Visual Tracking Speed Is Related to Basketball-Specific Measures of Performance in NBA Players

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Abstract

Mangine, GT, Hoffman, JR, Wells, AJ, Gonzalez, AM, Rogowski, JP, Townsend, JR, Jajtner, AR, Beyer, KS, Bohner, JD, Pruna, GJ, Fragala, MS, and Stout, JR. Visual tracking speed is related to basketball-specific measures of performance in NBA players. *J Strength Cond Res* 28(9): 2406–2414, 2014—The purpose of this study was to determine the relationship between visual tracking speed (VTS) and reaction time (RT) on basketball-specific measures of performance. Twelve professional basketball players were tested before the 2012–13 season. Visual tracking speed was obtained from 1 core session (20 trials) of the multiple object tracking test, whereas RT was measured by fixed- and variable-region choice reaction tests, using a light-based testing device. Performance in VTS and RT was compared with basketball-specific measures of performance (assists [AST]; turnovers [TO]; assist-to-turnover ratio [AST/TO]; steals [STL]) during the regular basketball season. All performance measures were reported per 100 minutes played. Performance differences between backcourt (guards; $n = 5$) and frontcourt (forward/centers; $n = 7$) positions were also examined. Relationships were *most likely* present between VTS and AST ($r = 0.78$; $p < 0.003$), STL ($r = 0.77$; $p < 0.003$), and AST/TO ($r = 0.78$; $p < 0.003$), whereas a *likely* relationship was also observed with TO ($r = 0.49$; $p < 0.109$). Reaction time was not related to any of the basketball-specific performance measures. Backcourt players were *most likely* to outperform frontcourt players in AST and *very likely* to do so for VTS, TO, and AST/TO. In conclusion, VTS seems to be related to a basketball player's ability to see and respond to various stimuli on the basketball court that results in more positive plays as reflected by greater number of AST and STL and lower turnovers.

Key Words visual tracking speed, visual perception, reaction time methods, decision making, sport science, fitness assessment

Introduction

In professional basketball, each position has a predefined strategic role where aptitude is measured by game-related statistics of productivity (31,36). The ability of a specific player to meet the demands of their role is considered to be a function of several physiological, visual-motor reaction speed, and perceptual-cognitive capability measures (7,15,21,28,32). To date, however, only 1 study has related player-specific characteristics to game-related performance measures in professional basketball players (25). McGill et al. (25) reported that stability, agility, and flexibility were associated with minutes played, assists (AST), rebounds, blocked shots, and steals (STL) per game. However, the specific roles of visual-motor reaction speed and perceptual-cognitive capability to game-related measures of performance in professional basketball players are unknown.

Although conceptually unique, a clear distinction of how visual-motor reaction speed and perceptual-cognitive capability affect athletic performance does not exist. Visual-motor reaction speed is a measure of the length of time encompassing the onset of a stimulus, an individual's recognition of the stimulus, and the length of time necessary to complete their response to the stimulus (15,26,33). Presumably, athletes who are capable of recognizing and responding (to a stimulus) within a shorter amount of time would possess a competitive advantage. To date, however, research demonstrating a positive relationship with athletic performance is equivocal (7,15,21,26,29,34). However, perceptual-cognitive capability may be related to an athlete's ability to efficiently devote attentive resources in response to the movement patterns of several key components within a dynamic environment

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(10). In this case, timely and positive decisions made by athletes with superior perceptual-cognitive ability might be possible because of additional time for a response created by their more rapid assessment of the given scenario. Nevertheless, evidence supporting this notion in professional athletes is quite limited.

Pylyshyn and Storm (30) first introduced the multiple object tracking (MOT) task as a measure of perceptual-cognitive capability, by determining the individual's capability to maintain their focus on a subgroup of identical objects within a dynamic environment where all elements are in constant interaction. Evidence suggests that this ability is a function of the objects' speed and proximity. When objects are in close proximity, fewer objects are tracked as the speed of the objects increase. Conversely, the ability to track more fast-moving objects is improved when greater distance separates these objects (2). Therefore, the ability to track multiple objects will be dependent on the movement speed of those objects when they are confined to a constant arena, where the ability to create space between objects is limited. As such, perceptual-cognitive capability might be assessed by controlling either the speed of the object or the quantity of objects and measuring the alternative. However, these 2 variables exist on different continuums. Although the number of objects is limited to only positive integers, the speed in which multiple objects may be visually tracked (visual tracking speed [VTS]) exists among an infinitely larger scale of numerical possibilities. As such, VTS has been suggested as the preferred dependent variable used to precisely distinguish athletic ability because it may vary significantly among several observers with a similarly established ability to track a specific number of objects (10).

Previously, professional soccer, hockey, and rugby players have been demonstrated to possess an ability to track multiple objects at greater speeds in comparison with amateur athletes and nonathletic control subjects (8). Although superior VTS skills have not been investigated in elite basketball populations, it is reasonable to assume that VTS plays a comparable role, given the similarities among these sports. In general, team sports value effective ball control, which essentially depends on the speed in which players can integrate and process multiple information sources within a dynamic 3-dimensional (3D) environment and react in a timely manner (9,26,34,39,41). In basketball, a player may use this ability to simultaneously monitor the movements and positions of several players (teammates and opponents), as well as the basketball, all in relation to themselves, each other, and the basket. Individuals who excel in this ability allot themselves more time to make a positive play and avoid costly mistakes. From a performance standpoint, this ability may be quantified by the number of AST, TO, and STL accumulated by the player because these have been shown to be predictive of a winning outcome (5,13,14,17,19). Positive statistics (AST and STL) would indicate the player's ability to observe and correctly respond to various stimuli occurring simultaneously on the court, in a timely fashion, whereas a negative statistic (turnovers) may indicate an environmental misconception or an incorrect (or untimely) response that results in the loss of ball control. Furthermore, the ratio of assists to turnovers (AST/TO) would provide additional insight into how efficiently a player distributes the ball to his teammates and gains AST without turning the ball over. Consequently, demonstrating the relationship between tracking ability and measures of ball control would be beneficial from recruitment and needs analysis standpoints. Therefore, the main purpose of the present investigation was to determine the relationships between VTS and reaction time (RT) on game-related measures of ball control in professional basketball players. It is hypothesized that players who produce more AST, STL, and have a greater AST/TO ratio would also possess greater VTS and faster visual-motor RT. However, superior ball handling, which is considered to be an important aspect of successful basketball performance (5,14,19), may not be paramount for all positions. Passing skills, as well as gaining and maintaining ball control, appear to be of greater importance for backcourt players (guards) than frontcourt players (forward and centers) (36). Thus, a secondary purpose of this study was to compare VTS and visual-motor reaction speed between backcourt and frontcourt players.

Methods

Experimental Approach to the Problem

Visual tracking speed and RT were examined in professional basketball players on a National Basketball Association (NBA) team before the commencement of the 2012–13 regular season. Players reported to the Human Performance Laboratory during the week immediately before the start of the regular season. All testing sessions occurred approximately 60–90 minutes following a morning shoot-around practice and breakfast at the team's training facility. Relationships were examined between these measures and accumulated basketball-specific measures (e.g., AST, turnovers, STL, and the AST/TO ratio) over the course of the entire regular season (82 games), normalized to account for individual differences in playing time.

Subjects

De-identified data from a convenience sample of backcourt ($n = 5$; 26.8 ± 2.9 years) and frontcourt ($n = 7$; 23.2 ± 2.6 years; range: 19.4–30.7 years) players under contract to play for the NBA franchise Orlando Magic completed testing at the beginning of the season. Players gave their informed consent as part of their sport requirements. This study was considered to be exempt in accordance with our university's institutional review board policies for use of human participants in research.

Visual Tracking Speed

Visual tracking speed was assessed by the completion of 1 core session on the Neurotracker (NT; CogniSens Athletic, Inc., Montreal, Quebec, Canada) 3D MOT device by each

Figure 1. Neurotracker 3-dimensional (3D) multiple-object tracking. For testing, the participant sits upright on a stool placed 7 feet in front of a projection screen (8 × 8 ft) while wearing specialized 3D glasses.

player. As previously recommended, a core session consisted of 20 individual trials used to quantify spatial awareness by determining the player's threshold speed for effective perception and processing of visual information sources (9). For each trial, players were instructed to sit upright on a stool placed 7 feet in front of a projection screen (8 × 8 ft) with the size of the 3D volume space being 46° of visual angle at the level of the screen. All players wore specialized glasses to make the objects appear 3D in the simulator (Figure 1). Before each trial, a 3D transparent cube containing 8 identical yellow balls, measuring 5.5 inches in diameter, was presented on the screen (Figure 2A). Four of these balls were randomly illuminated for 2 seconds before returning to the baseline yellow color (Figure 2B). The player was instructed to track these 4 balls for the duration of the individual trial. During the trial, all 8 yellow balls moved simultaneously and individually throughout all regions of the cube for 8 seconds (Figure 2C). The random, continuous movement patterns of each ball were only affected by collisions (impact and bounce) with the wall of the cube and the other balls. At the conclusion of 8 seconds, the balls were frozen in place and were each assigned a display number, 1 through 8, by the computer (Figure 2D). The player was instructed to identify, by number, the 4 balls that were originally illuminated at the start of the trial (Figure 2E). The speed at which the balls moved on the next trial was dependent on the correct identification of the illuminated balls and was adjusted between trials in a staircase (1 up 1 down) fashion, which has been previously demonstrated to be an efficient and reliable psychometric estimator (greater than maximum likelihood) in small experiments (less than 30 trials) (22,38). If the player correctly selected all 4 balls, the speed of the balls was increased. Otherwise, the speed of the balls was reduced for the next trial. At the end of the 20 trials, VTS was determined to be the fastest speed (in centimeter per second) at which the player could correctly identify, with 100% accuracy, all 4 illuminated balls. For the first trial, the speed in which the balls moved was standardized to be 68 $cm \cdot s^{-1}$. To avoid a training effect confound (8), all players began their core session completely unfamiliar to the NT device.

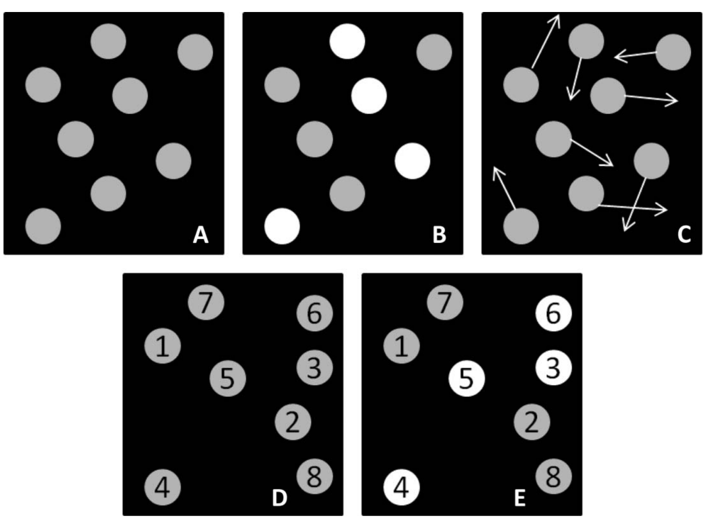

Figure 2. Neurotracker 3-dimensional (3D) multiple-object tracking assessment protocol. A) Eight spheres are presented within a 3D cube. B) Four spheres are randomly highlighted by the computer for 2 seconds. C) All 8 identical spheres randomly move throughout the cube for 8 seconds. D) Spheres are randomly assigned a number (1–8). E) The correct 4 spheres are highlighted after participant makes selections.

Visual-Motor Reaction Time

Visual-Motor RT to a visual stimulus was assessed using the light training reaction device, Dynavision D2 (Dynavision International LLC, West Chester, OH, USA), in a manner consistent with what has been previously described (16,37). Briefly, the D2 is a vertically adjustable board (4 ft × 4 ft) that consists of 64 target buttons, arranged into 5 concentric circles, which can be illuminated to serve as a stimulus for the player. In the present investigation, the D2 was adjusted so that its digital screen, located slightly higher than the center of the board, was at the player's eye level. At a standing distance of 2 feet (eyes to screen) and focus being placed on the digital screen, peripheral vision angle was 34° to the uppermost button, 43° to the furthest buttons laterally, and 45° to the lowest button. For each test, the player stood in an athletic stance, in front of the board, with the outermost buttons within arm's reach. Lighting conditions were standardized for all D2 measures. Two separate choice reaction assessments were conducted.

The first choice reaction assessment measured the player's visual, motor, and physical reaction in seconds to a 4-choice stimulus with the dominant hand within a controlled region. The player initiated the test by placing his hand on an illuminated "home" button. Subsequently, the D2 would initiate the visual stimulus by lighting a single button in 1 of 4 locations adjacent to the "home" button on the same horizontal plane. Visual reaction time (VIS-RT) was measured by how quickly the player recognized the stimulus and removed his hand from the "home" button. The motor reaction time (MTR-RT) recorded how quickly the player reached the lit button, whereas physical reaction time (PHY-RT) measured as the length of time between the initiation of the stimulus and the player's return back to the "home" button. This was repeated 9 times per assessment.

The second choice reaction assessment used all 64 buttons to provide stimuli that randomly occurred within the player's center of gaze and throughout their peripheral vision. During this variable region choice reaction test (VR-CRT), the players began in an athletic stance with their hands raised (approximately shoulder height) and ready to strike any button on the D2 device. An initial stimulus would present on the D2 in a random location. The stimulus remained lit until it was struck by the player. Another stimulus would then appear at another random location. The player was instructed to successfully identify and strike as many stimuli as possible within 60 seconds. The number of hits per minute was recorded for each player.

Game-Related Performance Statistics

Ball control performance was determined from accumulated AST, turnovers (TO), and STL, as well as minutes played over the course of regular season basketball play. Assists are awarded to a player who passes the ball to a teammate in a way that leads to a scored basket (not by foul shot). Turnovers are counted when the player loses possession of the ball because of a mistake, which may include having the ball stolen, an errant pass, or committing an offensive violation (travelling or stepping off-sides/out of bounds). Steals are earned when a defensive player gains possession of the ball either by intercepting a pass or opponent's dribble, without making contact with the offensive player's hands. These statistics were obtained from a published statistics resource (27) for professional basketball players. To normalize the data for individual differences in playing time, these measures of ball control were analyzed per 100 minutes played. Additionally, the ratio of AST/TO, calculated by dividing total AST by total turnovers, was included in the analysis.

Table 1. Qualitative inferences on the magnitude of the relationship between game-related measures of performance, perceptual-cognitive function, and visual-motor reaction time ($n = 12$).*

	r	Positive	Trivial	Negative	Qualitative inference†
Visual tracking speed					
AST	0.78	99.7	0.2	0.0	Most likely positive
TO	0.49	90.1	6.9	2.9	Likely positive
STL	0.77	99.7	0.3	0.0	Most likely positive
AST/TO	0.78	99.8	0.2	0.0	Most likely positive
Visual reaction time					
AST	−0.22	16.5	19.0	64.5	Unclear
TO	−0.18	19.8	20.5	59.7	Unclear
STL	0.02	40.9	23.6	35.5	Unclear
AST/TO	−0.16	21.3	21.0	57.7	Unclear
Motor reaction time					
AST	0.04	42.5	23.5	33.9	Unclear
TO	0.29	72.2	16.1	11.7	Unclear
STL	0.19	61.4	20.0	18.6	Unclear
AST/TO	−0.07	30.5	23.2	46.4	Unclear
Physical reaction time					
AST	−0.13	24.6	22.0	53.3	Unclear
TO	0.01	39.0	23.7	37.3	Unclear
STL	0.10	50.0	22.6	27.4	Unclear
AST/TO	−0.14	23.7	21.8	54.5	Unclear
Variable region choice reaction					
AST	0.07	46.1	23.2	30.7	Unclear
TO	0.15	55.7	21.5	22.8	Unclear
STL	0.27	69.9	17.1	13.1	Unclear
AST/TO	−0.05	32.8	23.4	43.8	Unclear

*AST = assists; TO = turnovers; STL = steals; AST/TO = assists-to-turnovers ratio.
†Threshold set to 0.1 for all relationships.

Statistical Analyses

To account for the small sample ($n = 12$), the relationships between VTS, visual-motor RT, and game-related measures of

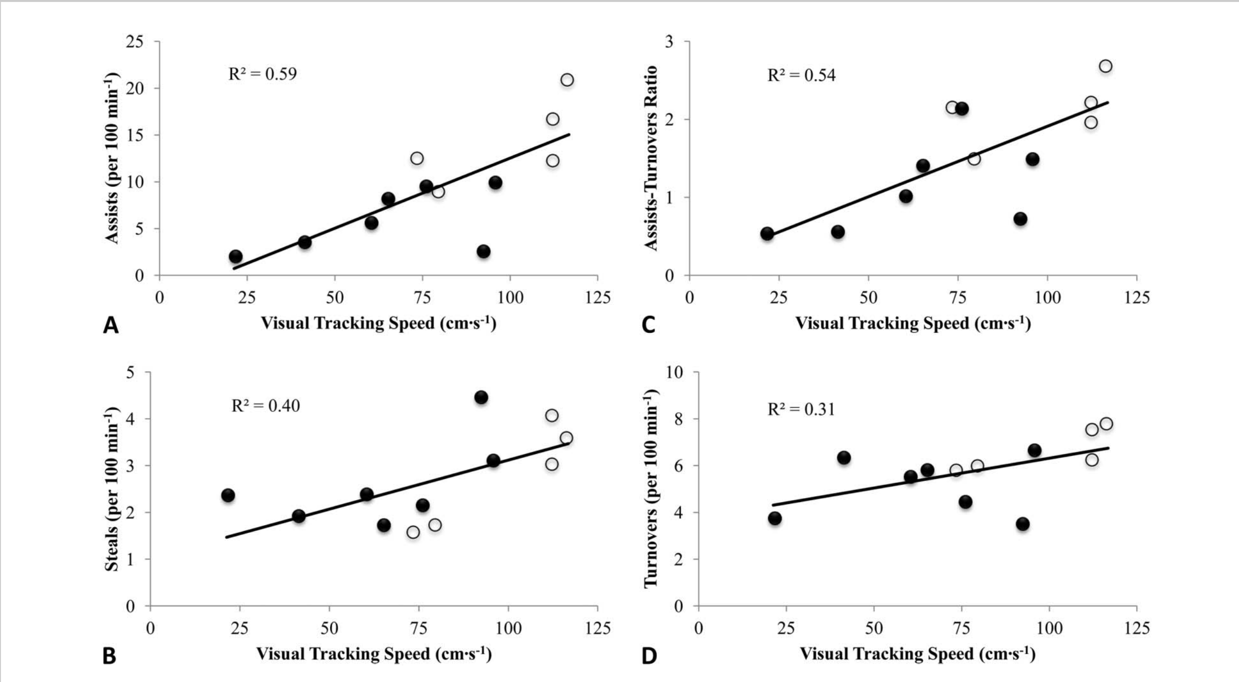

Figure 3. Bivariate relationships between visual tracking speed and game-related measures of performance in professional basketball backcourt ($n = 5$) and frontcourt ($n = 7$) players: (A) assists (100 per minute), (B) steals (100 per minute), (C) assists-to-turnovers ratio, and (D) turnovers (100 per minute). Open spheres = back court players; closed spheres = front court players; solid black line = line of best fit.

ball control were interpreted through the analysis of the magnitude of their relationships (3,6). Statistical Software (SPSS; V. 20.0; SPSS, Inc, Chicago, IL, USA) was used to calculate Pearson's product-moment correlation coefficients and the *p*-value of the relationship, which along with the sample size were input into the correlation coefficient statistic on a published spreadsheet (3) to determine the magnitude of the effect. The threshold values for positive or negative correlations were set at 0.1, which was previously reported to be the smallest clinically important correlation (6).

Similarly, inferences were made on the magnitude of the differences between backcourt (guards) and frontcourt (forward/centers) players in game-related measures of performance, VTS, and visual-motor RT. Microsoft Excel (Excel; 2007; Microsoft Corp, Redmond, WA, USA) was used to calculate a *p*-value from an independent *t*-test. This value, along with the minimal difference threshold value (20% of the grand mean) and the degrees of freedom, was entered into the raw difference between means and other t-distributed effect statistics calculator of a published spreadsheet for interpretation (3). All data are expressed as a mean ± *SD*.

Qualitative inferences on correlations and group differences were determined as positive, trivial, or negative according to methods previously described (3) and were based on the confidence interval range relative to the smallest clinically meaningful effect to be positive, trivial, or negative. The percent chances of a positive or negative outcome was evaluated with the following scale: <1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99% very likely; and >99% almost certain. If the likely range substantially overlapped both positive and negative values, it was inferred that the outcome was unclear (18). In the event of a positive or negative result, correlations were re-examined at 0.3 and 0.5 threshold values to determine if the low correlation was in fact a moderate or high correlation, respectively (6).

Results

Before regular season competition, the players' VTS averaged 78.9 ± 29.1 $cm \cdot s^{-1}$, whereas VIS-RT averaged 0.41 ± 0.08 seconds, MTR-RT averaged 0.27 ± 0.06 seconds, PHY-RT averaged 0.69 ± 0.10 seconds, and CRT performance resulted in an average of 82.5 ± 8.5 hits per minute. Over the course of the entire regular season, the players averaged 1,518.2 ± 732.5 minutes played, 143.0 ± 118.8 AST, 86.6 ± 46.1 TO, and 39.7 ± 23.7 STL, which equated to 9.37 ± 5.69 AST per 100 minute, 5.77 ± 1.34 TO per 100 minute, 2.68 ± 0.97 STL per 100 minute, and a 1.53 ± 0.71 AST/TO ratio.

No clear relationships were observed between minutes played, VTS, or any measure of RT. Within the measures of RT, PHY-RT was a most likely related (99.8% positive) to VIS-RT ($r = 0.83$; $p = 0.002$) and likely related (92.5% positive) to MTR-RT ($r = 0.54$; $p = 0.084$). VIS-RT and MTR-RT

Table 2. Positional differences in perceptual-cognitive function, visual-motor reaction time, and statistical performance measures of ball control in National Basketball Association players.*

	Back court	Front court	Mean difference† ± 90% CI‡	Percent			Qualitative inference
				Positive	Trivial	Negative	
Visual tracking speed ($cm \cdot s^{-1}$)	98.7 ± 20.5	64.8 ± 26.7	34.0 ± 26.0	96.1	2.9	1.0	Very likely positive
Reaction time							
Visual (s)	0.41 ± 0.13	0.42 ± 0.05	−0.01 ± 0.08	28.5	27.2	44.4	Unclear
Motor (s)	0.27 ± 0.04	0.28 ± 0.07	−0.01 ± 0.06	25.0	26.4	48.6	Unclear
Physical (s)	0.67 ± 0.14	0.69 ± 0.08	−0.02 ± 0.10	23.7	26.1	50.2	Unclear
CRT ($hits \cdot min^{-1}$)	86.8 ± 8.2	80.1 ± 8.3	6.6 ± 9.5	81.6	11.3	7.1	Unclear
Ball control statistics							
Assists ($100 \cdot min^{-1}$)	14.25 ± 4.62	5.88 ± 3.32	8.40 ± 4.10	99.5	0.4	0.1	Most likely positive
Turnovers ($100 \cdot min^{-1}$)	6.67 ± 0.92	5.13 ± 1.25	1.50 ± 1.20	95.8	3.1	1.1	Very likely positive
Steals ($100 \cdot min^{-1}$)	2.80 ± 1.11	2.59 ± 0.93	0.21 ± 1.00	51.1	23.8	25.1	Unclear
AST/TO ($100 \cdot min^{-1}$)	2.10 ± 0.43	1.12 ± 0.59	0.98 ± 0.56	98.9	0.9	0.2	Very likely positive

*CI = confidence interval; CRT = choice reaction time; AST/TO = assists-to-turnovers ratio.
†Mean difference refers to the first named group minus the second named.
‡Add and subtract this number to the mean effect to obtain the 90% confidence intervals for the true difference. Qualitative inference represents the likelihood that the true value will have the observed magnitude.

were not related. Inferences based on the magnitude of the relationships between VTS, visual-motor RT, and game-related measures of ball control are displayed in Table 1. In relation to measures of ball control, the analyses revealed that the observed relationship between VTS and AST ($r = 0.78$; $p = 0.003$), VTS and STL ($r = 0.77$; $p = 0.003$), and VTS and AST/TO ($r = 0.78$; $p = 0.003$) were most likely positive, whereas a likely positive relationship was also observed between VTS and TO ($r = 0.486$; $p = 0.109$). These relationships are graphically represented in Figure 3. No significant relationships were observed between any of the RT measures and these basketball-specific performance measures.

Comparisons between backcourt and frontcourt players revealed that backcourt players ($98.7 \pm 20.5\ cm \cdot s^{-1}$) possessed significantly ($p = 0.032$) faster VTS in comparison with frontcourt players ($64.8 \pm 26.7\ cm \cdot s^{-1}$). Significant differences were also observed between backcourt and frontcourt players in AST ($p = 0.004$), TO ($p = 0.043$), and AST/TO ($p = 0.010$). No differences were found for STL ($p = 0.724$) or in the RT measures: VIS-RT ($p = 0.829$), MTR-RT ($p = 0.747$), PHY-RT ($p = 0.716$), and CRT ($p = 0.234$) (Table 2).

Discussion

The results of our investigation indicate that VTS is *most likely* related to the athletes' -ability to see and respond to various stimuli on the basketball court. In consequence, possessing greater VTS may result in more positive plays as reflected by greater rate for accumulating AST and STL, and AST in relation to turnovers across an entire regular season. Furthermore, backcourt players (both point guards and shooting guards) seem to possess a faster speed threshold for tracking multiple objects throughout a wide 3D space along with greater productivity in game-related measures of ball control. These findings seem to be the first to demonstrate the assessment of VTS in NBA players and relate them to game-related measures of productivity. Previously, professional soccer, hockey, and rugby players were shown to have greater speed threshold values than amateur athletes and nonathletic control subjects (8). These results were the first to suggest that enhanced tracking capability is a discerning measure for predicting or evaluating athletic performance. Our data support the work of Faubert (8) and also suggest that VTS may be able to differentiate between positions among athletes as our results showed that the basketball players who are most responsible for ball control and passing (e.g., backcourt players) possessed significantly faster speed threshold scores and a greater AST/TO than the other players. Although our data also showed a *likely* positive relationship between VTS and TO, it was not as strong as the relationships between VTS and AST and between VTS and AST/TO. Potentially, the increase in TO rate is the consequence of more attempts being made to make positive plays. Alternatively, the VTS capability of the opposition may also play a contributing role. As such, future exploration into these hypotheses is warranted.

Although our data may indicate a potential role for VTS in the playmaking ability of professional basketball players, it does not indicate such a role for visual-motor RT. These findings support previous reports of elite basketball players from Greece possessing significantly greater predictive and selective attention skills in comparison with amateur athletes, but only possessing comparable visual-motor RT capability (21). Although possibly aided by faster oculomotor reactions to visual stimuli (34), elite athletes seem to be more capable of correctly assessing and responding to a dynamic environment (8,26). This ability may be the consequence of being able to correctly identify key indicators, within a dynamic environment, that will allow an individual to deduce future occurrences (1,23). To perform this task, a person will typically centralize their gaze direction to a localized region, which would enable them to accumulate the greatest amount of critical information from the surrounding regions (24,40). Being able to efficiently assess the relevant information from this scene will determine the time and opportunity the individual will have to respond appropriately to the demands of the given scenario (20,42). Similarly, the NT device presents useful information (ball position, ball trajectories, ball collisions, and noncollisions) from several points across the visual field, which may allow the individual to deduce future ball positions, enabling them to maintain their attention on the items of interest. In basketball, for example, as the ball handler monitors the movements (planned and unplanned) of his teammates, he may also analyze the positioning of the defenders as movement progresses. From this information, the ball handler may determine if 1 or more of his teammates will reach an advantageous (in relation to his defender and the basket) position. As such, our data indicate that players who can make this determination faster are *most likely* to make an AST. Conversely, a defending player who quickly makes this determination is *most likely* to recognize the future position of the basketball in time to make an interception. However, not all the variance in performance can be explained by the current methodology for determining VTS. It is important to account for the effect of personal movements that occur while the player assesses the dynamic scene, as well as his ability to maintain track of relevant items with momentary shifts in focus. Such movement and shifts in focus have been demonstrated to impair tracking ability (11,35), although the current VTS assessment required the player to maintain constant focus from a fixed position. Consequently, the MOT task on the NT device seems to be able to distinguish the elite cognitive processing used by elite competitors (12,24), although not completely in a manner that distinguishes elite play in basketball.

In contrast, RT measured by 2 simple CRTs was not related to measures of ball control nor were significant differences observed between position types. Previously, using a similar CRT, no differences were observed between elite rugby, netball, or hockey players in comparison with normative samples (29). It is possible that the methodological design (e.g., randomly flashing lights) may not effectively distinguish between quick reflexes and the anticipatory capability of elite athletes. Although a simple luminance-based RT test may be able to identify faster reflexes in professional athletes compared with nonathletes (15), anticipatory capability cannot be discerned when performance is solely deterred by random pattern complexity (4). Likewise, in basketball, the most appropriate response to a given scenario cannot be determined by simply reacting to any random stimulus on the court; the stimulus must have meaning. In concordance with this notion, RT has been demonstrated to be predictive of athletic ability when the task involved a complex component, thus allowing the athlete to predict or anticipate the stimulus and respond accordingly (26). However, the RT tasks of the present investigation did not provide such indicators. In the second test (VR-CRT), the athlete would have to continuously change his focus to cover all possible board regions because all possibilities were always equal in likelihood. During competitive play, this strategy would not be efficient for deducing the appropriate course of action. With so many possible focal points performing, such a search has been reported to result in a very high ratio of perceptual blur (40), ultimately leaving the athlete largely uninformed. Even when the region was fixed and choices were limited, as they were in the first test, the athlete was still incapable of deducing which light would be next to illuminate; they simply had to react. Although evidence does suggest that the ability to react quickly to visual stimuli is important in team sports (7,34), the results of the present investigation do not indicate a relationship between RT, measured by the D2 device, and measures of ball control in basketball. It is possible, however, that our small sample may have inhibited our power to see an effect, whereas greater familiarity with the D2 device, as recently recommended by Wells et al. (37), may have generated a more exact RTs for statistical analysis. Therefore, future designs, seeking to examine the effect of training (on the NT and D2 devices) on game-related performance measures, should consider these possibilities.

The accumulation of positive statistics that measure ball control (AST and STL), while avoiding turnovers, is a valued quality for all basketball positions (5,14,19). Generally, certain players and positions are granted more opportunities for such plays (positive and negative) because of team strategy or individual skill. In the present investigation, backcourt players (point guards and shooting guards) were *most likely* to accumulate AST at a faster rate than frontcourt players. This may have been the consequence of these players being *very likely* to also possess greater VTS, although greater VTS may have also been the consequence of accumulated experience at positions that necessitate this ability for success. Ironically, these players were also *very likely* to possess a greater rate of turnovers. However, this rate was still *very likely* to be slower than their rate of AST (AST/TO) and possibly the consequence of their role as ball handlers. It is typical for these players to maintain possession of the ball, and be defended by similar players, while they attempt to make passes to teammates who try to secure strategically advantageous positions (36). Thus, more ball handling opportunities may lead to both a greater amount of positive and negative plays, although the lack of a clear difference in STL was surprising. However, this finding may be related to equal stealing opportunities arising at both the passing and the receiving ends of a pass attempt. Given the small sample size, and the general nature in which positions were examined, these results may not be reflective of the entirety of the NBA. Future studies may build upon this investigation by examining these phenomena across several teams and by individual position.

To the best of our knowledge, only one other investigation has reported relationships between game-related ball control statistics and measures of physical performance. In collegiate athletes, McGill et al. (25) demonstrated relationships between core stability and AST ($r = 0.60$) agility ($r = -0.74$) and STL ($r = 0.54$). Those investigators also reported a significant correlation between agility and STL ($r = -0.69$). Although the authors did not provide any explanation of these relationships, it is likely that core stability and agility would have some relevance to AST and STL because they both are measures of body control. Comparatively, however, the present investigation found similar, if not stronger, relationships between VTS and AST ($r = 0.78$) and STL ($r = 0.77$). Although these relationships are population dependent, it is possible that the variance in STL and AST cannot be completely explained by a single variable (i.e., VTS, agility, core stability). Rather, a multivariate approach may be necessary to understand how these measures contribute to a basketball player's ability to produce more positive plays while avoiding costly turnovers.

Practical Applications

Considering the observed relationships between VTS and game-related measures of ball control, the findings of this investigation indicate a potentially important role in basketball player evaluation. Visual tracking speed is a measure of a player's ability to track multiple objects (i.e., teammates and opponents movements on the court) within a fast-paced dynamic setting, which would allow the player more time to appropriately respond to the demands of the given situation. Although preliminary, the data from our investigation suggest that greater VTS is related to game-related measures of ball control (AST, TO, AST/TO, and STL). Thus, the ability to evaluate a player's capability to perform in measures that are related to team success would prove beneficial for player recruitment and needs analysis.

References

1. Aglioti, SM, Cesari, P, Romani, M, and Urgesi, C. Action anticipation and motor resonance in elite basketball players. *Nat Neurosci* 11: 1109–1116, 2008.
2. Alvarez, GA and Franconeri, SL. How many objects can you track?: Evidence for a resource-limited attentive tracking mechanism. *J Vis* 7: 14, 1–10, 2007.
3. Batterham, AM and Hopkins, WG. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perform* 1: 50–57, 2006.
4. Blaser, E and Sperling, G. When is motion "motion"? *Perception* 37: 624, 2008.
5. Calvo, L, Ruano, M, Toro, E, Godoy, S, and Sampaio, J. Game related statistics which discriminate between winning and losing under-16 male basketball games. *J Sports Sci Med* 9: 664–668, 2010.
6. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences.* 2nd ed. Routledge Academic, 1988. pp. 75–105.
7. Doğan, B. Multiple-choice reaction and visual perception in female and male elite athletes. *J Sports Med Phys Fitness* 49: 91–96, 2009.
8. Faubert, J. Professional athletes have extraordinary skills for rapidly learning complex and neutral dynamic visual scenes. Scientific Reports 3, 2013.
9. Faubert, J and Sidebottom, L. The NeuroTracker System: Its role for perceptual-cognitive training of athletes and its potential impact on injury reductions and concussion management in sports. *J Clin Sports Psychol* 2012.
10. Faubert, J and Sidebottom, L. Perceptual-cognitive training of athletes. *J Clin Sport Psychol* 6: 85, 2012.
11. Fencsik, DE, Klieger, SB, and Horowitz, TS. The role of location and motion information in the tracking and recovery of moving objects. *Percept Psychophys* 69: 567–577, 2007.
12. Garland, DJ and Barry, JR. Sport expertise: The cognitive advantage. *Percept Mot Skills* 70: 1299–1314, 1990.
13. Gómez, M, Lorenzo, A, Ortega, E, Sampaio, J, and Ibáñez, S. Game related statistics discriminating between starters and nonstarters players in Women's National Basketball Association League (WNBA). *J Sports Sci Med* 8: 278–283, 2009.
14. Gómez, M, Lorenzo, A, Sampaio, J, Ibáñez, S, and Ortega, E. Game-related statistics that discriminated winning and losing teams from the Spanish men's professional basketball teams. *Coll Antropol* 32: 451–456, 2008.
15. Harbin, G, Durst, L, and Harbin, D. Evaluation of oculomotor response in relationship to sports performance. *Med Sci Sports Exerc* 21: 258–262, 1989.
16. Hoffman, JR, Williams, DR, Emerson, NS, Hoffman, MW, Wells, AJ, McVeigh, DM, McCormack, WP, Mangine, GT, Gonzalez, AM, and Fragala, MS. L-alanyl-L-glutamine ingestion maintains performance during a competitive basketball game. *J Int Soc Sports Nutr* 9: 1–8, 2012.
17. Hofler, RA and Payne, JE. Efficiency in the National Basketball Association: A stochastic frontier approach with panel data. *Manage Decis Econ* 27: 279–285, 2006.
18. Hopkins, WG, Batterham, AM, Marshall, SW, and Hanin, J. Progressive statistics. *Sportscience* 13: 55–70, 2009.
19. Ibáñez, S, Sampaio, J, Feu, S, Lorenzo, A, Gómez, M, and Ortega, E. Basketball game-related statistics that discriminate between teams' season-long success. *Eur J Sport Sci* 8: 369–372, 2008.
20. Iordanescu, L, Grabowecky, M, and Suzuki, S. Demand-based dynamic distribution of attention and monitoring of velocities during multiple-object tracking. *J Vis* 9.4:1, 2009.
21. Kioumourtzoglou, E, Kourtessis, T, Michalopoulou, M, and Derri, V. Differences in several perceptual abilities between experts and novices in basketball, volleyball and water-polo. *Percept Mot Skills* 86: 899–912, 1998.
22. Levitt, H. Transformed up-down methods in psychoacoustics. *J Acoust Soc Am* 49(Suppl. 2): 467–477, 1970.
23. Mann, DL, Abernethy, B, and Farrow, D. Visual information underpinning skilled anticipation: The effect of blur on a coupled and uncoupled in situ anticipatory response. *Atten Percept Psychophys* 72: 1317–1326, 2010.
24. Mann, DT, Williams, AM, Ward, P, and Janelle, CM. Perceptual-cognitive expertise in sport: A meta-analysis. *J Sport Exerc Psychol* 29: 457, 2007.

25. McGill, SM, Andersen, JT, and Horne, AD. Predicting performance and injury resilience from movement quality and fitness scores in a basketball team over 2 years. *J Strength Cond Res* 26: 1731–1739, 2012.

26. Mori, S, Ohtani, Y, and Imanaka, K. Reaction times and anticipatory skills of karate athletes. *Hum Mov Sci* 21: 213–230, 2002.

27. Players. National Basketball Association. Available at: <http://stats.nba.com/players.html>. Accessed September 2013.

28. Ostojic, SM, Mazic, S, and Dikic, N. Profiling in basketball: Physical and physiological characteristics of elite players. *J Strength Cond Res* 20: 740–744, 2006.

29. Paterson, G. *Visual-Motor Response Times in Athletes and Non-athletes.* Stellenbosch, South Africa: University of Stellenbosch, 2010.

30. Pylyshyn, ZW and Storm, RW. Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spat Vis* 3: 179–197, 1988.

31. Sampaio, J, Janeira, M, Ibáñez, S, and Lorenzo, A. Discriminant analysis of game-related statistics between basketball guards, forwards and centres in three professional leagues. *Eur J Sport Sci* 6: 173–178, 2006.

32. Simenz, CJ, Dugan, CA, and Ebben, WP. Strength and conditioning practices of National Basketball Association strength and conditioning coaches. *J Strength Cond Res* 19: 495–504, 2005.

33. Smith, LE. Reaction time and movement time in four large muscle movements. *Res Quarterly* 32: 88–92, 1961.

34. Ando, S, Kida, N, and Oda, S. Central and peripheral visual reaction time of soccer players and nonathletes. *Percept Mot Skills* 92: 786–794, 2001.

35. Thomas, LE and Seiffert, AE. Self-motion impairs multiple-object tracking. *Cognition* 117: 80–86, 2010.

36. Trninić, S and Dizdar, D. System of the performance evaluation criteria weighted per positions in the basketball game. *Coll Antropol* 24: 217–234, 2000.

37. Wells, AJ, Hoffman, JR, Beyer, KS, Jajtner, AR, Gonzalez, AM, Townsend, JR, Mangine, GT, Robinson, EH IV, McCormack, WP, and Fragala, MS. Reliability of the Dynavision™ D2 for assessing reaction time performance. *J Sports Sci Med* 13: 145–150, 2014.

38. Wetherill, G. Sequential estimation of quantal response curves. *J R Stat Soc Ser B* 25: 1–48, 1963.

39. Williams, AM. Perceptual skill in soccer: Implications for talent identification and development. *J Sports Sci* 18: 737–750, 2000.

40. Williams, AM, Davids, K, Burwitz, L, and Williams, JG. Visual search strategies in experienced and inexperienced soccer players. *Res Q Exerc Sport* 65: 127–135, 1994.

41. Williams, AM and Hodges, NJ. Practice, instruction and skill acquisition in soccer: Challenging tradition. *J Sports Sci* 23: 637–650, 2005.

42. Zhang, H, Xuan, Y, Fu, X, and Pylyshyn, ZW. Do objects in working memory compete with objects in perception? *Vis Cogn* 18: 617–640, 2010.