Perceptual and Cognitive Skill Development in Soccer:
The Multidimensional Nature of Expert Performance

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This study examined the relative contribution of visual, perceptual, and cognitive skills to the development of expertise in soccer. Elite and sub-elite players, ranging in age from 9 to 17 years, were assessed using a multidimensional battery of tests. Four aspects of visual function were measured: static and dynamic visual acuity; stereoscopic depth sensitivity; and peripheral awareness. Perceptual and cognitive skills were assessed via the use of situational probabilities, as well as tests of anticipation and memory recall. Stepwise discriminant analyses revealed that the tests of visual function did not consistently discriminate between skill groups at any age. Tests of anticipatory performance and use of situational probabilities were the best in discriminating across skill groups. Memory recall of structured patterns of play was most predictive of age. As early as age 9, elite soccer players demonstrated superior perceptual and cognitive skills when compared to their sub-elite counterparts. Implications for training perceptual and cognitive skill in sport are discussed.

Key Words: anticipation, memory recall, situational probabilities, visual function

The quest to identify key factors underlying the acquisition of expert performance has stimulated much discussion in recent years (e.g., Howe, Davidson, & Sloboda, 1998). The nature/nurture debate has often taken center stage and divergent explanations of exceptional performance have emerged (Ericsson, Krampe, & Tesch-Römer, 1993; Winner, 1996). Although polar accounts of expertise have been considered contentious (e.g., Sternberg, 1998), particularly in sport (Singer & Janelle, 1999), some research still promotes a parochial view of skilled performance. A popular standpoint advocated by optometrists is that successful athletes are endowed with superior visual systems, supporting a "hardware" account of expert performance (Coffey & Reichow, 1995; Loran & Griffiths, 1998; Sherman, 1990).

It has been argued that athletes need above-average levels of visual function in order to meet the demands of their sport and fulfill their role efficiently (Gardner & Sherman, 1995). However, support for the presumption that athletes possess
superior vision is equivocal at best (Williams, Davids, & Williams, 1999). Attempts to characterize expertise from this perspective appear to provide only limited insight into the factors underlying the development of visual-perceptual skill.

It is clear from the increasing body of knowledge on expertise that skill, and talent, are multifaceted in nature (Helsen & Starkes, 1999; Simonton, 1999; Williams & Reilly, 2000). Wrisberg (1993) was among the first to suggest that research on expertise should be both interactionist and multidimensional, and that the relative weight of factors contributing to skilled performance in each domain should be examined. Researchers using such an approach have investigated the visual, perceptual, and cognitive skills of adult athletes in field hockey (Starkes, 1987), snooker (Abernethy, Neal, & Koning, 1994), and soccer (Helsen & Starkes, 1999). This research suggests that expert athletes are not endowed with superior visual function, and that perceptual and cognitive factors are better discriminators of skilled performance in adults (for a recent review, see Starkes, Helsen, & Jack, 2001).

When compared with their less-skilled counterparts, adult experts are better at anticipating opponents' intentions based on partial information or advance cues (Abernethy & Russell, 1987; Jones & Miles, 1978; Williams & Burwitz, 1993), and can more consistently pick up the minimal essential information (e.g., relative motion) needed for successful anticipation (Ward, Williams, & Bennett, 2002). Experts typically exhibit more effective visual search strategies (Helsen & Starkes, 1999; Williams & Davids, 1998; Williams, Davids, Burwitz, & Williams, 1994) and are faster and more accurate at recognizing and recalling typical patterns of play from memory (Starkes, 1987; Williams & Davids, 1995; Williams, Davids, Burwitz, & Williams, 1993).

The relative contribution of visual, perceptual, and cognitive skills to expertise in sports throughout late childhood, adolescence, and early adulthood has received limited attention. Sports vision research has typically focused on the effects of chronological age rather than the interaction between age and expertise. Current understanding suggests that the visual system develops throughout infancy and early childhood (Hubel, 1988). For instance, peripheral visual field size increases in breadth from 15° at 2 weeks to 40° by the 5th month (Tronick, 1972), and binocularity and depth perception improve substantially between 2 and 5 years of age (H.G. Williams, 1983). Adult levels of acuity (H.G. Williams, 1983) and contrast sensitivity (Banks & Salapatek, 1983) are attained by 10 to 12 years of age, and synaptic junction density in the striate cortex reaches adult level at a similar age (Teller, 1997). Whether the development of the visual system, and the subsequent quality of visual information available for processing, are related to sports performance has not yet been adequately addressed.

Our understanding of how motor and cognitive aspects of performance contribute to the development of expertise during childhood and adolescence has been considerably enhanced by the work of Thomas and colleagues (for a recent summary, see French & McPherson, 1999; Thomas, Gallagher, & Thomas, 2001; Thomas & Thomas, 1999). However, relatively few studies have examined how skills such as anticipation and pattern recognition improve with age and experience (for exceptions, see Abernethy, 1988; Tenenbaum, Sar El, & Bar Eli, 2000). Chase and Simon (1973) originally proposed that expert performance could be explained on the basis of superior domain-specific knowledge. Rather than possessing a greater general capacity, skilled chess players used their more elaborate knowledge to create meaningful "chunks," enabling a faster and more accurate response.
It appears that children can develop chunking skills as early as 5 years of age when prompted to adopt a modified strategy, and at 9 years of age without external assistance (Zaichowsky, 1974). When comparing skilled 10-year-old chess players with novice adults, Chi (1978) noted that the acquisition of appropriate knowledge structures allowed age-related differences in performance to be circumvented. Early perceptual organization and the associated domain-specific knowledge base have also been hypothesized to be critical factors in skillful soccer performance (Williams et al., 1993, 1994; Williams & Davids, 1995, 1998).

While it appears that some components of perceptual skill emerge relatively early in development, the ability to accurately “read the play” in sport may not develop until much later. Abernethy (1988) used both temporal and event occlusion techniques to examine the development of anticipatory skill in badminton players ages 12, 15, and 18 years. Although the ability of experts to utilize advance cues improved with age, skill-based differences in anticipatory performance were not evident until adulthood, as determined from an earlier study with adults (see Abernethy & Russell, 1987).

Tenenbaum et al. (2000) recently reported similar observations when comparing anticipatory skills of low- and high-skill tennis players throughout development (ages 8-10, 11-13, 14-17, 18+ years). In the absence of significant differences, the authors reported only low to moderate effect sizes between skill groups for the three youngest groups. These effect sizes were not as consistent nor of comparable magnitude to those reported for the oldest group. Abernethy’s (1988) and Tenenbaum et al.’s (2000) research examined the ability to “read” postural cues in a racket sport context. An interesting issue is whether similar findings may be observed in team sports and whether other perceptual and cognitive skills such as pattern recognition and the use of situational probabilities develop at a comparable rate.

In recent years, researchers have also examined the development of tactical and strategic decision-making in sport (French, Nevett, Spurgeon, et al., 1996; McPherson, 1999; McPherson & Thomas, 1989). These studies suggest that the knowledge bases and cognitive strategies underlying effective performance develop gradually as a result of extensive task-specific practice. Prior to the teenage years, skilled tennis players and baseball players are generally unable to discriminate task-relevant from task-irrelevant information (French et al., 1996; McPherson, 1999; McPherson & Thomas, 1989). In addition, relatively few specialized processing strategies are developed that would allow future actions to be monitored, planned, and predicted (McPherson, 1999, 2000). Between the ages of 7 and 12 years, the problem representations of experts were suggested to be more elaborate than those of novices, although still limited when compared to those of adult experts (French et al., 1996; Nevett & French, 1997). Novices have been shown to adopt far weaker strategies to resolve problems at all ages, and are much less likely to reach an appropriate solution when under the pressure of time (French & McPherson, 1999). Chi (1977) observed that these age-related differences in memory performance are not necessarily reflective of structural limitations, but of faster encoding times and a greater number of alternative or mnemonic strategies.

During the development of expertise, task-relevant knowledge structures and both general and domain-specific processing strategies have been hypothesized to combine into two specific memory adaptations, or “profiles” (McPherson, 1999). As children acquire greater experience with age and task-specific practice, rule-
based problem representations emerge with increasing complexity (i.e., action-plan profiles). The ability to accurately monitor current task demands, use strategic and tactical planning, predict probable outcome with increasing sophistication, and anticipate opponents’ intentions (i.e., current-event profiles) continues to develop into early adulthood. Integral to the development of these current-event profiles is the ability to synthesize contextual information with expectations stored in memory via the acquisition, adaptation, and development of domain-specific skills (Ericsson & Kintsch, 1995). However, domain-specific memory skills and related current-event profiles may take up to 10 years to acquire (Chase & Simon, 1973; Ericsson et al., 1993; Ericsson & Kintsch, 1995) and are rarely demonstrated before 15 to 16 years of age (French & McPherson, 1999).

One of the most effective ways of assessing expert performance is by asking players to select the next best move (de Groot, 1978). In determining the outcome of an evolving pattern of play, it is likely that novices of all ages may use an inappropriate selection strategy and generate far fewer task solutions. In soccer, experts are likely to dismiss many events as being highly improbable and attach a hierarchy of probabilities to the remaining possibilities (Gottsdanker & Kent, 1978). Such strategies are likely to become more refined with experience and age as their domain-specific knowledge and associated memory skills become more sophisticated. The suggestion is that anticipatory decisions are initially guided by expectations of what is likely to happen next (i.e., use of situational probabilities). As the action unfolds, expectations are integrated with contextual information to provide an “on-line” confirmation or modification of the anticipated response (McPherson, 1999; Williams, 2000).

The role of expectations has been particularly under-researched in soccer (for an exception, see Cohen & Dearnaley, 1962). In a racket sport context, Alain and Proteau (1980) asked participants to anticipate an opponent’s actions and then to comment on the probabilities they had assigned to each possible outcome. Participants were found to initiate a response once a probability threshold of 70% had been surpassed. At this threshold, the benefits of anticipation were perceived to far outweigh the costs of responding incorrectly. In soccer, novices may not be adept at assigning an appropriate probability hierarchy to important events and may be over-exclusive or over-inclusive in their selection strategy (Ross, 1976). By contrast, experts are likely to hedge their bets judiciously, putting situational probabilities and contextual information to effective use. While these information sources would seem to be an important precursor to skilled prediction, no published research has examined the use of situational probabilities in soccer, or in a developmental context.

The aim of this study was to examine how visual, perceptual, and cognitive skills develop as a function of age and skill in soccer. A secondary aim was to determine the measures that most discriminate between age and skill groups. In view of the relative lack of research in this area, this study was partly exploratory in nature. While performance on tests of visual and perceptual-cognitive skill was expected to improve as a function of age and experience, the exact nature of any interaction was difficult to predict. Previous research suggests that visual function improves with age, but how this interacts with the performer’s skill level or the development of sport-specific perceptual and cognitive skills has not yet been addressed. Research on strategic and tactical decision-making suggests that the un-
derlying knowledge bases develop gradually throughout childhood and adolescence (French & McPherson, 1999). However, research in racket sports indicates that the ability to anticipate may develop only in early adulthood (Abernethy, 1988). These findings may not generalize to more open-play team sports such as soccer, or to other perceptual and cognitive skills.

**Methods**

**Participants**

Elite and sub-elite male soccer players (N = 137) were selected as participants. Elite players were recruited from English Premier League Academies, while sub-elite players were recruited from local elementary and secondary schools. Elite participants played at the highest level of national competition for their respective age, whereas sub-elite participants played no higher than recreational or school level. Both groups began participating in soccer at similar ages (M age: elite = 6.04 ± 2.15 years; sub-elite = 6.42 ± 3.07). Within each skill group, an average of 14 participants were recruited from each of five age groups; 9 and under (U-9), U-11, U-13, U-15, U-17. Table 1 summarizes the mean age of participants in each subgroup, and the amount of time the elite group accrued in a professional coaching environment. The U-17 elite players attended the academy full time from the age of 16 years. The elite 9- to 15-year-olds attended the academy part time. The sub-elite players had not received any specialized training other than through regular physical education classes at school. Informed consent was given prior to participation in the study.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Age M</th>
<th>Age SD</th>
<th>Years in Academy M</th>
<th>Academy SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>U-9</td>
<td>9.32</td>
<td>(0.34)</td>
<td>1.32</td>
<td>(0.82)</td>
</tr>
<tr>
<td>U-11</td>
<td>11.37</td>
<td>(0.41)</td>
<td>1.90</td>
<td>(1.07)</td>
</tr>
<tr>
<td>U-13</td>
<td>13.25</td>
<td>(0.29)</td>
<td>2.77</td>
<td>(1.91)</td>
</tr>
<tr>
<td>U-15</td>
<td>15.14</td>
<td>(0.29)</td>
<td>4.65</td>
<td>(2.28)</td>
</tr>
<tr>
<td>U-17</td>
<td>17.59</td>
<td>(0.54)</td>
<td>5.08</td>
<td>(2.15)</td>
</tr>
<tr>
<td>Sub-Elite</td>
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<td></td>
</tr>
<tr>
<td>U-9</td>
<td>9.42</td>
<td>(0.30)</td>
<td></td>
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</tr>
<tr>
<td>U-11</td>
<td>11.29</td>
<td>(0.33)</td>
<td></td>
<td></td>
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<tr>
<td>U-13</td>
<td>13.11</td>
<td>(0.30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-15</td>
<td>15.35</td>
<td>(0.25)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-17</td>
<td>17.39</td>
<td>(0.32)</td>
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</tbody>
</table>
Procedure

Four measures of visual function were recorded using standardized equipment: static visual acuity; dynamic visual acuity; stereoscopic depth sensitivity; and peripheral awareness (see Gardner & Sherman, 1995). Participants were tested in the field, on an individual basis, and in their normal viewing mode (no correction = 79%, spectacles = 15%, contact lenses = 6%). A counterbalanced design was used to minimize any potential order effect.

**Static Visual Acuity.** A Bailey-Lovie logMAR eye chart was used to test binocular static acuity at a distance of 6 meters (m). Players began reading rows of letters diminishing in size until the letters could no longer be accurately discriminated. Static visual acuity was measured in minutes of arc (min.arc) and compared to a 6/6 (20/20) standard.

**Dynamic Visual Acuity.** The Sherman Dynamic Acuity Disc was used to assess players' dynamic visual acuity levels. This test was designed specifically for testing sports vision (Gardner & Sherman, 1995). Participants tracked a disc rotating with decreasing velocity until they could accurately discriminate various letters (sized at 10/30) placed 10.5 cm from the central axis of rotation. Testing was conducted at a distance of 3 m. Binocular dynamic acuity was measured in revolutions per minute (rpm).

**Stereoscopic Depth Sensitivity.** A random dot stereogram (TNO test) was used to assess stereoscopic depth sensitivity (i.e., binocular depth perception) by viewing standard anaglyphs through filter spectacles. Participants attempted to perceive an embedded object at six levels of retinal disparity. Success rate was measured in seconds of arc (sec.arc) at a distance of 40 cm.

**Peripheral Awareness.** The Wayne Peripheral Awareness Tester was used to assess the ability to respond to peripheral stimuli (see Coffey & Reichow, 1995). While participants focused on a central target, a light-emitting diode was randomly illuminated in each of eight meridians (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°). The stimulus subtended a visual angle of approximately 60°, standing 40 cm from the apparatus. Participants responded using a handheld joystick. Response time was measured in milliseconds (ms).

Film-based simulations were used to examine perceptual skill. Action sequences were edited from professional and semi-professional matches and presented on a large video screen. Participants responded using pencil and paper in a time-constrained context. Although previous reviews have argued that more ecological responses are needed to preserve expert/novice differences (Abemethy, Thomas, & Thomas, 1993; Williams, Davids, Burwitz, & Williams, 1992), construct validity is retained and significant skill-based differences still emerge when using techniques similar to those in this study (cf. Williams et al., 1999). Participants were tested on anticipatory performance, memory recall, and the use of situational probabilities.

**Anticipation.** The temporal occlusion paradigm was used to assess anticipatory performance (see Abernethy & Russell, 1987). Participants were presented with soccer action sequences including 1 v. 1 (2-choice response), 3 v. 3 (4-choice response), and 11 v. 11 (10-choice response) simulations (see Williams et al., 1994; Williams & Davids, 1998). Each clip was edited 120 ms prior to foot contact with the ball. After three practice trials, eight test trials were randomly presented for
each type of soccer simulation \( (N = 24) \). Trials lasted approximately 10 seconds and were interspersed with a 5-s intertrial interval. Participants attempted to anticipate the direction of a dribble (1 v. 1) or pass (3 v. 3, 11 v. 11). Response accuracy was reported as a percentage.

**Memory Recall.** The recall paradigm was used to assess participants' skill in encoding and retrieving typical patterns of structured and unstructured play from memory (see Williams et al., 1993; Williams & Davids, 1995). Structured conditions included 11 v. 11 attack and defensive action sequences. Unstructured trials included periods of inactive play (e.g., warm-up sessions, players walking on and off the field, or players standing around during a break). Following three practice trials, eight test trials were randomly presented in each condition \( (N = 16) \). After every 10-s trial, participants were asked to recall the position of particular players from both teams using a procedure employed by Williams and colleagues (see Williams et al., 1993; Williams & Davids, 1995). Participants marked player positions on a replication of the field of play \( (30 \times 20 \text{ cm}) \) using an X to represent the location of the player's hip. The \( x \)- and \( y \)-coordinates of recalled and actual player positions were compared. Response accuracy was measured in radial error using simple Pythagoras.

**Situational Probabilities.** A novel paradigm was employed to assess the use of expectations. Offensive 11 v. 11 patterns of play were filmed from an elevated perspective behind the goal. Each simulation lasted approximately 10 s and was then frozen 120 ms prior to the player in possession passing the ball. The still image remained on screen for 20 seconds while participants completed the following tasks. First they were asked to highlight key players in a good position to receive the ball, based on players' expectations of what should happen next. The percentage of key players correctly highlighted, and the total number of non-key players selected, were measured against a panel of expert coaches (interobserver agreement = 90.4\%). Then the participants ranked each highlighted player in terms of his perceived attacking importance. A point system was devised whereby one point was awarded for correctly matching the assigned importance of each player previously determined by the panel of coaches. Three practice trials and 18 test trials were presented.

**Data Analyses**

Separate two-way ANOVAs were used to analyze three of the four visual function variables (static visual acuity, stereoscopic depth sensitivity, peripheral awareness) as well as the anticipation and situational probabilities variables. The between-participant factors were age (U-9, U-11, U-13, U-15, U-17) and skill (elite, sub-elite). Where the normality assumption was violated, data were first transformed using either reflect and square root (anticipation: 1 v. 1), square root (peripheral awareness, situational probabilities: non-key players), logarithmic (stereoscopic depth sensitivity), or inverse (static visual acuity) transformations. Significant main effects and interactions were followed up using Scheffé post hoc tests. Where a suitable transformation was not available, a generalized rank-order method for nonparametric analysis of data was employed (Thomas, Nelson, & Thomas, 1999). The Puri and Sen (1985) \( L \)-statistic was then calculated for dynamic visual acuity using a two-way ANOVA, and for memory recall using a three-way ANOVA in which condition (structured, unstructured) was the withi-
participant factor. The Bonferroni procedure was used to adjust for the overall number of statistical tests performed (0.05/13). The alpha level was set at 0.004. Effect sizes were calculated using pooled standard deviation (Thomas, Salazar, & Landers, 1991).

Separate forward stepwise discriminant function analyses were employed to determine which variables were most predictive of age and skill, respectively, and to determine how accurately the model predicted group membership. The criteria for entering and removing variables in the discriminant function model was based on the adjusted alpha (Biddle, Markland, Gilbourne, Chatzisarantis, & Sparkes, 2001). The $L$-statistic was calculated at each step.

**Results**

**Visual Function**

*Static Visual Acuity.* A significant main effect was observed for age, $F(4, 127) = 5.78$, $p < .001$. Post hoc analyses indicated a significant improvement in static acuity between 9 and 13 years of age for all participants (ES = 1.12). The results of all visual function tests are listed in Table 2.

*Dynamic Visual Acuity.* No significant effects were found.

*Stereoscopic Depth Sensitivity.* A total of 5.1% (3 elite, 4 sub-elite) of the sample tested were unable to perceive an image embedded in the random dot stereogram. This proportion is within the normal range (Julesz, 1971). These participants did not achieve a valid score on the TNO test and were excluded from the

<table>
<thead>
<tr>
<th>Group</th>
<th>Visual Acuity</th>
<th>Stereoscopic Depth Sensitivity</th>
<th>Peripheral Awareness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Static (min.arc)</td>
<td>Dynamic (rpm)</td>
<td>(sec.arc)</td>
</tr>
<tr>
<td>Elite group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-17</td>
<td>-0.10 (0.07)</td>
<td>89.93 (10.89)</td>
<td>28.75 (16.25)</td>
</tr>
<tr>
<td>U-15</td>
<td>-0.07 (0.10)</td>
<td>83.00 (14.59)</td>
<td>26.54 (12.48)</td>
</tr>
<tr>
<td>U-13</td>
<td>-0.03 (0.18)</td>
<td>77.00 (16.24)</td>
<td>52.50 (28.96)</td>
</tr>
<tr>
<td>U-11</td>
<td>-0.01 (0.03)</td>
<td>78.00 (11.73)</td>
<td>63.75 (25.04)</td>
</tr>
<tr>
<td>U-9</td>
<td>0.06 (0.11)</td>
<td>77.98 (11.98)</td>
<td>52.50 (15.29)</td>
</tr>
<tr>
<td>Sub-Elite group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-17</td>
<td>-0.02 (0.13)</td>
<td>72.13 (9.78)</td>
<td>41.79 (26.43)</td>
</tr>
<tr>
<td>U-15</td>
<td>-0.03 (0.08)</td>
<td>75.31 (11.00)</td>
<td>64.00 (37.38)</td>
</tr>
<tr>
<td>U-13</td>
<td>-0.12 (0.07)</td>
<td>79.53 (9.44)</td>
<td>32.50 (17.15)</td>
</tr>
<tr>
<td>U-11</td>
<td>-0.02 (0.11)</td>
<td>74.43 (9.96)</td>
<td>31.15 (14.31)</td>
</tr>
<tr>
<td>U-9</td>
<td>-0.01 (0.07)</td>
<td>77.36 (10.92)</td>
<td>49.29 (27.24)</td>
</tr>
</tbody>
</table>
analysis. An Age x Skill interaction was observed, \( F(4, 118) = 9.903, p < .001 \). Post hoc comparisons did not reveal the source of this interaction. However, effect sizes indicate a meaningful difference in favor of sub-elite participants at ages 11 and 13 years (ES = 0.96 and 0.74 respectively), and elite players at age 15 years (ES = 0.59).

**Peripheral Awareness.** There were significant main effects for age, \( F(4, 127) = 28.40 \); skill, \( F(1, 127) = 43.34 \); and an Age x Skill interaction, \( F(4, 127) = 10.40 \), all \( p < .001 \). Significant differences in peripheral awareness were found between elite U-9 and U-13 age groups, \( p < .001 \) (ES = 2.21). Both the U-11 and U-13 elite groups responded significantly quicker than their age-matched, sub-elite counterparts, \( p < .001 \) (ES = 2.08 and 3.11, respectively). Sub-elite players improved their response times later in development, between 11 and 15 years of age, \( p < .001 \) (ES = 1.52). At 15 and 17 years of age, no skill-based differences were evident.

**Perceptual and Cognitive Skills**

***Anticipation: 1 v. 1.*** A significant main effect was found for skill, \( F(1, 127) = 9.206, p < .003 \). Elite players demonstrated superior anticipatory performance in 1 v. 1 simulations when compared with sub-elite participants (ES = 0.50) (see Table 3).

***Anticipation: 3 v. 3.*** There was a main effect for age only, \( F(4, 127) = 5.71, p < .001 \). The U-13 groups performed significantly poorer than both the U-9 (ES = 0.91) and U-17 (ES = 1.13) age groups on the 3 v. 3 simulations.

| Table 3 | Mean Percentage Accuracy (± SD) for Elite and Sub-Elite Players on the 1 v. 1, 3 v. 3, and 11 v. 11 Anticipation Tests |
| --- | --- | --- | --- | --- |
| Group | 1 v. 1 (%) | 3 v. 3 (%) | 11 v. 11 (%) |
| | \( M \) | \( SD \) | \( M \) | \( SD \) | \( M \) | \( SD \) |
| Elite group | | | | | | |
| U-17 | 84.33 | (10.92) | 56.25 | (12.50) | 70.83 | (12.31) |
| U-15 | 87.31 | (11.20) | 48.08 | (21.56) | 67.31 | (13.05) |
| U-13 | 82.69 | (9.60) | 33.65 | (20.66) | 63.46 | (9.49) |
| U-11 | 80.00 | (15.81) | 45.00 | (17.87) | 65.00 | (11.49) |
| U-9 | 72.32 | (14.85) | 66.96 | (18.09) | 65.18 | (17.11) |
| Sub-Elite group | | | | | | |
| U-17 | 78.33 | (8.80) | 56.67 | (15.57) | 50.83 | (15.28) |
| U-15 | 77.34 | (17.21) | 48.44 | (19.83) | 55.47 | (17.06) |
| U-13 | 66.67 | (16.28) | 42.50 | (17.38) | 54.17 | (17.68) |
| U-11 | 76.79 | (9.63) | 47.32 | (12.19) | 46.43 | (10.32) |
| U-9 | 76.79 | (9.63) | 42.86 | (11.72) | 54.47 | (13.53) |
Anticipation: 11 v. 11. ANOVA revealed a significant main effect for skill, $F(1, 127) = 30.85, p < .001$. Regardless of age, elite players were more successful at anticipating pass destination in 11 v. 11 simulations (ES = 0.95).

Memory Recall. A significant main effect was found for structure only, $L(4) = 16.47, p < .004$. All participants made more errors in recalling player positions during structured versus unstructured trials. However, the magnitude of the difference between structured conditions represented only a small effect (ES = 0.19). The mean ($\pm SD$) radial error was $30.18 \pm 13.90$ mm for structured trials and $29.77 \pm 14.42$ mm for unstructured trials. Although the age main effect and the Skill x Age x Structure interaction were not significant ($p = .02$ and .04, respectively), moderate to large effect sizes indicated that meaningful differences were apparent. All participants between 11 and 13 years of age improved their general memory recall (ES = 1.42). In the structured condition only, elite players at 9 years of age made fewer errors in recall (ES = 0.65), and those between 15 and 17 years of age improved beyond their sub-elite counterparts (ES = 1.32) (see Figure 1).

Situational Probabilities: Key Players. Main effects for age, $F(4, 127) = 6.10$; skill, $F(1, 127) = 44.76$; and an Age x Skill interaction, $F(4, 127) = 17.00$; all $p < .001$, were obtained. The performance of sub-elite participants between 9 and 13 years of age improved significantly, $p < .004$ (ES = 2.23). In comparison, elite players maintained the same level of performance across age groups, although they more accurately highlighted a greater percentage of key players than did sub-elite participants at ages 9 years, $p < .001$ (ES = 1.94), and 11 years, $p < .003$ (ES = 1.83). While there was no statistical difference between elite and sub-elite players in the older groups, the effect size indicated that the observed differences in skill were also meaningful at 13 years of age (ES = 1.08) (see Figure 2).

Situational Probabilities: Non-Key Players. A significant main effect was obtained for age only, $F(4, 127) = 8.56, p < .001$. Between 11 and 17 years of age,
players from both skill groups reduced the number of non-key players highlighted, \( p < .002 \). The Age \( \times \) Skill interaction approached significance, \( p = .005 \). Moderate to large effects sizes for comparisons across skill groups at U-13, U-15, and U-17 suggest that as age increased, the elite players meaningfully reduced the number of non-key players selected in comparison to the sub-elite players (ES = 0.53, 0.83, and 1.27, respectively) (see Figure 3).

**Situational Probabilities: Probability Hierarchy.** Main effects were found for age, \( F(4, 127) = 26.80 \), and skill, \( F(1, 127) = 40.83 \), both \( p < .001 \). When compared to sub-elite participants, elite players at every age were better at assigning a correct probability value to key players in the most threatening position (ES
Predicting Performance in 9- to 17-Year-Olds: Discriminant Analyses

**Age.** Four significant discriminant function variates were calculated with a combined $\chi^2 (16) = 160.78$, $p < .001$. A strong association between predictors and groups remained when the first function was removed, $\chi^2 (9) = 30.517$, $p < .001$. The remaining two functions did not significantly contribute to the model. The first two functions accounted for 87.8 and 6.9% of the between-group variability, respectively. Variables predicted by the model were significant at each of the first four steps (max. 24 steps), $L(11) = 65.63$ to 92.16, $p < .001$. The standardized canonical discriminant function coefficients ($\beta$) indicated that structured memory recall was the greatest contributor to the first function and explained the greatest amount of variance ($\beta = .817$, $r^2 = .52$). The remaining variables entered into the model at each step were peripheral awareness ($\beta = .483$), anticipation: 3 v. 3 ($\beta = .299$), and situational probabilities: probability hierarchy ($\beta = -.291$). Each variable explained only an additional 5 to 6% of the true variance. Consistent with the effect size reported for memory recall, the greatest influence of this dimension occurred between 11 and 13 years of age (group centroids = 1.619 and -1.112, respectively). The model accurately predicted 44.4 to 78.6% of age-group membership. These values represent an improved prediction of 24.4 to 58.6% above chance levels.

**Skill.** The discriminant function variate calculated for skill was significant and accounted for the total between-group variability, $\chi^2 (2) = 40.75$, $p < .001$. Variables predicted by the model were significant at the second step, $L(11) = 35.53$, $p < .001$ (max. 24 steps). Standardized canonical coefficients suggest that both anticipation in 11 v. 11 game play situations ($\beta = .738$) and percentage of key players highlighted (situational probabilities) ($\beta = .633$) contributed similarly to
the model ($r^2 = .19$ and .28, respectively). The model accurately predicted skill-group membership for 79.5% of the participants. Improved prediction was 29.0% beyond chance.

**Discussion**

This study examined the relative contribution of visual, perceptual, and cognitive skills to the development of expert performance using a multidimensional approach. A further aim was to determine which variables best discriminated between skill and age. The variables that predicted elite performance in the present study were perceptual or cognitive in nature. These findings are in agreement with earlier research using adult participants in snooker, soccer, and field hockey (Abernethy et al., 1994; Helsen & Starkes, 1999; Starkes, 1987). Perceptual and cognitive skill variables have been shown to account for much of the variance in soccer skill between adult groups (Helsen & Starkes, 1999). The amount of true variance between elite and sub-elite groups explained by perceptual and cognitive skill variables in the present study was 47%. These findings extend the current body of knowledge by demonstrating that perceptual and cognitive skills also reliably discriminate elite from sub-elite players between 9 and 17 years of age. Moreover, the perceptual-cognitive skill model identified in this study accurately predicted elite status in approximately 80% of developing players.

As early as 9 years of age, elite players were better at predicting key player involvement when observing offensive plays and more accurately assigned appropriate probability values to each key player. They were also more effective at using advance information available from emerging patterns of play and from postural cues. These findings suggest that 9-year-old elite players possess a comprehensive knowledge of the relationships between players, readily perceive the relative importance of each one, and can pick up on their intended actions to a greater extent when compared to sub-elite players.

Although the use of adult memory strategies (i.e., rehearsal and retrieval) have previously been demonstrated at 9 years of age (Gallagher & Thomas, 1984), skilled 8- to 10-year-olds have generally been reported to have inadequate problem representations and processing operations to facilitate an appropriate solution (French et al., 1996; Nevett & French, 1997). It may take extensive amounts of practice over several years (e.g., 10-year rule) to fully acquire the knowledge and domain-specific memory skills needed for expert performance (Chase & Simon, 1973; Ericsson et al., 1993; Ericsson & Kintsch, 1995). However, the present study indicates that limited practice and high quality coaching can have a significant impact on the acquisition of perceptual and cognitive skills at an early age.

The results from the situational probabilities paradigm suggest that elite players exhibited a greater degree of situational awareness from an earlier age. The number of key players highlighted was one of the most discriminating factors of skill. Regardless of age, elite players were relatively accurate at picking up task-relevant information while viewing each simulation, and were able to integrate this information with prior experiences to predict the best options available to the player in possession of the ball. Furthermore, elite players between 9 and 15 years of age improved their ability to predict the next best move by assigning an appropriate probability hierarchy to the most important players, thus improving the certainty of an event's occurrence. That is, not only were they able to select key players
in the game but, with increasing likelihood, were able to use each key player’s level of threat as a relative index of attention allocation.

The analysis of non-key players also indicates a meaningful contribution to the observed level of skill. Elite players between 13 and 17 years of age improved their selectivity beyond that of sub-elite participants, excluding more non-key players who did not pose an immediate threat within the impending attack (ES = 0.53 to 1.27). Although sub-elite players between 9 and 13 years of age improved their ability to identify key players, the reduction of task-irrelevant information processing (i.e., non-key players) on the part of elite players suggests that skill level, rather than age, contributed more to the shift from an over-inclusive to a selective attention strategy (Ross, 1976). By using a more refined selection strategy and probability hierarchy, developing elite players are able to decrease the decision threshold necessary to predict the likely outcome of a situation.

Accurate prediction appears to be a consequence of integrating contextual information with situational probabilities or expectations stored in memory. With increasing age, elite players became more adept at predicting and confirming or adapting their typical response (Williams, 2000). This is consistent with McPherson’s (1999) “current event profile” account of the development of expertise. However, French and McPherson’s (1999) suggestion that such memory adaptations are seldom developed prior to 15 or 16 years of age may be open to debate given that, in the present study, elite 9-year-old soccer players were able to make relatively accurate and sophisticated predictions.

The results of the temporal occlusion paradigm partly support previous research that has employed a similar design to test anticipation (e.g., Williams et al., 1994). However, of the three game-play sequences used to assess anticipation, only 11 v. 11 simulations were included in the discriminant analysis model for skill. The suggestion is that the complex patterns of play in the 11 v. 11 simulations require more sophisticated knowledge and domain-specific memory to reach an appropriate solution. In comparison, in the 1 v. 1 and 3 v. 3 simulations, fewer relations between players and possible outcomes need to be considered. The perceptual-cognitive skill model highlighted in this study suggests that both the ability to anticipate what happens next (i.e., appropriate use of contextual information) and knowledge of what could happen next (i.e., integration of expectations stored in memory) in macro-states of play are vital components of expert performance.

The lack of skill-based differences in the ability to extract task-relevant information, such as postural cues, in micro-states of play (i.e., 3 v. 3) provides partial support for Abernethy’s (1988) findings in racket sports. However, skill-based differences in the 1 v. 1 simulations indicate that 9- to 17-year-old elite players are still able to anticipate effectively based on postural information, albeit to a lesser extent. In comparison to sub-elite players, elite players were approximately 12% more accurate in 11 v. 11 simulations (ES = 0.95), yet only 6% more accurate in 1 v. 1 simulations (ES = 0.50). Abernethy’s claim that experts do not develop superior anticipatory skill until early adulthood is refuted, given that elite players in the present study were able to anticipate opponents’ intentions, particularly in 11 v. 11 simulations, from 9 years of age. The present results suggest that anticipation based on the global relationships between players in emerging patterns of play may be more important for early skill development in soccer than the ability to utilize more subtle postural information. Further research is required to verify this issue.
The ability to retrieve player positions from memory in attack and defensive 11 v. 11 simulations was examined in the recall paradigm. Although no significant age or skill interactions were reported, the large effect size suggests there was a large improvement in the ability of elite and sub-elite players to recall both structured and unstructured patterns of play between 11 and 13 years of age (ES = 1.42) (see Figure 1). Such increments in performance may indicate an age-related increase in available processing strategies, as identified by Chi (1977).

The continued improvement in structured recall by the elite players between 15 and 17 years suggests that, at this age, they begin to develop a more organized and accessible encoding and retrieval system compared to their sub-elite counterparts (ES = 1.32). The results of the U-17 groups support Williams et al.'s (1993) work in soccer where experienced adults demonstrated less error in recalling key player positions from typical patterns of play when compared to inexperienced players. The U-17 results are also in agreement with Ericsson and Kintsch’s (1995) and McPherson’s (1999, 2000) propositions that domain-specific memory adaptations acquired through years of deliberate practice contribute to the perceptual advantage.

In the present study, age was a stronger predictor of structured memory recall than skill. Similar findings have been noted in research using participants at the other end of the age spectrum (M age = 60.3 years) (Krampe & Ericsson, 1996). However, previous work on young adults (M age = 23.2 years) has found recall of patterns of play to be the most significant discriminator of expertise, and the most predictive of anticipatory skill (Williams & Davids, 1995).

The lack of significance in the memory recall paradigm may have been due to the large standard deviations observed. It is likely that the recall task used in this study was too complex for younger participants to consistently differentiate between skill groups. Moreover, instructions to recall specific player positions may have required them to recall players that did not necessarily form part of the perceptual signature. Current research is under way in our laboratory that employs a free-recall paradigm to determine the nature of information encoded during viewing. In accordance with de Groot’s (1978) findings, the move-selection task used in the situational-probabilities paradigm and the anticipation of 11 v. 11 simulations apparently were better discriminators of skilled performance throughout development than the structured memory-recall task used in this study.

Elite and sub-elite soccer players were not consistently or meaningfully discriminated based on their visual function throughout late childhood, adolescence, or early adulthood. There was a general trend for static acuity, and in particular peripheral awareness, to improve up to around 13 years of age. This finding was confirmed by the inclusion of peripheral awareness in the discriminant analysis model for age and is consistent with research on perceptual-motor development (H.G. Williams, 1983). However, these improvements were not skill dependent. The skill-based differences observed in visual function throughout the age range were either highly variable, transient (e.g., superior peripheral awareness by elite players at U-11 and U-13 only), or equally favored sub-elite participants (e.g., stereoscopic depth sensitivity at U-11 and U-13).

In previous studies using adult populations, the true variance explained by variables related to visual function has demonstrated only a negligible contribution (3–5%) to skilled behavior (Abernethy et al., 1994; Helsen & Starkes, 1999). The exclusion of visual “hardware” variables from the discriminant analysis model
for skill illustrates their lack of contribution to elite performance throughout development. The optometric and physical properties of the visual system may well set limits on performance, but these do not appear to be skill dependent. No single variable related to visual function consistently discriminated elite from sub-elite soccer players between 9 and 17 years of age.

In conclusion, the present research suggests that elite and sub-elite soccer players are not meaningfully discriminated on nonspecific tests of visual function throughout late childhood, adolescence, or early adulthood. Instead, elite players develop superior perceptual and cognitive skills that allow them to perform more successfully in each of the respective age groups. The perceptual-cognitive skill model indicates that from as early as 9 years of age, elite players can effectively utilize and integrate contextual information with expectations stored in memory in ways that differ systematically from those of their sub-elite counterparts.

The present study has important implications for training perceptual skill in sport. Previous guidelines have suggested that players should be amenable to perceptual training by 12 years of age (Williams & Grant, 1999). In light of the current findings, there is a plausible argument for reducing this age recommendation. Indeed, McPherson and Thomas (1989) have demonstrated that the decision-making skills of 8- to 10-year-old tennis players could be improved following specific instruction. However, French and McPherson (1999) provide evidence that children may not develop task-specific cognitive or perceptual skills before the physical mastery of related technical skills. Moreover, the content and focus of practice sessions are likely not only to regulate motor skill development but also produce different knowledge representations that affect how players “read the game.” Therefore, a note of caution is made with respect to implementing perceptual skills training programs too early. In our view, the primary goal of instruction at an early age should be to develop key technical skills. When a sufficient level of mastery has been attained and the rules of the game are understood, the inclusion of perceptual and cognitive skills training that is relevant to the current strategies being implemented may be conducive for developing appropriate game-reading skills.

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