apple Corporation, Cuptertino, CA), which is connected via wireless input to the computer so that it could interact with the station's screen monitor. These tests include Visual Clarity, Contrast Sensitivity, Depth Perception (Stereopsis) at Far, Near–Far Quickness and Target Capture (dynamic visual acuity). For more information about the reliability and validity of the Nike SST output parameters please refer to the study by Erickson et al. (2011).

Visual clarity (static visual acuity). Landolt rings, with gaps at the top, bottom, left and right, are presented on a white background on the 22-inch screen in random order at preset acuity demands. The participant is instructed to swipe the screen of the iPod touch in the direction of the gap in the ring as soon as it is identified. Final threshold acuity is measured between the demands of −0.4 logMAR and 0.7 logMAR using a staircase reversal algorithm, beginning with a 0.4 logMAR stimulus. The size is decreased until the participant cannot correctly identify the stimulus. The procedure is continued until several reversal points are achieved (the exact number of reversal points for the algorithm is proprietary and not available for publication). Static visual acuity was based on the number of correct responses, with consideration for guessing. The sequence of testing proceeds from the right eye (OD) to the left eye (OS) and finally both eyes (OU).

Contrast sensitivity. Contrast sensitivity is measured with the participant facing the screen, which displays four concentric ring targets, each of which subtends 0.82° and is presented on a light grey background in a diamond configuration covering 2.35°. One circle at random contains a pattern of concentric rings that varies sinusoidally in brightness from the centre to the edge. Participants are instructed to swipe the screen of the iPod touch in the direction of the circle with the pattern. Contrast sensitivity is measured binocularly at two spatial frequencies, 6 and 18 cycles per degree (cpd), using a staircase reversal algorithm. Final threshold contrast sensitivity is measured between 10% and 1.0% (1.0 to 2.0 log units) contrast at 6 cpd and between 32% and 2.5% (0.5 to 1.6 log units) contrast at 18 cpd.

Depth perception (stereopsis at far). For the measure of distance depth perception the participant wears a pair of liquid crystal goggles (NVIDIA 3D Vision, Santa Clara, CA), connected via wireless link to the computer, and faces the Nike Sensory Station 22-inch display. The liquid crystal shutter system creates simulated depth in one of four black rings presented on a white background, such that one ring appears to float in front of the screen. The size and arrangement of the rings are identical to those of the circles used in Contrast Sensitivity. The width of the lines defining each ring is 12 mm, subtending 0.14°. Participants are instructed to swipe the screen of the iPod touch in the direction of the floating ring and are encouraged to respond as quickly as possible. Threshold stereopsis is measured between 237 and 12 arc seconds using a staircase reversal algorithm similar to that described previously. In addition, response time for the first two stimulus presentations at the participant's threshold is recorded, and an average response time for the testing is automatically calculated by the software. Next, the participant is instructed to turn 90° to the right and turn the head to left in order to view the screen in a way that would test stereopsis while viewing over the left shoulder. The procedure is then repeated. Following this, the participant is instructed to turn 180° and turn the head to the right in order to view the screen in a way that would test stereopsis while viewing over the right shoulder. The procedure is again repeated.

Near–far quickness. The participant is instructed to hold the iPod touch at 16 inches (40 cm) from the eyes, with the top edge positioned just below the bottom of the far screen. In alternating style, a 20/80 equivalent black Landolt ring is presented in a box on the hand-held screen, and a black Landolt ring 0.1 log unit above the threshold determined with the Visual Clarity assessment is presented on the far screen. The participant is instructed to swipe the screen of the iPod touch in the perceived direction of the gap in the ring presented on each display. Each participant continually switches focus between the far and near screens for 30 s, trying to correctly identify as many rings as possible. The number of correct responses determines the score.

Dynamic visual acuity (target capture). Dynamic visual acuity (DVA) generally is defined as the ability of the visual system to resolve detail when there is relative movement between the target and the observer (Erickson et al., 2011). The method of DVA assessment used in the Nike SST, however, does not conform to the traditional method involving a moving target. Its construct validity is yet to be determined. The developers of this test refer to it as "target capture". On this test the participant is instructed to fixate a central white dot until a yellow-green Landolt ring (dominant wavelength about 555 nm at maximum saturation possible on the display) appears briefly in one of the four corners of the screen. The size of the Landolt ring is automatically set by the computer at 0.1 log unit above the threshold determined with the Static Visual Acuity assessment, and the angular distance along the diagonal from the fixation dot to the centre of the Landolt ring is 6.1°. Since there is a reduction in visual acuity the farther the stimulus is away from the fovea, individuals with visual acuity of 20/50 or better would need to saccade from the fixation dot to the Landolt ring to correctly discriminate the direction of the gap. This quick saccade coupled with a need to quickly (within milliseconds) identify the target (the direction of the gap) is thought to assess DVA (Erickson et al., 2011).

The participant is instructed to move the eyes from the centre fixation dot to the Landolt ring that would briefly appear at one of the four random corners of the screen and to try to correctly discriminate the direction of the gap by swiping the screen of the iPod touch. The duration of the Landolt ring presentation starts at 500 ms and is progressively shortened after a correct response. The threshold stimulus exposure duration is determined using a staircase reversal algorithm.

The four remaining Nike SST tests are performed within arm's reach of the instrument and utilises the high definition 42-inch touch screen monitor. These tests include Perception Span, Eye–Hand Coordination, Go/No-Go and Hand Reaction Time.

Perception span. The standing participant is positioned within arm's length of the Nike Sensory Station's 42-inch touch-sensitive display, with the centre of the screen at about eye level. Automated instructions direct the participant to focus on a shrinking white dot in the centre of a grid pattern composed of up to 30 circles. When the dot disappears, a pattern of yellow-green dots (same colour parameters as above) flashes simultaneously for 100 ms within the grid. The participant then touches the screen to recreate the pattern of dots. If the participant achieves a passing score (greater than or equal to 75% correct), the grid pattern increases in size with an increasing number of dots. The first two levels have six circles in the grid pattern with 2 and 3 dots, the next five levels have 18 circles with 3 to 7 dots, and the last four levels has 30 circles with 7 to 10 dots. Each circle is 19 mm in diameter, and the largest grid pattern is 18 cm in diameter. The grids and dot patterns are preset by the computer to maintain standardisation. The overall score for this assessment is based on the cumulative number of correct responses; missed responses and extra guesses are subtracted from the cumulative score. If the participant does not achieve a passing score on a level, that level is repeated until two consecutive failures after which the assessment is terminated. The maximum score possible on this assessment is 64.

Eye–hand coordination (peripheral eye–hand response). Participants stand in front of the 42-inch touch-sensitive display screen holding their arms at shoulder height within easy reach of a grid of circles presented on the display. The grid consists of 8 columns (68.6 cm) and 6 rows (44.5 cm) of equally spaced circles, with each circle 48 mm in diameter. During the assessment, a yellow-green dot (same colour parameters of above) appears within one circle of the grid. Automated instructions direct the participant to touch the dot as quickly as possible using either hand. As soon as the dot is touched, a subsequent dot is presented. The score recorded is the total time to touch all 96 presented dots.

Go/No-Go. The position of the participant and the grid pattern remains the same as that used for Eye–Hand Coordination but the dot stimulus presented is either yellow-green (same parameters as above) or red (dominant wavelength about 620 nm at maximum saturation possible on the display). If the dot is yellow-green, the participant is instructed to touch it as before. But if the dot is red, the participant is instructed not to touch it. Both the red and yellow-green dots appear at random locations for only 450 ms, with no time gap between dot presentations. If a yellow-green is not touched within this time, no point is awarded for that presentation; if a red dot is touched, a point is subtracted from the overall score. Again, participants are encouraged to touch as many yellow-green dots as possible. Ninety-six total dots (64 yellow-green, 32 red) are presented, and the overall score is calculated as the cumulative number of yellow-green dots touched minus any red dots touched.

Hand reaction time (central eye–hand reaction and response time). For this test participants remain standing at arm's length from the 42-inch touch-sensitive display. Two annular patterns appear on the screen with centres 30.5 cm apart; each annulus consists of two concentric circles, 11.4 cm and 3.2 cm in diameter. Automated instructions direct the participant to place the fingertips of the dominant hand on the inner circle of the annulus on that side of the screen, with no portion of the hand extending across the boundary line marked on the screen. If the hand is aligned correctly, this control annulus changes colour to yellow-green (same colour parameters as above). The participant is instructed to centre the body in front of the opposite test annulus and focus attention on the centre of that annulus. After a randomised delay of 2, 3 or 4 s, the test annulus turns yellow-green, and the participant moves the hand to touch its inner circle as quickly as possible. Five trials are conducted per participant to calculate average reaction and response times. Reaction time is measured as the elapsed time between onset of the test annulus and release of the control annulus. After five trials, the computer calculates the averages and standard deviations for the reaction and response times. If any single measure differs from the mean by more than two standard deviations in either direction, another trial is conducted to replace the outlying measure for that trial. The software is programmed such that no more than two trials are repeated for any participant.

Procedure

All testing was carried out over the summer after the completion of the 2011–2012 season and before the beginning of the 2012–2013 season. Since several of the players tested were new recruits and did not have any 2011–2012 statistics, while some other players missed a number of games in the 2011–2012 season due to injury, we aggregated data over two regular seasons to achieve greater accuracy of dependent measures and greater statistical power for the sample. Following the testing (during the 2012–2013 season) none of the evaluated players underwent any visual therapy (including sports vision), performed any supplementary training (beyond conventional protocols) or altered their visual correction.

Upon arrival at the testing location (a local optometric clinic) informed consent was obtained from each participant followed by administration of a Z-View Aberrometer & Autorefractor (Ophthonix, Vista, CA) over the participant's habitual playing refraction to determine what, if any, refractive error or residual error there might be for each eye under non-cyclopleged conditions. If contact lenses were worn, the test was repeated without contact lenses and the lenses were replaced on the participant's eyes after the test was completed. The refractive outcome (uncorrected refraction or contact lens over-refraction) was then recorded for each eye along with the Aberration Index.

The athletes then completed the Nike SST assessment, which took approximately 30 min.

Predictors. Eleven Nike SST variables were used to predict performance measures. They were obtained from the nine Nike SST tests described above. Each test was associated with one corresponding variable except depth perception (the test generated two variables: *depth perception threshold (arc seconds)*, *depth perception response time (ms)*) and hand reaction time (comprised: average reaction time and average response time (ms)). The average reaction and response times were significantly correlated (r = 0.43, p < 0.01). To avoid the issue of multiple collinearity, we created a calculated variable "average motor time", which was derived by subtracting the average reaction time from the average response time (how long it took to touch the test annulus from its onset – ms). The average reaction time and the average motor time were not significantly correlated (r = −0.28, p = 0.07). Other predictors included mean static visual acuity (average between left, right and binocular values expressed as logarithmically transformed minimum angle of resolution – logMAR), mean binocular contrast sensitivity (between 8 and 16 cycles of spatial frequency per degree – cpd), near–far quickness score (number of correct responses), dynamic visual acuity (target capture (ms)), perception span (number of correctly remembered dots), the eye–hand coordination score (number of yellow dots touched) and the total score on the Go/No-Go trials (cumulative number of yellow-green dots touched minus any red dots touched),

Dependent measures. For dependent measures we used the official University of North Dakota 2011–2012 and 2012–2013 season cumulative statistics for each player, goal percentage (from all shots on goal), total number of points scored divided by the number of games played (average number of points per game) and the average number of penalty minutes per game (total number of penalty minutes divided by the number of games played).

Statistical analyses. Collected measures of visual processing were used to predict individual player's performance statistics using a series of linear multiple regression analyses. To determine which variables should be included into the prediction equation for each dependent measure, we first obtained individual Pearson's r correlation coefficients between SST variables and dependent measures. Variables with significant bivariate correlations were then included into the regression models to determine the relative contributions of specific visual/perceptual/motor skills in explaining variance on performance measures.

We determined the maximum allowable number of predictors in our model based on the number of available data points for each dependent measure. For the offensive statistics (average number of game points per game and percent goals) we only used data for forwards (n = 24), since on both of the above measures their means were significantly different from those of defensemen (see Table I). These position-related differences are expected as forwards and defensemen generally have different game functions. Bivariate correlation coefficients between Nike SST and dependent measures for men and women were very similar. For this reason sex was not included as a separate predictor.

For the multiple regression analyses we chose the backward elimination procedure to obtain the most parsimonious model capable of explaining the greatest amount of variance in the criterion with the minimum number of predictors at the final step. In backward elimination all predictors are entered into the model first and then at each step the predictor that produces the smallest increment in R^2 is tested (using a partial F-test) to determine whether it should be removed from the equation.

At the final step we checked for multiple collinearity problems first by examining general indexes of collinearity such as tolerance and VIF values (i.e. tolerance values < .10 and VIF > 10), followed by analyses of more specific statistics such as eigenvalues and condition indexes (CI). According to Belsley, Kuh, and Welsch (1980), a CI > 15 suggests

Table I. Means and standard deviations for dependent variables as a function of player position.

	Player position type					
	Forward (n = 23)		Defence (n = 13)			
Variable Name	Mean (s)	95% CI	Mean (s)	95% CI	t	Hedges' g
Per cent goals	0.10 (0.05)	0.08–0.12	0.06 (0.03)	0.04–0.08	3.17**	1.0
Average number of points per game	0.53 (0.56)	0.30–0.80	0.27 (0.13)	0.19–0.35	2.16*	0.75
Average number of penalty minutes per game	0.64 (0.51)	0.45–0.89	0.70 (0.61)	0.34–1.07	0.31	0.11

Note: *Significant at α = 0.05.
**Significant at α = 0.01.

a possible multicollinearity problem, and a CI > 30 suggests a serious multiple collinearity problem.

Finally, using G-Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009) we performed *post hoc* analyses of achieved statistical power of each model based on the observed effect sizes (Cohen's f^2) and $\alpha = 0.05$ to determine the sensitivity of the model to Type II error (failure to reject the null hypothesis when it is false).

Results

Per cent goals

Four Nike SST variables had significant bivariate correlations with goal percentage (see Table II and Figure 1 for details). These variables were then entered into a regression model using a stepwise backward elimination procedure.

The results showed that the final model contained all four of the entered variables. The linear model was able to explain the variability in the criterion significantly better than chance ($F_{(4,16)} = 8.93$, $p < 0.01$) and accounted for 69% of the total variance in the goal percentage. Regression coefficients for all of the variables were statistically significant at $\alpha = 0.05$. These results are presented in Table III. The *post hoc* test of the achieved power of the model was determined on the basis of the obtained effect size (f^2). With explained variance of 0.69 and residual

Table II. Significant bivariate correlations (Pearson *r*) of Nike SST measures with measures of athletic performance in Division I hockey players.

			Pearson *r*		
NST measure	Mean (*s*)	95% CI	Game point average (n = 24)	Per cent goals (n = 24)	Average penalty minutes per game (n = 38)
Near–far quickness	24.71 (5.79)	22.26–27.15	ns	0.44	ns
Go/No-Go total	26.75 (10.57)	22.29–31.21	0.57	0.56	ns
Perception span	38.67 (12.45)	33.41–43.93	ns	0.47	ns
Average reaction time (ms)	347.55 (23.58)	337.59–357.51	ns	−0.45	−0.37
Depth perception mean reaction time (ms)	1556.94	1298.30–1829.13	ns	ns	−0.35

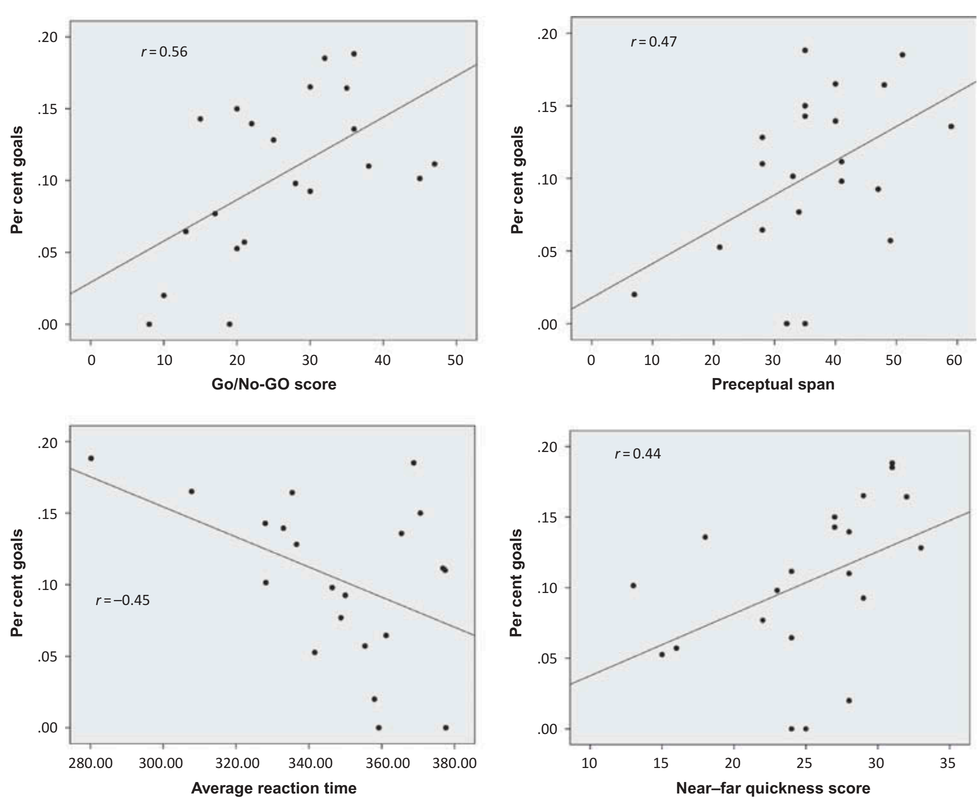

Figure 1. Bivariate correlations between total goal percentage and variables entered into the multiple regression model: the "total score on the Go/No-Go trials", the "near–far quickness score", "perception span" and the "average reaction time to a visual stimulus".

Table III. Regression analyses summary for individual Nike SST variables predicting performance measures in Division I hockey players.

Criterion	Predictors	B	SEB	β
Per cent goals	Near–far quickness score	0.004	0.001	0.406*
	Perception span	0.002	0.001	0.320*
	Go/No-Go total score	0.002	0.001	0.375*
	Average reaction time over five trials (ms)	−0.001	0.00	−0.332*

Notes: Adjusted R^2 = 0.61 (n = 22, p = 0.01); f^2 = 2.23. B = Unstandardised coefficient B; SEB = Standard Error of B; β = Standard Error of β.
*p < 0.05.

Mean points per game	Go/No-Go total score	0.026	0.009	0.29**

Note: Adjusted R^2 = 0.29 (n = 21, p = 0.01); f^2 = 0.49.
**p < 0.01.

Average number of penalty minutes per game	Depth perception; mean reaction time (ms)	0.000	0.000	−0.323*
	Average reaction time over five trials (ms)	–0.004	0.002	−0.351*

Note: Adjusted R^2 = 0.20 (n = 36, p = 0.01); f^2 = 0.31.
*p < 0.05.

variance of 0.31, the obtained effect size (using G-Power 3.1) was 2.23, which was very large according to Cohen's (1988) guidelines. With this effect size the power of the final model at α = 0.05 was 0.99, suggesting good model sensitivity to Type II error – despite a relatively small sample size.

Overall the results showed that 69% of variance in the goals made by forwards in 2011–2013 could be predicted by their faster reaction time to a visual stimulus, better visual memory, better visual discrimination and a faster ability to shift focus between near and far objects.

Average number of points per game

Only one variable "the total score on the Go/No-Go trials" showed a significant bivariate correlation with the criterion (average number of points per game, see Table II and Figure 2). When entered into a regression model it accounted for 33% of the variance in "the average number of game points" (R^2 = 0.33), which was statistically significant ($F_{(1,20)}$ = 9.63, p < 0.01) . The obtained power of the model based on f^2 of 0.49 (large according to Cohen's (1988) guidelines) was 0.90, suggesting that the model was well powered to detect the true effect of the predictor variable.

The results, thus, suggested that a greater number of game points to a significant extent are related to better discrimination among competing visual stimuli (greater number of hits on the Go/No-Go test) and the ability to inhibit non-target responses (false alarms on the Go/No-Go test).

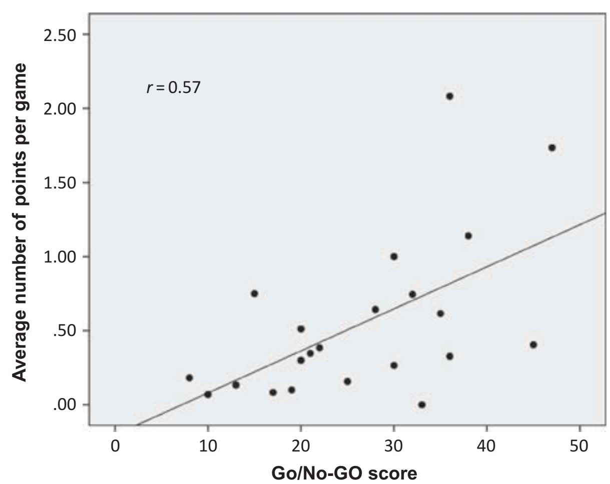

Figure 2. Bivariate correlations between the average number of game points and variables entered into the regression model: the total score on the Go/No-Go trials.

Average number of penalty minutes per game

"Depth perception mean response time" (dynamic stereopsis) and "average reaction time" were the only two variables that had significant correlations with the "average number of penalty minutes per game" (see Table II and Figure 3). These variables were then entered into a backward, stepwise regression model.

The results showed that both variables were retained in the final model and each variable by itself was significant at α = 0.05 in explaining variability in the criterion. The model with two predictors accounted for the total of 24% of variance in the "average number of penalty minutes per game",

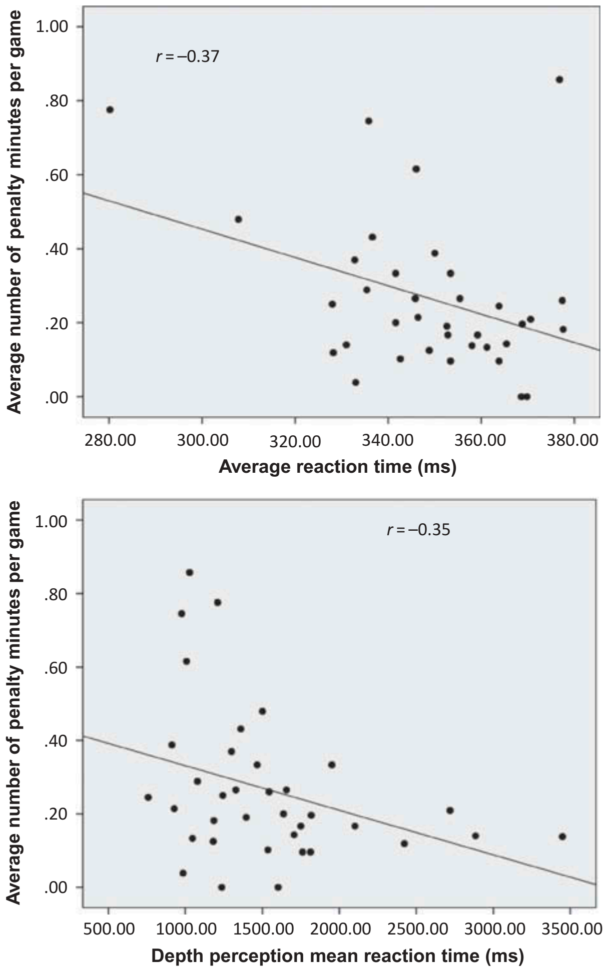

Figure 3. Bivariate correlations between average number of penalty minutes per game and variables entered into the regression model: average reaction time (ms) and depth perception men reaction time (ms).

which was significantly better than chance ($F_{(2,35)} = 5.25$, $p = 0.01$).

The obtained power of the model with 38 participants, two tested predictors and the observed effect size of f^2 =0.31 (medium-to-large, according to Cohen's (1988) guidelines) was 0.85, suggesting that the model was adequately powered to detect the true effects of the predictor variables.

The results thus showed that about a quarter of variance in penalty minutes was related to a faster ability to identify a 3-D target and a faster general reaction time to visual stimuli. The latter variable thus seems to be associated not only with a greater goal but also with more time spent in the penalty box.

Discussion

In the present study measures collected with the Nike SST were used to predict real game performance statistics in elite ice hockey players. In support of our original hypothesis, static visual processing and nearpoint visual skills (i.e. static visual acuity (SVA), contrast sensitivity and stereopsis) were not significantly related to indexes of on-the-ice performance. At the same time more dynamic components of visual perception and visuomotor control such as stimulus discrimination, near–far quickness and dynamic stereopsis predicted significant amounts of variance in our dependent measures. Somewhat contrary to the original hypothesis dynamic visual acuity (DVA) and eye–hand coordination were not significantly associated with either goal scoring or average number of game points.

The lack of a significant relationship between offense statistics and static measures of visual perception observed in the present study with ice hockey players is in line with the relative weights assigned to these visual functions by Ciuffreda and Wang (2004) in their meta-analysis of studies that related visual functions to athletic performance. For example, using a 5-point Likert scale to estimate the importance of a specific visual function for commonly played dynamic sports in the US such as football, baseball, basketball, tennis and soccer, the authors gave a mean rating of 3.5 to SVA and 1.3 to contrast sensitivity.

Contrary to our hypothesis neither DVA nor eye–hand coordination were significantly related to successful offensive performance in our ice hockey sample.

In an early review of the literature, Stine, Arterburn, and Stern (1982) reported that athletes show superior DVA abilities compared with non-athletes and that elite athletes have better DVA than do amateur or non-elite athletes, suggesting that there is an important link between elite athletes and DVA ability. On the other hand, Ward and Williams (2003) failed to report significant DVA differences in performance of elite and subelite youth soccer players. In the present study the Nike SPARQ system may have not provided an adequate environmental simulation of DVA demands of a large-field, dynamic sport, such as ice hockey. Although stimulation of saccadic eye movements by brief stimulus presentation in a random location on a screen or stimulation of vestibular ocular reflex by quick head turning towards a stationary target have previously been used to assess DVA in normal (Erickson et al., 2011) and clinical populations (Rine et al., 2012) as well as in athletes including ice hockey players (Schneider, Emery, Kang, & Meeuwisse, 2014); studies actually reporting DVA differences between elite athletes and non-athletes usually employ fast-moving Landolt C ring targets to test DVA (Ishigaki & Miyao, 1993; Uchida, Kudoh, Higuchi, Honda, & Kanosue, 2013). On these types of tests the latency of onset of saccadic eye movements in response to a fast-moving target seems to be one of the key factors influencing one's DVA (Kohmura, Aoki, Honda, Yoshigi, & Sakuraba, 2008). Since the Nike SST test of "target capture", purported to assess DVA, did not involve either a moving target or head turning, it may have measured something other than dynamic visual acuity.

An alternative explanation (provided that "target capture" does represent DVA) is that DVA decreases with increased target velocities and decreased target size (Hoffman, Rouse, & Ryan, 1981), producing an increased physiological demand on the observer (e.g. resolving power of the eye, oculomotor abilities, peripheral awareness and psychological abilities to interpret what is seen). It is thus possible that at certain puck speeds DVA ceases to be a reliable visual cue facilitating decision-making and offensive play.

Similarly, the measure of eye–hand coordination in the present study involved rapid touching of lit-up dots on the touch-sensitive display using either hand depending on the target location. This procedure may have not adequately simulated eye–hand coordination tasks involved in ice hockey where (except for goaltenders) both hands typically work in synchronicity (wielding a hockey stick) when interacting with the target (i.e. the puck).

On the other hand other general visuomotor variables in combination with perceptual, attentional and cognitive parameters showed a much stronger relationship to goal scoring and average number of game points. Specifically, faster simple motor reaction time in combination with a greater perception span, better visual discrimination (decision-making) and a faster ability to shift focus between near and far objects (dynamic visual attention) predicted 69% of the variability in the goals made by forwards in 2011–2013. Additionally, visual attention and motor control as measured by the total score on the Go/No-Go trials were shown to predict the average number of game points. Regression analyses of individual Nike SST variables demonstrated that about 33% of variability in accumulated game points could be explained by better decision-making as measured by the ability to rapidly discriminate among competing visual stimuli and to inhibit non-target motor responses.

The above findings are consistent with previous studies that suggested that the ability to quickly read offensive and defensive play patterns is critical in ice hockey (Martell & Vickers, 2004). The ability to quickly read and react in ice hockey has been defined as the perceptual ability to selectively attend to key components of the game and rapidly execute the correct decision. According to Martell and Vickers (2004), this perception – action relationship – in ice hockey ensures that preparatory and attentional factors assist in the production of critical movement decisions, which in turn affects performance.

Reaction time and response time (movement time) are considered to be the classic measurements of the efficiency and effectiveness of an individual" capacity to perform sport skills (Magill, 2006). Together, reaction time plus movement time is equal to visual motor response time (VMRT). VMRT has been identified as a key performance indicator of proficiency in many ball sports (Erickson, 2007). Ciuffreda (2011) reports that VMRT in the retinal periphery can be reduced with training by up to 20 ms, which could confer to the athlete potentially significant benefits on the field. Similar improvements around 20 ms in choice reaction time (a measure of the time from the arrival of a suddenly presented stimulus (visual reaction time) until the beginning of the actual action (motor response)) have been recently reported by Schwab and Memmert (2012) in youth male field hockey players following a 6-week generalised visual training programme (DynamicEye® SportsVision Training Program). The authors, however, did not report any improvement following training on a multiple object-tracking task thought to be important for the sport.

There are many situations in sport that require the athletes to make a specific and appropriate motor response to a certain visual stimuli (stimulus discrimination). Therefore, both the speed and the accuracy of linking visual to neuromuscular processing were associated by Erickson (2007) as evidence of the integrity of the visual motor control system. In the present study the ability to quickly recognise and accurately respond to visual stimuli (total score on the Go/No-Go measure) was an important variable in predicting individual goal percentages and the mean number of game points.

A significant relationship between the ability to quickly shift attentional focus from near to far objects and the athletic performance has previously been demonstrated in volleyball players (Di Russo et al., 2003). Ciuffreda and Wang (2004) further contended that specialised visual attentional training emphasising dynamic shifting of one's visual attentional focus can significantly contribute to the overall improvement of the athlete's performance and should, thus, be incorporated into any sports vision training programme. Our findings are, indeed, in line with this recommendation as the near–far quickness scores were also predictive of the goal percentage.

The results further suggest that a decrease in simple reaction time alone is not enough to facilitate performance on the ice: improvements in simple reaction times need to be accompanied by corresponding improvements in higher level information processing/decision-making. Otherwise rapid motor responses in some cases may result in faster non-target responses, which may lead to a greater number of penalty minutes. In the present study faster simple reaction time to a visual stimulus as well as faster stereopsis of a 3-D target in 24% of the cases predicted greater mean duration of the player's penalty time. Certain personality characteristics of athletes may help explain these findings. Although in the present study we did not measure impulsivity, Edman, Schalling, and Levander (1983) found significantly shorter simple reaction times on a choice reaction time task in more impulsive participants, who also made significantly more errors than less impulsive participants. Logan, Schachar, and Tannock (1997) further reported problems with inhibitory control in more impulsive participants as was evident in their study from significantly longer stop-signal reaction times. More recently Lage et al. (2011) reported that in handball female athletes' impulsivity as measured by Conner's Continuous Performance Task (CPT-II) and the Iowa Gambling Task (IGT) was positively correlated with offensive fouls. The researchers suggested that this type of non-planning impulsivity results in risky decisions that may seem to produce immediate rewards but are potentially fraught with longer-term negative consequences (e.g. penalty). Our results seem to be in agreement with this conclusion.

Study limitations

One of the natural limitations of studying elite athletes is a highly circumscribed participant pool. Although we were able to test 88.4% of the target population (hockey players who appeared on the roster for the NCAA 2011–2013 seasons (n = 43)), the number of participants was still relatively small to allow regression modelling with more than four predictors and was adequate to detect only large effect sizes. Thus, some of other potentially important relationships may have been overlooked due to the lack of statistical power.

There is always a danger with small sample sizes that you will be capitalising on chance when using predictors that have significant bivariate correlations with the criterion (the significance of the correlation could be due to a chance fluctuation in the data), but in the present study it was probably not the case as adjusted indexes of explained variance in the population (adjusted R^2 reported in Table II) remained relatively close to the proportions of explained variance in our sample.

Another obvious limitation of the current study design is the correlational nature of the observed relationships. Nevertheless, this is one of the first steps in the direction of designing sport-specific visual training programmes that may supplement currently existing conventional training protocols, which may result in additional benefits to players and improved performance in the field. A corollary of the present study may be a study of performance improvements in hockey players following a sport vision therapy that specifically emphasises the aspects of visual perception and visuomotor control described above.

Conclusion

This is one of the first studies to show that some of the visual skills that state-of-the-art generalised sports vision programmes are purported to target may indeed be important for hockey players' actual performance on the ice, as in our study faster reaction time to a visual stimulus, faster visual stimulus discrimination, better visual memory and a faster ability to shift focus between far and near objects significantly predicted such an important performance statistic as goal percentage.

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