

Anticipation Skill in a Real-World Task: Measurement, Training, and Transfer in Tennis

A. Mark Williams, Paul Ward, John M. Knowles, and Nicholas J. Smeeton
Liverpool John Moores University

Anticipation skill in tennis was examined using realistic film simulations, movement-based response measures, and a portable eye movement recording system. Skilled players were faster than their less skilled counterparts in anticipating the direction of opponents' tennis strokes, with this superior performance being based, at least in part, on more effective visual search behaviors. The processes mediating superior performance were then modeled in groups of recreational tennis players using video simulation, instruction, and feedback. Players who received perceptual training improved their performance on laboratory- and field-based tests of anticipation when compared with matched placebo and control groups that did not receive any instruction regarding expert performance strategies. The approach used may have practical utility in a variety of performance contexts.

Perceptual skills play a crucial role in the performance of everyday tasks such as driving (McKenna & Horswill, 1999), reaching and grasping (Goodale & Servos, 1996), and sports participation (Williams, Davids, & Williams, 1999). The ability to anticipate a future event based on information arising early in the display is often regarded as one of the most important perceptual skills underlying effective motor performance. For example, skilled drivers are able to anticipate hazardous traffic situations more effectively than novices, thereby reducing their accident liability (McKenna & Horswill, 1999). Similarly, in sports such as tennis, the ability to anticipate an opponent's intentions based on postural cues provides a crucial performance advantage (e.g., see Rowe & McKenna, 2001; Singer et al., 1994).

The majority of researchers working on perceptual (and cognitive) expertise have adopted an information-processing framework and used the expert–novice paradigm to isolate the important attributes that differentiate skilled from less skilled individuals. The consensus seems to be that expert performers develop knowledge and skills that enable them to deal effectively with a variety of related performance scenarios. The relationship between visual perception, memory, and skill has previously been explained through reference to the perceptual “chunking” model proposed by Chase and Simon (1973). This model suggests that experts can exceed the capacity of short-term memory by clustering or grouping individual elements (e.g., individual player positions) into larger and more meaningful units (e.g., game configurations). More recently, Gobet and Simon's (1996) template theory integrates perceptual features such as chunks with high-level cognitive processes such as schematic knowledge and planning through complex data structures referred to as *templates*. In contrast, the

long-term working memory theory proposed by Ericsson and colleagues (e.g., Ericsson & Delaney, 1999; Ericsson & Kintsch, 1995) suggests that experts bypass the limitations of short-term working memory by acquiring skills that promote both rapid encoding of information in long-term memory and allow selective access to this information when required. With extensive practice, experts index information in such a way that they can successfully anticipate future retrieval demands. Retrieval cues kept in short-term working memory facilitate access to information stored in long-term memory. Expert performers, therefore, acquire flexible representations that facilitate performance and allow them to adapt rapidly to changes in situational demands.

Although research on perceptual expertise is rapidly expanding, knowledge as to the mechanisms underpinning anticipation skill is somewhat limited, and there have been few attempts to determine whether its acquisition can be facilitated through training and instruction (see Williams et al., 1999). In this article, we use the expertise approach advocated by Ericsson and Smith (1991) to rectify perceived shortcomings in the literature. In Experiment 1, the important characteristics of anticipation skill in a real-world task are identified by using realistic film simulations, movement-based response measures, and a portable eye movement recording system. The intention was to analyze and describe the perceptual processes critical to expert performance on the task. In Experiment 2, knowledge derived from Experiment 1 is used to create a systematic training program with the intention of improving anticipation skill. The approach used in this program of research, namely that of developing a realistic performance measure so as to capture and analyze expert performance and then using this information to design and implement a suitable training intervention, might have practical utility in a variety of performance contexts.

A. Mark Williams, Paul Ward, John M. Knowles, and Nicholas J. Smeeton, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, England.

Correspondence concerning this article should be addressed to A. Mark Williams, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, The Henry Cotton Building, 15–21 Webster Street, Liverpool L3 2ET, England. E-mail: m.williams@livjm.ac.uk

Experiment 1

Anticipation in Real-World Tasks

One of the earliest studies to examine anticipation skill in a real-world task was carried out by Jones and Miles (1978). In this study, a film-based temporal occlusion approach was used to

investigate whether expert, intermediate, and novice tennis players could successfully anticipate the direction of an opponent's serve. Three different temporal occlusion periods were used: 336 ms after ball–racket impact, 126 ms after impact, and 42 ms before impact. Participants were required to indicate where they thought the ball would land on a schematic representation of the service court area. The expert tennis players' performance was significantly better than novices at the earliest occlusion periods only, signifying that they were able to use information available before ball–racket contact more effectively than their novice counterparts. Following the seminal work of Jones and Miles (1978), other researchers have reported similar findings (e.g., see Isaacs & Finch, 1983; Rowe & McKenna, 2001; Tenenbaum, Levy-Kolker, Sade, Liebermann, & Lidor, 1996).

Although these studies highlighted the importance of anticipation skill in real-world tasks, no attempts were made to identify the important information cues underpinning successful performance. Singer et al. (1996) addressed this issue by using an eye movement registration system to identify differences in visual search behaviors between expert and novice tennis players. Participants were required to move a handheld joystick in response to serve and passing shots presented on a small (12-in [30-cm]) television monitor. The expert players were quicker and more accurate in their response to the filmed sequences. Also, differences in visual behaviors were observed between skill groups. The experts focused on the racket and shoulder–trunk regions to glean information concerning the ball's likely destination, whereas novices tended to fixate on more distal and potentially less relevant cues such as the ball, head, and nondominant side of the body (cf. Buckolz, Prapavesis, & Fairs, 1988; Goulet, Bard, & Fleury, 1989).

In recent years, researchers have been criticized for using small television displays and simplistic response protocols to replicate the performance setting. Artificial laboratory tasks may negate experts' advantage over novices by denying them access to information that they would normally use, limiting them to use different information to solve a particular problem (Abernethy, Thomas, & Thomas, 1993; Williams et al., 1999). In response to this criticism, attempts have been made to develop more realistic laboratory protocols (e.g., Ward, Williams, & Bennett, 2002) and to measure anticipatory performance in situ (e.g., Singer et al., 1998). However, empirical effort is still required to develop appropriate measures of anticipatory performance in real-world settings (Rowe & McKenna, 2001).

In this experiment, skilled and less skilled tennis players were required to perform simulated tennis strokes in response to near life-size images of opponents playing forehand and backhand groundstrokes. We assessed the participants' anticipatory performance and their visual search behaviors as they viewed and moved in response to the action sequences. The eye movement patterns and interspersed fixations provided an indication of the underlying perceptual and cognitive processes used during task performance (see Rayner, 1998). We hypothesized that the skilled tennis players would demonstrate superior anticipation and more selective and effective visual search behaviors than their less skilled counterparts.

Method

Participants

Eight skilled (mean age = 23.0 years, $SD = 7.3$) and 8 less skilled (mean age = 27.2 years, $SD = 4.4$) male tennis players were recruited. The skilled participants were defined as *club level performers or above*, with an average of 11.9 ($SD = 4.7$) years playing experience, during which they had played an average of 500 ($SD = 308$) tournament matches. The less skilled participants had an average of 3.8 ($SD = 1.0$) years of recreational tennis experience and had not played in any tournament matches. The less skilled participants reported that they were physically active and participated in sports other than tennis at a competitive level. Informed consent was obtained before commencing the experiment.

Test Film

Two club level, male tennis players were used as models. The players were required to play forehand and backhand strokes during simulated match play situations toward four locations on court (left court, right court, center forecourt, and center backcourt). Each player was positioned on the baseline and filmed "front on" using a VHS video camera (Panasonic MS-4). This viewing position provided the same perspective as an opponent positioned mid-court on the other side of the net. The film sequences were edited to produce 6 practice and 16 test trials (8 forehand and 8 backhand shots). The stroke type and ball end locations were randomized. Each trial lasted approximately 4 s and included the model's preparatory movements and stroke execution. An intertrial interval of 5 s was used.

Procedure

The test film was back-projected (SharpVision XG-NV2E, Mahwah, NJ) onto a large screen (3 m \times 3.5 m) located 5 m from the participant such that the visual angle subtended by the opponent was similar to the real-world situation (approximately 8.5°). Participants stood on two pressure sensitive pads, holding a tennis racket in a ready position, and were asked to respond quickly and accurately to each tennis stroke. Responses were made by taking a step to one of four pressure sensitive pads located 0.4 m directly in front, behind, to the left or right of the participant, and by swinging the racket as if to intercept the ball. A schematic of the experimental setup used is presented in Figure 1A. The film was occluded after initiation of the participant's response to prevent feedback on task performance. Participants' responses were measured with a choice response time system activated by the pressure sensors (Movement Science Reaction Timer, 1993; Clinical and Biomedical Engineering, Royal Liverpool University Hospital). The test session took approximately 30 min to complete.

Eye movements were recorded with an eye-head integration system comprised of an Applied Science Laboratories (Bedford, MA) 5000SU eye tracker and Ascension Technologies (Burlington, VT), Flock of Birds magnetic head tracker (Model 6DFOB). The integrative system allows freedom of movement within 1.22 m in any direction and collects three pieces of information to calculate eye line of gaze; displacement between pupil and corneal reflection, position of eye in head, and position and orientation of head in space. This information is calculated with respect to a precalibrated 9-point grid overlaid onto the scene plane. A simple eye calibration was performed to verify point of gaze before each participant was tested. Periodic calibration checks were conducted before and during presentation of the test trials; however, recalibration was not required for any participant. The integrated system was accurate to within 1° of visual angle.

Dependent Measures and Statistical Analysis

Two measures of anticipatory performance were obtained.

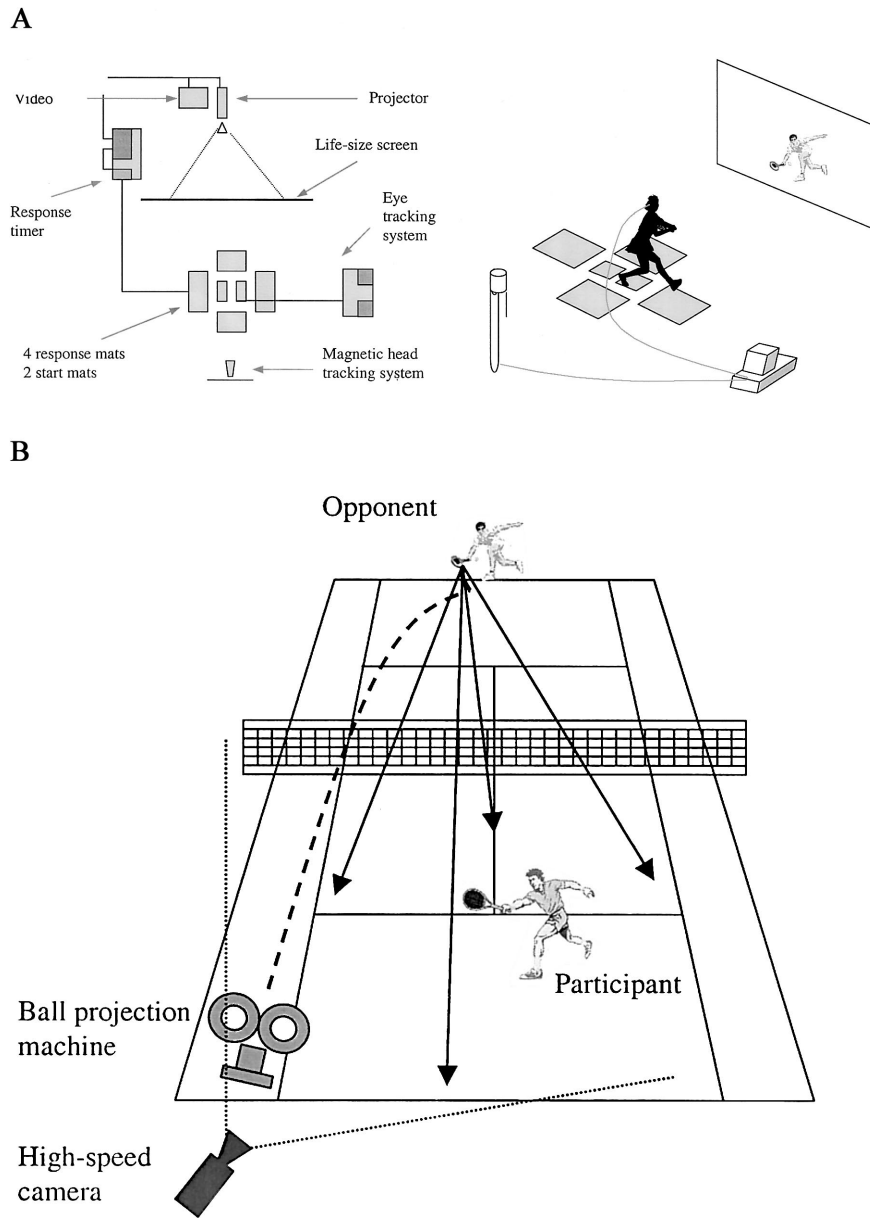


Figure 1. The experimental setup used during the laboratory- (A) and field-based (B) tests of anticipation skill.

Response accuracy (RA). This was defined as the mean correctness of the participant’s response relative to the actual shot destination across all trials (in percentages).

Decision time (DT). This was the mean time from onset of the film clip to the initiation of the participant’s movement response across all trials (in milliseconds). The response was completed when the participant lifted his foot off one of the pressure sensitive pads.

Performance on the anticipation test was analyzed statistically using a one-way multivariate analysis of variance (MANOVA), with group (skilled, less skilled) as a between-participant factor and DT and RA as the dependent measures. Planned comparisons were carried out to compare the performance of both groups on each dependent measure, respectively. Effect sizes were calculated using the Cohen’s *d* statistic.

Three measures of visual search behavior were recorded.

Percentage viewing time. This measure was the percentage of time spent fixating on each area of the display. The display was divided into

seven fixation locations: head–shoulder, trunk–hips, arm–hand, leg–foot, racket, ball, and racket–ball contact areas. A further “unclassified” category was included to account for those fixations that did not fall within any of the above areas (i.e., net, court, or background areas). Fixation locations were classified objectively by superimposing scan paths over the dynamic display. Percentage viewing time was analyzed using a factorial analysis of variance (ANOVA) in which group was a between-participant factor and fixation location was a within-participant factor.

Search rate. This measure was comprised of the average number of fixation locations per trial, the average number of fixations per trial, and mean fixation duration (in milliseconds). As in previous research (e.g., Williams & Davids, 1998), a *fixation* was defined as the period of time (≥ 100 ms) when the eye remained stationary within 1.5° of movement tolerance. Each variable was analyzed separately using a one-way ANOVA, with group as a between-participant factor.

Search order. This variable was defined as the average frequency with which a combination of successive fixation locations was observed on each trial (i.e., fixations immediately prior to or following the current fixation). Initial analyses were performed descriptively using a series of transition matrices. Two variables were subsequently analyzed using separate one-way ANOVAs, with group as a between-participant factor. These variables were the number of transitions between racket, ball, and racket-ball contact areas and the number of transitions between head-shoulder and trunk-hip region.

Results

Anticipation Test

The results of the MANOVA are presented in Table 1. Planned comparisons indicated that the skilled players were significantly quicker than the less skilled participants in responding to the virtual tennis strokes ($p < .01$, $d = 1.77$). No differences were observed between groups in response accuracy ($p > .05$, $d = 0.49$). The mean data are presented in Table 2.

Percentage Viewing Time

Mauchly's test of sphericity highlighted a significant violation of the sphericity assumption for repeated measures ANOVA, $\chi^2(27, N = 28) = 50.42$, $p < .01$, $\epsilon = .87$. We used the Huynh-Feldt correction procedure to adjust the degrees of freedom. The results of the ANOVA are presented in Table 3. Significant effects were observed for location, $F(6.08, 85.15) = 17.80$, $p < .01$, $\omega^2 = .70$, and the Location \times Group interaction, $F(6.08, 85.15) = 5.27$, $p < .01$, $\omega^2 = .18$. Newman-Keuls analysis indicated that the skilled tennis players spent significantly more time fixating on the head-shoulder region of the body in comparison to more peripheral areas of the body such as the arm-hand, leg-foot, ball, and unclassified locations (all $ps < .01$, $d = 0.58, 0.46, 0.54$, and 0.84 , respectively). Similarly, the skilled players spent a longer period of time fixating on the trunk-hip region compared with the arm-hand and ball regions ($p < .05$, $d = 0.45, 1.54$) and the leg-foot and unclassified locations ($p < .01$, $d = 1.40$ and 2.50 , respectively). In contrast, less skilled participants spent significantly more time viewing the racket compared with the head-shoulder, trunk-hips, arm-hand, leg-foot, ball, unclassified, and racket-ball contact areas (all $ps < .01$, $d = 1.85, 2.71, 3.38, 2.73, 3.01$, and 2.42 , respectively). The less skilled participants also spent considerably more time fixating on the racket than the high-skilled players ($p < .01$, $d = 1.92$). The mean results are presented in Figure 2.

Search Rate

As highlighted in Table 4, no significant differences were found between the skilled and less skilled players in the average number

Table 1
MANOVA Test Results for the Skilled and Less Skilled Players on the Field-Based Anticipation Test

Effect	Λ	F	df
Group	.41	9.52**	2, 13

Note. MANOVA = multivariate analysis of variance.
** $p < .01$.

Table 2
Mean and \pm Standard Deviation Decision Time (DT) and Response Accuracy (RA) Scores of the Laboratory-Based Anticipation Test

Group	Mean error rate		Standard deviation	
	DT (ms)	RA (%)	DT (ms)	RA (%)
Skilled	3,817.5	68.4	63.3	4.0
Less skilled	3,954.5	64.5	89.5	10.3

of locations fixated per trial, the average number of fixations per trial, or the mean fixation duration (all $ps > .05$, $d = 0.59, 0.17$, and 0.20 , respectively). Participants averaged 6.5 ($SD = 1.20$) fixations per trial, with a mean duration of 526.6 ($SD = 134.5$) ms, whereas an average of 4.2 ($SD = 0.5$) locations were fixated on per trial.

Search Order

The results of an analysis of the transitions between head-shoulder and trunk-hip regions are presented in Table 5, along with a separate analysis involving transitions within and between racket, ball, and racket-ball contact areas. Skilled tennis players used more successive fixations within and between the head-shoulder and trunk-hip regions ($M = 6.1$, $SD = 2.9$) than their less skilled ($M = 4.5$, $SD = 2.8$) counterparts ($d = 0.56$). In contrast, the less skilled players alternated their gaze between racket and ball areas of the display more frequently ($M = 8.3$, $SD = 2.6$) than skilled ($M = 3.8$, $SD = 2.2$) players ($d = 1.88$).

Discussion

The aim of Experiment 1 was to identify skill-based differences in anticipatory performance by using a real-world task involving tennis forehand and backhand strokes. A secondary aim was to determine whether skilled and less skilled performers used different visual search behaviors as they viewed the film-based tennis strokes. We hypothesized that the skilled players would demonstrate superior anticipatory performance and more effective visual search behavior than less skilled players.

As expected, the skilled players exhibited superior anticipatory performance compared with the less skilled performers. This finding supports previous research using representative real-world tasks (e.g., McKenna & Horswill, 1999), especially in tennis (e.g.,

Table 3
ANOVA Test Results to Examine Differences in Fixation Location Across Groups

Factor	Effect		Error		F
	df	MS	df	MS	
Group	1	0.00	14	0.00	1.10
Location	6.08	992.69	85.15	55.76	17.80**
Group \times Location	6.08	293.92	85.15	55.76	5.27**

Note. ANOVA = analysis of variance.
** $p < .01$.

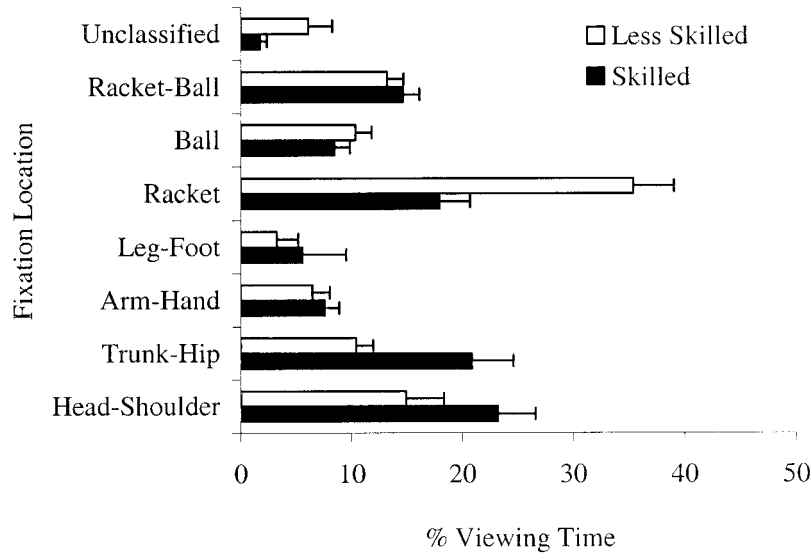


Figure 2. Mean (\pm SE) percentage time spent viewing each fixation location for skilled and less skilled participants.

Jones & Miles, 1978; Rowe & McKenna, 2001; Singer et al., 1996). The skilled players made a decision approximately 140 ms earlier than the less skilled players did, thereby providing a considerable performance advantage with regard to successful stroke execution.

Systematic differences in gaze behavior were observed across the two skill groups. The less skilled players preferred to focus on more obvious, deterministic cues from the racket and ball regions. In contrast, the skilled players utilized a more synthetic search strategy, using prior knowledge and experience to direct their gaze toward additional, perhaps more subtle task-relevant information cues located around the central body areas (i.e., head-shoulder, trunk-hip). Also, with an increase in skill level, there was an enhanced ability to search for, and utilize, cues from earlier occurring events within the display. The less skilled players relied on later occurring, distal cues; information that was likely to have been only confirmatory in nature for the high-skilled players. These differences in visual behavior across skill groups are similar to those presented in previous studies involving both eye movement recording (e.g., Singer et al., 1996; Ward et al., 2002) and retrospective verbal reports (e.g., Buckolz et al., 1988).

The search order data suggested that the skilled players also considered the subtle relations between areas within the central body region, such as the degree of rotation of the torso or the orientation of the shoulders relative to the hips (cf. Ward et al., 2002). In contrast, the search order data suggest that the less skilled participants primarily considered the relationships between the movements of the racket and ball trajectory relative to the impending racket-ball contact zone.

In summary, skilled tennis players demonstrated superior anticipatory performance compared with their less skilled counterparts. The experts' anticipation skill was based, at least in part, on more refined and effective visual search behaviors. The skilled players spent longer periods of time fixating on central body regions such as the head-shoulders and trunk-hip regions compared with less skilled players who, in contrast, used more distal cues such as the racket and ball to guide their anticipatory response. In Experiment 2, we used information about the processes mediating superior performance to develop a systematic training program to enhance anticipation skill in less skilled tennis players. We used various instructional approaches coupled with an innovative field-based measure of performance transfer.

Table 4
The Results of Separate ANOVA Tests for the Mean Number of Fixation Locations, Number of Fixations, and Fixation Duration Per Trial

Variable	Effect		Error		F
	df	MS	df	MS	
No. of fixation locations	1	0.03	14	0.29	0.12
No. of fixations	1	2.15	14	1.62	1.33
Fixation duration	1	3,011.26	14	19,165.92	0.18

Note. ANOVA = analysis of variance; No. = number.

Table 5
The Results of Separate ANOVA Tests to Examine Differences in Search Order Transitions Between and Within Different Display Areas

Search order transitions	Effect		Error		F
	df	MS	df	MS	
Head-shoulders, trunk-hips	1	42.25	14	5.26	8.02**
Racket, ball, racket-ball	1	81.00	14	5.75	14.10**

Note. ANOVA = analysis of variance.
** $p < .01$.

Experiment 2

Training Anticipation Skill in Real-World Tasks

In contrast to the exhaustive literature on expert performance, the issue of whether, or how, anticipation skill can be enhanced through practice and instruction has received limited attention. In two recent reviews, Williams and colleagues (e.g., Williams & Grant, 1999; Williams & Ward, in press) concluded that cognitive interventions that develop the underlying knowledge base have practical utility for enhancing anticipation skill in sport and other contexts. The typical approach has involved using video simulations that re-create the participant's customary view of the action (e.g., return of serve in tennis, hazardous driving situation, various surgical situations). These film sequences are presented to the learner coupled with the directive to focus attention on the most informative cues. This process is presumed to facilitate perceptual learning by increasing the amount of attention paid to perceptual features that are important and decreasing attention to irrelevant features of the display (Goldstone, 1998). The relationship between these key sources of information and the subsequent action requirements are also highlighted, and feedback about the correct response is provided. For example, this type of approach has already been used successfully to train police officers, aviation pilots, whitewater rafting guides, and sports performers (see Abernethy, Wood, & Parks, 1999; Allerton, 2000; Helsen & Starkes, 1999; O'Hare, Wiggins, Williams, & Wong, 1998).

Although these studies highlight the potential of perceptual training programs, various shortcomings prevent a clear evaluation of their usefulness. The majority of researchers have failed to use placebo (e.g., viewing other instructional material or mere observation of training film without receiving formal instruction) and control (e.g., no training) groups in addition to the conventional training group. The improvements in performance observed in these studies may be due to conformational bias or increased familiarity with the test environment rather than any meaningful treatment effect (e.g., see Singer et al., 1994). Also, researchers have neglected to use suitable transfer tests to examine whether training facilitated performance in the real-world context (e.g., see Farrow, Chivers, Hardingham, & Sachse, 1998). The design and implementation of some measure of transfer is essential to determine whether the improvements observed in the laboratory setting actually transfer to the real-world setting (cf. Scott, Scott, & Howe, 1998; Singer et al., 1994; Starkes & Lindley, 1994).

Another important issue is how relevant information should be conveyed to the learner during the instructional process. The traditional approach has been essentially prescriptive or highly directed in nature, with detailed instruction and feedback as to correct behavior being provided (e.g., see Abernethy et al., 1999; Farrow et al., 1998). However, scientists have recently advocated a more hands-off or less prescriptive approach to instruction (e.g., see Davids, Williams, Button, & Court, 2001; Williams et al., 1999). The suggestion is that guided discovery techniques may be more effective than explicit instruction strategies, particularly under conditions involving high uncertainty or stress (e.g., Hardy, Mullen, & Jones, 1996; Masters, 1992; Maxwell, Masters, & Eves, 2000). When skills are learned through explicit or prescriptive approaches, the emphasis is on verbalization and active cognition such that the knowledge once acquired can be verbally mediated.

In contrast, learners have difficulty or are unable to verbalize knowledge acquired through more implicit or guided discovery techniques (see Gentile, 1998; Green & Shanks, 1993; Stadler & Roediger, 1998). Although prescriptive approaches may facilitate short-term solutions to the problem at hand, they may not allow learners to develop the flexible and adaptive knowledge systems required to deal with a variety of performance contexts. The suggestion is that instructional approaches based on guided discovery provide the learner with the opportunity to explore different solutions to the problem at hand. The role for the instructor in this latter approach is to manipulate the constraints of the learning environment such that desired behavior emerges through practice and exploration, a process commonly referred to as *search plus selection under constraint* (e.g., see Thelen, 1995).

A potential implication when attempting to train anticipation skill is that visual attention should merely be directed toward "information rich" areas of the display as opposed to specific information cues (see Magill, 1998). In this approach, knowledge is acquired more implicitly through guided discovery rather than via conscious or intentional processes. For example, when learning to anticipate an opponent's serve in tennis, players should not be directed to focus their gaze on specific information cues such as the ball and racket orientation at impact. Players should merely be directed toward the contact zone so that they can discover the regularities between racket and ball orientation for each type of serve. Highly directed instruction does not allow players to learn how to search, whereas completely random searching is likely to be time-consuming and inefficient and could lead to losses in self-confidence and motivation. Different combinations of ball and racket orientations are required so that the learner can become progressively attuned to the invariant regulatory features. Thus far, these predictions have not been tested empirically.

With these issues in mind, we used knowledge derived from Experiment 1 regarding the visual search strategies used by skilled players to train less skilled performers; we assessed anticipatory performance pre- and posttest by using laboratory- and field-based measures; and we examined the relative merits of explicit instruction and guided discovery approaches by using one group that was provided with prescriptive information as to the important cues underlying performance, whereas we invited another group to pick up the same information through guided discovery. Finally, we made attempts to improve on previous research by using matched control and placebo groups to ensure that any improvements were due to meaningful training effects rather than to the result of potentially confounding factors such as increased test familiarity or expectancy effects.

Method

Participants

A total of 32 recreational level, male tennis players were recruited to participate in the experiment. These participants were similar in ability to those in the less skilled group in Experiment 1. However, because of the time-consuming nature of the intervention used, 4 of the participants withdrew from the experiment before participating in any program of intervention. The participants had played tennis for an average of 3.4 ($SD = 1.4$) years at a recreational level only. All were physically active athletes with comparable levels of sporting experience and attainment, albeit in nonracket sports. Informed consent was obtained prior to commencing the experiment.

Test Film

The same test film as in Experiment 1 was used.

Procedure

Laboratory test. The setup and procedure were the same as in Experiment 1.

Field test. Participants were required to respond to a male, club level player performing forehand and backhand groundstrokes from the baseline. A Bola Ball Trainer (TR85) projection machine was located in the left corner of the participant's baseline. The rally was initiated when a tennis ball was projected from the ball projection machine toward the feeding player at an average velocity of 12.7 m/s. The feeder was required to strike the ball with a similar velocity toward one of four different locations on the participant's side of the court (i.e., left court, right court, center forecourt, and center backcourt). The participant, located mid-court, was required to anticipate the opponent's stroke and to move to intercept the ball quickly and accurately, as in a match situation. The participant's actions were recorded with a digital video camera (JVC GR-DVL 9600) positioned behind and slightly to the right of the ball projection machine. The camera was positioned so that the club player, ball projection machine, and participant's actions were clearly visible within its field of view for subsequent analysis. The experimental setup is presented in Figure 1B. Six practice and 16 test trials (8 forehand and 8 backhand shots) were presented. The shot type and ball end location was randomized. An intertrial interval of approximately 10 s was used, and the test session took approximately 20 min to complete.

Training Protocol

Participants were divided randomly into four groups. Each group of participants completed the laboratory- and field-based pre- and posttests, although the order of completing the tests was counterbalanced to reduce the possibility of order or learning effects. Half the participants in each group completed the laboratory test initially, whereas the others were first tested in the on-court setting. The pre- and posttests for each group were undertaken a week apart. During the intervening period, the four groups of participants followed different protocols.

Explicit instruction group ($n = 8$). Participants who underwent explicit instruction completed 45 min of laboratory-based perceptual training followed by 45 min of field-based instruction on an individual basis. In the laboratory-based training, participants viewed film clips of a regional level tennis player executing forehand and backhand shots from an on-court perspective. Freeze-frame and slow-motion video playback facilities were used to highlight the important information cues underpinning successful anticipation skill and the relationship between these sources of information and eventual shot placement highlighted. The important information cues were derived from the data collected in Experiment 1. The training tape was repeated, allowing the participant the opportunity to reassess the linkages between a particular cue and eventual shot location.

Following the advance cue instruction, participants were provided with the opportunity to practice responding to similar film clips. A total of eight clips were presented using a temporal occlusion paradigm (see Williams et al., 1999). The film sequences were occluded at the moment of ball-racket contact, and participants were required to verbally indicate the ball's likely destination. Feedback was provided as to correct performance and any questions answered.

The structure of the on-court instruction followed the guidelines proposed by Abernethy et al. (1999) and Singer et al. (1994). This included formal instruction on the biomechanics of forehand and backhand shots, emphasizing the proximal-to-distal progression of stroke kinematics. The key information cues were highlighted using a regional level tennis player to demonstrate the linkage between a particular cue and the subsequent response requirements. Participants were then given the opportunity to

practice anticipating an opponent's intentions in a variety of realistic tennis drill and match situations. This realistic training protocol allowed participants to reestablish potentially important linkages between perception and action variables.

Guided discovery group ($n = 8$). Participants followed a similar training program to that highlighted for the explicit instruction group. However, rather than providing explicit instruction as to the most important information cues underlying performance, these participants were merely directed to focus on potential areas of interest. For example, rather than being informed that the orientation of the hip indicated whether the shot was going to be played cross-court or down-the-line, participants were directed to focus attention around the midriff region and to try and determine through guided discovery the relationship between hip orientation and shot outcome. Various verbal probes such as "Do you notice anything different between the cross-court and down-the-line shots?" were used to try and encourage problem solving and guide the learner toward the relevant information.

Placebo group ($n = 7$). Participants observed a 45-min instructional video focusing on technical skills. They were informed that this training tape was expected to be helpful in developing anticipation skill. This procedure was undertaken to provide an expectancy set for training benefits that was comparable to that of the perceptual training groups. No additional training information was provided.

Control group ($n = 5$). This group of participants received no instruction or training.

Dependent Measures and Statistical Analysis

The same measures of performance as reported in Experiment 1 were recorded on the laboratory-based test of anticipation skill. For the field-based test of anticipation, similar measures of performance were obtained following frame-by-frame analysis of the video data at a sampling frequency of 50 Hz. The on-court measures were the following:

DT: The mean time period from the projection of the ball to the initiation of the participant's initial step in the direction of the ball's anticipated landing position across all trials (in milliseconds).

RA: This was the mean accuracy of response relative to the ball's final destination across all trials. This measure was calculated as a proportion of the number of trials presented (in percentages).

Interobserver reliability measures were obtained for these dependent measures by using intraclass correlation techniques (see Atkinson & Nevill, 1998). The obtained intraclass correlation coefficients ranged from .90 to .96.

Because the duration of the film and on-court action sequences were not identical, data from the laboratory and field tests were analyzed separately by using a factorial MANOVA in which group (explicit instruction, guided discovery, control, placebo) was the between-participant variable; test (pre, post) was the within-participant variable; and DT and RA were the dependent measures. Planned comparisons were carried out to compare the performance of participants in the explicit instruction and guided discovery groups against those in the control and placebo groups on each dependent measure on the pre- and posttest, respectively. Also, planned comparisons were performed between the explicit instruction and guided discovery groups and between the control and placebo groups, respectively. Effect size calculations were based on the Cohen's d statistic.

Results

Laboratory Test

The results of the MANOVA are presented in Table 6. There was a significant interaction between group and test, Wilks's $\Lambda = .58$, $F(6, 46) = 2.41$, $p < .05$. Planned comparisons indicated that there were no significant differences in DT or RA between any of

Table 6
MANOVA Test Results for the Laboratory-Based Anticipation Test

Effect	Λ	F	df
Group	.91	0.36	6, 46
Test	.79	2.89	2, 23
Group \times Test	.57	2.40*	6, 46

Note. MANOVA = multivariate analysis of variance.
* $p < .05$.

the groups on the pretest (all $ps > .05$). However, we observed significant differences in RA when comparing the explicit instruction and guided discovery groups with the control and placebo groups on the posttest ($p < .01$, $d = 0.83$). The two training groups recorded significantly higher RA values on the posttest ($M = 72.1\%$, $SD = 15.6$) compared with the participants in the control and placebo groups ($M = 58.9\%$, $SD = 14.0$). No significant differences in DT were observed between the two training groups and the two control groups on the posttest ($p > .05$, $d = 0.21$). No significant differences in DT or RA were observed when comparing the explicit instruction group against the guided discovery group on the posttest ($p > .05$, $d = 0.25$ and 0.06) or when comparing the control and placebo groups on the posttest ($p > .05$, $d = 0.30$ and 0.47).

Participants in the explicit instruction and guided discovery groups significantly reduced their DT values from pre- ($M = 3,278.1$ ms, $SD = 197.3$) to posttest ($M = 3,160.0$ ms, $SD = 196.4$; $p < .01$, $d = 0.60$). No significant pre-to-posttest differences in RA were observed between the two training groups ($p > .05$, $d = 0.13$). Similarly, no significant pre-to-posttest differences in DT or RA were observed for the control and placebo groups ($p > .05$, $d = 0.11$ and 0.34 , respectively). The mean group performance scores across the dependent variables are presented in Figure 3.

Field Test

The results of the MANOVA are presented in Table 7. There was a significant effect for test, Wilks's $\Lambda = .31$, $F(2, 23) = 25.19$, $p < .01$, and for the Group \times Test interaction, Wilks's $\Lambda = .57$, $F(6, 46) = 2.44$, $p < .05$. Planned comparisons indicated that

Table 7
MANOVA Test Results for the Field-Based Anticipation Test

Effect	Λ	F	df
Group	.69	1.49	6, 46
Test	.31	25.19**	2, 23
Group \times Test	.57	2.44*	6, 46

Note. MANOVA = multivariate analysis of variance.
* $p < .05$. ** $p < .01$.

there were no significant differences in DT or RA between any of the groups on the pretest (all $ps > .05$). However, we observed significant differences in DT when comparing the explicit instruction and guided discovery groups with the control and placebo groups on the posttest ($p < .01$, $d = 1.03$). The two training groups recorded significantly faster DT values ($M = 2,001.0$ ms, $SD = 163.3$) compared with the participants in the control and placebo groups ($M = 2,186.7$ ms, $SD = 198.5$). No significant differences in RA were observed between the two training groups and the two control groups on the posttest ($p > .05$, $d = 0.25$). No significant differences in DT or RA were observed between the explicit instruction and guided discovery groups ($p > .05$, $d = 0.19$ and 0.10) or between the control and placebo groups on the posttest ($p > .05$, $d = 0.37$ and 0.43).

The explicit instruction and guided discovery groups recorded significantly faster DT values on the posttest ($M = 2,001.0$ ms, $SD = 163.3$) compared with the pretest ($M = 2,195.8$ ms, $SD = 125.3$; $p < .01$, $d = 2.08$). No significant pre-to-posttest differences in RA were observed for the two training groups ($p > .05$, $d = 0.40$). Similarly, no significant pre-to-posttest differences in DT or RA were observed for the control and placebo groups ($p > .05$, $d = 0.46$ and 0.04). The mean performance scores are highlighted in Figure 4.

Discussion

The intention in this experiment was to examine whether anticipation skill could be improved through the implementation of a training program based on video simulation and on-court training. A secondary aim was to examine the relative effectiveness of explicit instruction and guided discovery approaches when attempting to enhance anticipation skill in a real-world task involv-

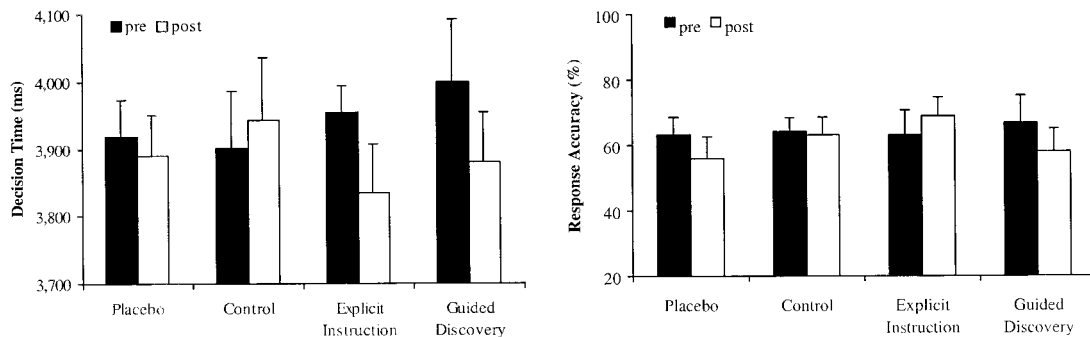


Figure 3. Mean (\pm SE) performance scores for the four groups of participants on the laboratory-based test of anticipation. pre = pretest; post = posttest.

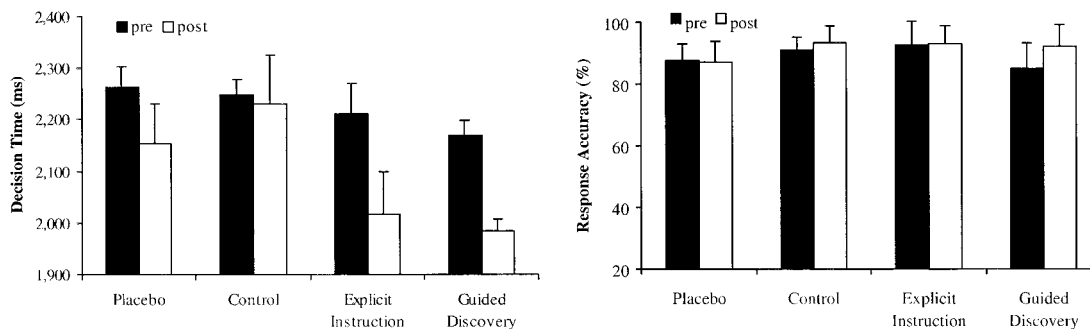


Figure 4. Mean (\pm SE) performance scores for the four groups of participants on the field-based test of anticipation. pre = pretest; post = posttest.

ing tennis forehand and backhand strokes. The use of matched placebo and control groups and a field-based measure of transfer provided further innovations.

The data from the laboratory-based test of anticipation skill showed that both the explicit instruction and guided discovery groups significantly improved their performance from pre- to posttest. The mean improvement in decision time from pre- to posttest for the two training groups was almost 120 ms ($d = 0.60$). This difference reflects a meaningful improvement in anticipatory performance to levels approaching those of the high-skill group in Experiment 1, presumably as a result of a more refined ability to pick up subtle postural cues and to ignore irrelevant sources of information (Goldstone, 1998). Findings provide support for other researchers who have attempted to enhance anticipation skill in sport and other settings (Abernethy et al., 1999; Helsen & Starkes, 1999; O'Hare et al., 1998).

Although there were no differences between groups in DT or RA on the pretest, the explicit instruction and guided discovery groups recorded higher levels of accuracy on the posttest compared with the control and placebo groups. In contrast, no significant pre-to-posttest differences in performance were evident for participants in the control and placebo groups. The improvement in performance in the two groups undertaking anticipation training is a meaningful training effect as opposed to the result of increased test familiarity or confirmation bias. The findings provide support for other recent studies (e.g., Abernethy et al., 1999; Farrow et al., 1998). It should be noted however that the participants in the placebo group in this experiment were not exposed to any on-court practice. Consequently, the possibility remains that the training improvement observed for the explicit instruction and guided discovery groups may be partly due to familiarity effects as a result of undertaking an extra 45 min of on-court instruction. This potential confound should be addressed in future experiments by requiring participants in the placebo group to undertake on-court practice in addition to video-based instruction, perhaps in relation to refining technical skills.

Another novel component of the current experiment was the inclusion of some measure of performance transfer from the laboratory to the field. Typically, researchers have failed to develop objective and sensitive measures of transfer. To promote the need for evidence-based practice, some measure of transfer is essential to determine whether improvements observed in the laboratory transfer to the performance setting. The results of the present

experiment showed that on the field-based test of anticipation, participants in the explicit instruction and guided discovery groups significantly improved their DT values on the posttest compared with their initial pretest scores. The mean improvement in decision time from pre- to posttest for the two training groups was almost 200 ms ($d = 2.08$). Also, although there were no differences between the four groups on the pretest, the two training groups recorded faster DT scores than the control and placebo groups on the posttest. The results provide further support for the practical utility of perceptual training programs and indicate that skills developed in the laboratory transfer to the field setting. Video simulation and field-based instruction help to develop the underlying knowledge structures and skills and facilitate the acquisition of anticipation skill in real-world tasks.

Although the performance of the two training groups on the field-based test closely mirrored that reported on the laboratory test, the RA scores were lower on the laboratory-based test than on the field-based test. In the field setting, the players could see the first, and if need be, the latter portions of ball flight, and as a consequence, made relatively few errors. In contrast, on the film-based test, the participants were constrained to anticipate early and were only allowed a relatively short view of the ball's trajectory. Also, it may be harder to anticipate ball direction from film clips compared with an actual situation (cf. Williams et al., 1999). The loss of dimensionality and auditory cues as well as the potential difficulty of orienting the response in relation to the film may make the laboratory task more difficult than the field test.

The field-based measure of anticipation used in this study offers much potential for the assessment of perceptual skill in a variety of sports, particularly those involving more "closed skills" such as the serve in various racket sports, the penalty flick in field hockey, or the penalty kick in soccer. Moreover, such techniques may be used effectively to measure performance in nonsport tasks such as police and military training or driving and aircraft piloting. The advent of high-speed (i.e., > 50 Hz) cameras and digital editing and coding systems should enhance measurement sensitivity and the potential benefits of using video analysis as a behavioral assessment tool.

No significant differences in performance were observed between the explicit instruction and guided discovery groups on the laboratory- or field-based pre- or posttests in DT ($\alpha = .07$ and $.28$) or RA ($\alpha = .06$ and $.06$). Researchers have proposed that guided discovery instruction may be more beneficial to performance,

particularly when performing in stressful environments (Masters, 1992; Maxwell et al., 2000). The suggestion is that guided discovery approaches allow learners to explore various ways to solve the problem, encouraging them to provide a variety of solutions and increasing perceptual flexibility and adaptability (Savelsbergh & Van der Kamp, 2000). In contrast, traditional explicit instruction approaches may be overly prescriptive, constraining the learner to rely on less efficient sources of perceptual information. It would be interesting to see if the improvements in perceptual skill are maintained over prolonged periods of time and whether the implicitly trained players' perceptual processes are more robust to changes in emotional states, as proposed by Masters and colleagues. Further research is required using larger sample groups to explore the relative effectiveness of these instructional techniques in facilitating the acquisition of perceptual skill.

General Discussion and Conclusions

This program of research had several objectives. First, we developed a realistic laboratory-based test of anticipation skill in a real-world task involving tennis using life-size film images and movement-based response measures and used a portable eye movement recording system to identify differences in visual search behavior between skilled and less skilled performers. Second, we used information derived from this test to develop a training program based on video simulation and instruction to enhance perceptual skill. We made an attempt to examine the relative effectiveness of explicit instruction and guided discovery instructional techniques. The inclusion of matched placebo and control groups along with a novel measure of transfer provided further innovations. We hoped that the three-step approach used in this program of research, whereby expert performance is initially captured with a realistic task, followed by more detailed analysis of the underlying processes, and then finally, an investigation of the important effects of practice and training on performance, would have implications in a range of settings, particularly where decisions have to be made under temporal constraint.

The findings show that anticipation skill in real-world tasks can be accurately measured in the laboratory with representative tasks that incorporated life-size film displays and realistic response measures. The skilled performers were faster in responding to the tennis simulations compared with their less skilled counterparts, and systematic differences in visual search behavior were observed between the two skill groups. The skilled performers extracted more meaningful information than the less skilled players did from the trunk and hip regions in attempting to anticipate the direction of an opponent's forehand and backhand drive shots. The processes mediating expert performance were then modeled successfully in a group of less skilled players using video simulation coupled with instruction and feedback. The two groups of participants who were exposed to perceptual training improved their performance on the anticipation test compared with matched placebo and control groups who did not receive any instruction. Moreover, the improvement in performance observed in the laboratory transferred to the field setting, confirming that the observed improvement was a meaningful treatment effect rather than the result of increased test familiarity or habituation. It appears that video simulation and instruction regarding expert performance

strategies has practical utility as a method of enhancing anticipation skill in real-world contexts.

The advantages of using video technology in this way are that learning can occur at a self-regulated pace, in a safe environment either at or away from the workplace, and the equipment is relatively inexpensive and accessible. Video images can be easily captured and manipulated for training purposes by, for instance, highlighting or occluding relevant or irrelevant sources of information. Video training may be supported by practice sessions undertaken in situ, whereas in future virtual reality may also provide exciting opportunities for those interested in designing and implementing perceptual training programs (e.g., see Loomis, Blascovich, & Beal, 1999).

Although the model of perceptual training proposed in this article offers much potential for enhancing performance in various settings, a number of outstanding issues need to be addressed. First, eye movement data were not collected on the laboratory-based posttest and consequently, it is not possible to conclude whether the observed improvements in anticipatory performance for the two training groups was reflected by the expected changes in visual search behaviors. Thus far, few researchers have examined whether, or how, visual behaviors change during skill acquisition, and consequently this is an area that merits further investigation (cf. Williams, 2002).

Another interesting issue is whether other perceptual skills can also be developed by using a combination of video simulation and instruction. There is evidence to suggest that pattern recognition skill can be improved through repeated exposure to a variety of related action sequences (see Wilkinson, 1992). A suggestion is that exposure to specific patterns of play in sport, for example, results in the development of specialized receptors or detectors through a process termed *imprinting* (Goldstone, 1998). These detectors are proposed to develop and strengthen with exposure to the stimulus or stimuli resulting in increased speed, accuracy, and general fluency with which stimuli are processed.

The question of how practice should be structured for effective learning has always been a topical area for debate in the motor skills literature (see, Lee, Chamberlin, & Hodges, 2001). The general consensus is that variability of practice and high-contextual interference practice conditions are beneficial for skill acquisition. In contrast, few researchers have examined whether similar principles apply in the learning of perceptual and cognitive skills (for a recent exception from the ergonomics literature, see de Croock, van Merriënboer, & Paas, 1998). Similarly, the optimal frequency and duration of perceptual training sessions has yet to be determined. The average length of a session has ranged from 15 min to 2 hr, whereas the frequency has varied from a single session to a 6-week training period (see Williams & Grant, 1999). Does perceptual skill continue to improve with training and practice, or is there an optimal point beyond which the additional training benefits are minimal? There is also controversy as to whether perceptual training programs should be used with experts, intermediates, or novices. Although the majority of training studies have used novice participants, the answer to this question may depend on the nature and difficulty of the skills being taught as well as the type of simulation used (for an interesting discussion, see Alessi, 1988). When attempting to answer these questions, some degree of guidance may be obtained from the extensive literature pertaining to the acquisition of motor skills; however,

concerted efforts involving systematic programs of research are necessary before this area of study can provide a more meaningful contribution to performance enhancement in real-world tasks.

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