MULTIDIMENSIONAL PERCEPTUAL-COGNITIVE SKILLS TRAINING REDUCES SPATIO-TEMPORAL ERRORS AND IMPROVES DYNAMIC PERFORMANCE AMONG SENIORS

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2007
This dissertation is dedicated to my mother and father. Thank you for making this dream come true.
ACKNOWLEDGMENTS

First, I thank my advisor, Dr. Christopher M. Janelle, for seeing me through the last leg of my journey. No words can express the respect I have for him as a professional and, more importantly, as a person. I also thank Dr. Robert N. Singer for his academic and life wisdom of which both have served me well throughout my time at the University of Florida. His friendship will stay with me forever. Special thanks goes to my doctoral committee, Dr. Heather Hausenblas, Dr. John Chow, and Dr. Ira Fischler, for their expertise, insight, and hard work. Finally, I thank my parents, Jean and Ron Caserta. Through their sacrifice and support, I was able to receive this Ph.D. However, they have given me the greatest gift of all – love.
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MULTIDIMENSIONAL PERCEPTUAL-COGNITIVE SKILLS TRAINING REDUCES SPATIO-TEMPORAL ERRORS AND IMPROVES DYNAMIC PERFORMANCE AMONG SENIORS

By

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May 2007

Chair: Christopher M. Janelle
Major: Health and Human Performance

The game of tennis is one of the most demanding of all sports, requiring physical strength and stamina, technical expertise, and mental prowess. Experts and recreational players alike are challenged by fast exchanges, limited space, and varying situations. Regardless of ability or age; however, winning and losing often lies in the perceptual-cognitive skills of the competitor, specifically their visual perception and decision-making capabilities. Though several viable training protocols have been shown to improve the anticipatory skills of dynamic sport athletes, such findings have generally been limited to junior and young adult athletes during laboratory-based tasks. Furthermore, the extant literature has failed to index how well these skills are retained after having been trained. The purpose of this investigation, therefore, was to examine the effectiveness of training situation awareness, anticipation, and decision-making (MPCT) in senior tennis players, when compared to anticipation-only (AT), technique-footwork (TFT), or no training. These training protocols were assessed in live
competitive performance situations both immediately following training and then six-weeks later. Intermediate/advanced senior tennis players (N = 50) were randomly assigned to one of the aforementioned groups according to gender and level of cognitive impairment, and were pretested in a 4-game set. After receiving five group-specific training sessions (30 min each), participants were posttested in a 4-game set, and again following a six-week retention period. Findings indicated that senior tennis players who received MPCT responded nearly twice as fast, two times more accurately, and made more than twice as many correct decisions during live, competitive match play when compared to AT, TFT, and control. More importantly, improvements made in response speed, response accuracy, and performance decision-making were retained in response demonstrating functional learning effects occurred. Along with improving these skills of interest, multidimensional perceptual-cognitive trained participants also won a higher percentage of points and games. These abilities were found to be beneficial to healthy older athletes and, specifically, those suffering from age-related cognitive declines. Suggestions are provided for future research in sport and dynamic life activities.
CHAPTER 1
INTRODUCTION

Dynamic sports competitors are constantly inundated with spatio-temporal information that places continuous demands on perceptual-cognitive abilities. In highly unpredictable situations, expert athletes are able to quickly and accurately shift their visual attention to preliminary movements and postural cues of their opponents (Goulet, Bard, & Fleury, 1989; Isaacs & Finch, 1983; Jones & Miles, 1978; Rowe & McKenna, 2001; Singer et al., 1996; Tenenbaum et al., 1996) so as to make efficient and appropriate decisions. In addition, experts are able to maintain high levels of perceptual expertise even when competing against a variety of opponents with variations in strategy and tactics. The ability to efficiently and reliably gather, sort, and process massive amounts of information and respond appropriately during predictable and unpredictable situations is critical to performance outcomes (Endsley & Garland, 2000). Sport-specific training of perceptual-cognitive strategies increases the speed of cognitive processing, the automaticity of accurate movements, and the ability to make rapid decisions that are necessary to be successful. As such, perceptual-cognitive skills training programs can alleviate the spatio-temporal challenges that exist in dynamic sports, while facilitating perceptual-cognitive skills acquisition.

Elite athletes were once thought to possess greater visual acuity, depth perception, and breadth of peripheral vision, thereby enabling them to respond faster than their non-elite counterparts. However, researchers (Cockerill, 1981; Starkes & Deakin, 1984) have demonstrated that some elite athletes have significantly lower static visual acuity and
peripheral vision as well as inconsistency in depth perception and simple reaction time. As such, it is apparent that variability in visual “hardware” does not account for expertise differences. More likely, the visual attention “software” of athletes is thought to contribute to the expert advantage, with substantial empirical evidence available to support this view (Abernethy, 1986; Applegate, 1992; Vinger, 1996). In an attempt to enhance performance and improve visual perception, recent empirical efforts have been made to identify of the most effective perceptual-cognitive skills and how those “software” skills should be trained (Abernethy, Woods, & Parks, 1999; Caserta & Singer, in press; Farrow et al., 1998; Grant & Williams, 1996; Scott et al., 1998; Singer et al., 1994; Smeeton, Williams, Hodges, & Ward, 2005; Williams & Ward, 2003; Williams, Ward, Knowles, & Smeeton, 2002; Williams, Ward, Smeeton, & Allen, 2004).

The effectiveness of training perceptual-cognitive skills has traditionally been determined by assessing improvements in anticipation, pre-performance cue usage, and decision-making speed and accuracy. Rarely have perceptual-cognitive skills training protocols produced significant improvements in both the speed and accuracy of response, and most assessments have been limited to laboratory-based tasks (for exceptions see Caserta, Young, & Janelle, in press; Singer et al., 1994; Smeeton et al., 2005; Starkes & Lindley, 1994; Williams et al., 2004). More importantly, the transference of these findings has been difficult to replicate in real-time competitive situations, and have failed to produce a higher percentage of successful performance outcomes.

Consideration of this lack of transference may be due to the wrong perceptual-cognitive strategies being trained, thereby causing errors when linking perception and action. Additional possibilities include the duration of training, or lack thereof, as well as
how perceptual-cognitive skills are trained (i.e., video-based vs. field-based, perception-only vs. perception-action). As such, sport scientists interested in improving perceptual-cognitive skills continue to search for the ideal training protocol to enhance both the speed and accuracy of visual perception, especially for elite and aged performers (see Caserta & Singer, in press; Caserta, Young, & Janelle, 2006; Ward et al., in press; Williams et al., 1999). Clearly, the optimal training program must positively transfer to real-time competitive situations.

Perceptual-Cognitive Skills Training in Military and Sport

The training of perceptual skills in sport was humbly initiated in 1955, as training principles were adopted from strategies used during World War II. The last 50 years has seen advancement in sport specific perceptual-cognitive training, but sport scientists interested in such training are now combining their efforts with those in the military psychology and human factors communities to identify the most effective means of training perceptual-cognitive skills. Most recently, Ward et al. (in press) reviewed the similarities and differences between the perceptual-cognitive and decision skills training research being conducted in sport psychology, expertise, human factors, and military psychology. Although the ability to efficiently detect and comprehend the salient information necessary to respond quickly and accurately during dynamic situations is critical to performance outcomes in all externally paced sports and military environments, Ward et al. (in press) emphasized that little to no interdisciplinary cross fertilization has occurred concerning how to train these skills. Moreover, perceptual-cognitive skills trained in military research have lacked the evidence-based practice approach to training, which has been the hallmark of the sport psychology literature (Williams & Ward, 2003).
According to Ward et al. (in press), military psychology and human factors researchers have trained multiple skills (e.g., operator decision-making, situation awareness, critical thinking, and stress- and event-based training) to develop the perception and cognition of individuals performing in dynamic situations. Few of these studies, however, have utilized objective assessments, evaluation, or validation of such training in “real-world” environments. In an attempt to inform military research, Ward et al. (in press) suggested that future research should move beyond training content knowledge to focus on empirically-based experimental designs, which examine improving such behaviors in live, competitive environments. Furthermore, the most appropriate factors that enhance both response speed and accuracy needed to be determined.

**Situation Awareness**

Human factors research on the multidimensional concept of situation awareness (SA) has explained how individuals performing in externally driven environments quickly and accurately perceive their surroundings despite rapid change and seemingly unpredictable conditions. Specifically defined, SA is “the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley, 1988, p. 97). The complete understanding of factors that contribute to the optimal performance of a dynamic task allows individuals with heighten awareness to respond appropriately, thus improving decisions made under duress.

To understand how experts perform in such complex environments, Endsley (1988) determined the importance of three levels of SA. The first level of SA represents the core of perception, which involves perceiving what pertinent elements are present, where they
are located, and the speed at which they are moving (i.e., temporal-spatial aspects). The inability to identify important information, which is fundamental in dynamic environments, reduces the odds of forming and/or tapping appropriate schemas/mental models. Expertise developed in Level 1 SA forms the basis of the following two levels and cannot solely represent effective SA. As such, Level 1 expertise is a necessary yet insufficient determinant of SA. Clearly, perfect recall of critical elements with no understanding of the implications of those patterns will preclude success in dynamic situations.

The second level of SA includes the comprehension and integration of cues (acquired in Level 1) that are necessary for realizing one’s goals. Attaining Level 2 SA requires a synthesis of diverse elements, which encompasses how to combine, interpret, store, and retain information. Performing in dynamic, time-demanding situations requires rapid integration of multiple pieces of information while deciphering between relevant and irrelevant information. This is achieved by activating long-term memory structures (Sohn & Doane, 2003). Beyond comprehending cues and the subsequent response requirements, Level 2 SA allows a performer to categorize dynamic situations from a limited set of potential alternatives formed through experience. Furthermore, developing this level of SA heightens the responsiveness to leverage points allowing individuals to control and dictate situations. Leverage points are timely opportunities for creating dramatic changes in a situation (Klein & Wolf, 1998). These leverage points are not merely features of proximal-to-distal progression of kinematics, but include functional expertise of the performer. For individuals to master Level 2 SA, awareness of
the temporal-spatial aspects that exist in externally paced environments allow leverage points to be exploited.

The third and final level of SA is the highest level of SA and consists of the ability to forecast future situation events and dynamics. The ability to project forward from current experiences impacts future anticipation and timely decision-making. To achieve Level 3 SA, knowledge must be developed from situational elements (Level 1 SA) and comprehension of how those elements influence a situation (Level 2 SA) (Endsley, 1995). Although extant research on perceptual expertise explains expert-novice differences in cue utilization (i.e., Level 1 SA), Endsley and Garland (2000) indicated that expert operators across a variety of fields (e.g., pilots, air traffic controllers, power plant operators, and emergency room doctors) depend heavily on future projections (i.e., Level 3 SA). In addition, times exist where expert’s project backward into the past. By generating appropriate mental models from experiences, predictions can be made to the future.

The state of the environment influences SA, which in turn plays and integral role in the decision-making process. Without appropriate levels of SA (trained or otherwise), performers would make unguided, random decisions. For example, a fighter pilot who lacks the necessary SA may choose an improper tactical decision that may allow the enemy to acquire missile lock. Whether during air-to-air combat or a championship tennis match, similar response parameters must be optimized for effective performance outcomes. In addition to developing appropriate SA and decision-making, these two factors and the performance of an individual is influenced by individual factors, including information processing, long-term memory stores, and automaticity.
Effective situational analysis should increase the probability of anticipating events that may occur (e.g., the opponent’s use of a topspin lob as opposed to a passing shot when the player is at net). In turn, such appropriate behaviors should enhance the probability of making better decisions/actions in such situations. Individuals performing in such changing environments must develop the appropriate perception of fundamental postural cues (SA Level 1), then expand on those simple perceptions through the comprehension of what those cues mean in accordance with achieving one’s goal and exploiting leverage points (SA Level 2), and ultimately apply this newly acquired understanding to future match situations (SA Level 3).

**Anticipation and Pre-Performance Cues**

Extant sport psychology research has examined the effectiveness of training anticipation and pre-performance cues since the mid-1960s. Since its earliest inception, training these perceptual skills of interest have been conducted in soccer (Franks & Harvey, 1997; James & Hollely, 2002; Williams & Burwitz, 1993), football (Christina, Barresi, & Shaffner, 1990), baseball (Burroughs, 1984), and field hockey (Williams, Ward, & Chapman, 2003). Much of the empirical work has also focused on improving perceptual skills with tennis players of varying ability levels (Abernethy et al., 1999; Day, 1980; Farrow & Abernethy, 2002; Farrow, Chivers, Hardingham, & Sachse, 1998; Haskins, 1965; Singer et al., 1994; Smeeton et al., 2005; Williams et al., 2002; Williams et al., 2004). Training protocols have centered on directing tennis players to attend to the salient anticipatory cues available prior to the point-of-contact to assist in detecting the direction of forehand and backhand groundstrokes or serves. Notably, all of the extant research examining the effectiveness of perceptual skills training has reported statistically significant improvements in response speed/decision time (Farrow et al., 1998; Haskins,
Although such training protocols have improved the perceptual skills of interest, serious limitations directly related to the lack of transference to improving real-time performance outcomes exist with these findings. First, improvements in response speed, while significant, have been minimal (see Table 1-1). More importantly, such response speeds would be too slow for serves or groundstrokes hit between 64 and 120 km/h (40-75 mph), which allows only 1,250 to 900 ms for the ball to travel the length of the court (see Shea & Paull, 1996 for similar issues in other sports). Times as slow as these often mean the ball has already passed the net, making perceptual abilities less important if not completely irrelevant. Furthermore, some perceptually trained participants actually reduced their directional accuracy during posttesting by over 23% (see Farrow et al., 1998).

Table 1-1. Response Speed Findings

<table>
<thead>
<tr>
<th>Extant Sport Research</th>
<th>Laboratory-Based Tests</th>
<th>Field-Based Tests</th>
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<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
</tr>
<tr>
<td>Haskins (1965)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Farrow et al. (1998)</td>
<td>3,270 ms</td>
<td>3,190 ms</td>
</tr>
<tr>
<td>Singer et al. (1994)</td>
<td>1,685 ms</td>
<td>1,455 ms</td>
</tr>
<tr>
<td>Williams et al. (2002)**</td>
<td>3,975 ms</td>
<td>3,870 ms</td>
</tr>
<tr>
<td>Williams et al. (2004)**</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Indicates the number of frames per sec from contact to initial movement.
** Mean response speed for both experimental groups combined.

Second, improvements made in the accuracy of responses during laboratory-based testing have not transferred to on-court testing, and have critically lacked a measure of response speed (Day, 1980). Finally, regardless of the improvements in response speed or accuracy, replicating laboratory-based improvements in the field has proven difficult (Day, 1980; Singer et al., 1994) (for exceptions see Smeeton et al., 2005; Williams et al.,
This raises an important question. Is the lack of transference to real-time on-court situations a result of *how* perceptual skills are being trained? Alternatively, perhaps the appropriateness of *what* is being trained is insufficient for *real-world, real-time competitive situations*? With the speed of dynamic sports increasing, perceptual skills training protocols need to improve *both* response speed and accuracy (see Ward et al., in press; Williams et al., 1999). One without the other provides little benefit to recreational athletes, not to mention elite and senior athletes. Beyond these limitations, extant research has rarely examined the maintenance and retention of perceptual skills training (for exception see Farrow & Abernethy, 2002). This is cause for serious concern given the lack of a follow up retention test makes it difficult to ascertain whether significant performance gains are attributable to functionally significant learning effects or merely transient performance effects.

**Multidimensional Approach**

After examining past perceptual-cognitive training from military and sport, Caserta and Singer (in press) proposed that dynamic sport situations required training that addressed more than any single factor (e.g., anticipation, pattern recognition, or decision-making training) could provide. To determine the most effective way to train perceptual-cognitive skills in tennis match play situations, the most relevant perceptual constructs from military psychology were combined with those from the field of sport psychology. By merging the recommendations of these related bodies of literature, recent investigations (Caserta & Singer, in press; Caserta, Young, & Janelle, in press) assessed the effectiveness of a multidimensional intervention (including situation awareness, anticipation, and decision-making) on dynamic sport performance.
Initial findings (Caserta & Singer, in press) indicated that intermediate tennis players receiving only 30 min of multidimensional perceptual-cognitive training (i.e., situation awareness, anticipation, and decision-making) outperformed all other participants (situation awareness/anticipation or control) by responding a half second faster (averaging 1,563 ms), while continually improving the percentage of accurate responses (averaging over 10% more accurate) during a laboratory-based task. Most recently, empirical support for this type of approach to training perceptual-cognitive skills (relative to a physical skills comparison group) has been conducted with senior tennis players, some of which were determined to have mild levels of cognitive impairments (Caserta, Young, & Janelle, in press). On average, multidimensional perceptually trained participants improved their response speed by nearly a half second (pretest: 1,050 ms, posttest: 568 ms), responded nearly three times more accurately (pretest: 31%, posttest: 88%), and more than doubled the number of correct decisions (pretest: 35%, posttest: 81%) during live on-court singles matches. As with past perceptual training studies, these investigations enhanced situation awareness, anticipation, and decision-making skills; however, understand which perceptual-cognitive skills improve the performance outcomes of athletes competing in dynamic sports remains necessary and elusive.

**Acquisition and Retention of Perceptual-Cognitive Skills in Older Athletes**

Among those conducting skill acquisition, perception, and expertise research, few have considered how such abilities are retained in older athletes (Krampe & Ericsson, 1996; Starkes et al., 1999, 2003; Weir et al., 2002). Even fewer have been concerned with how to acquire or enhance these skills (Caserta, Young, & Janelle, in press). Recent interest in the acquisition and retention of expert perceptual-motor performance has
produced a life-span model (Starkes, Cullen, & MacMahon, 2004) that outlines the transitions in perceptual-cognitive and perceptual-motor behavior across differing levels of performance during aging. Starkes, Cullen, and MacMahon (2004) proposed that a “constant interaction and exchange between what one is able to perceive and understand (i.e., perceptual-cognitive stream) and what one is able to perceive and do (i.e., perceptual-motor stream) [either constrains or facilitates performance outcomes]” (p. 259). As one ages, physical constraints can drastically affect performance outcomes. Physical declines include decreased flexibility, loss in muscle size and strength, and lowered aerobic capacity. However, Starkes, Cullen, and MacMahon (2004) advocate that “adaptations within perceptual-cognitive [skills] can ‘make-up’ for losses within perceptual-motor [skills]” (p. 271).

Cognitive Function

Age-related declines in cognitive functioning are well documented and directly affect functional performance in everyday tasks as well as sport activities. A limited capacity to hold information in working memory (Baddeley, 2003; Hasher & Zacks, 1988), the reduced ability to perform multiple tasks simultaneously (Navon, 1984; Salthouse, 1985, 1988, 1996), generalized slowing of cognitive processing (Birren, 1970; Cerella, 1994; Salthouse, 1985), and/or decreased selective attention from inefficient inhibitory mechanisms (Hasher, Lustig, & Zacks, in press; Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999; Layton, 1975) all create significant declines in performance. Of particular concern is cognitive speed, which directly influences the perceptual-cognitive skills necessary to perform in dynamic environments. Although age-related cognitive declines naturally occur as we age, evidence exists regarding effective intervention strategies.
Recently, researchers examining the effects of cognitive training with aged individuals have found that interventions significantly improve specific cognitive abilities, most notably processing speed (e.g., Ball et al., 2002; Edwards et al., 2005; Roenker, Cissell, Ball, & Edwards, 2003; Wood et al., 2005). Ball et al. (2002) indicated that 87% of speed of processing (visual search and identification) trained older adults exhibited reliable cognitive improvement post-intervention, and with “booster” training (11 months post-intervention) such gains were maintained on a 2-year retention test. Roenker, Cissell, Ball, & Edwards (2003) found speed of processing training improved older adults’ choice reaction time on driving tasks, which relied heavily on visual attention and high-order processing (i.e., situation awareness). Benefits of this training program were evident in an 18-month retention test absent of “booster” training.

Cognitive Performance

Evidence also exists that older adults can benefit from perceptual training (Caserta, Young, & Janelle, in press; Kramer, Larish, & Strayer, 1995; Kramer, Larish, Weber, & Bardell, 1999), and such training is transferable to actual performance (e.g., driving) and improved situation awareness (Sifrit et al., 2001). Kramer and his colleagues found that the attentional control of older adults approached that of younger participants on post-intervention dual task assessments. In a simulated driving task, Sifrit et al. (2001) indicated that speed of processing training led to greater levels of situation awareness. Caserta, Young, and Janelle (in press) revealed that multidimensional perceptual-cognitive training, including situation awareness, anticipation, and decision-making, dramatically improved older adult tennis players’ response speed, response accuracy, and performance decisions in singles match play situations. Wood et al. (2005) emphasized the importance of multidimensional training programs to maintain and potentially
enhance performance abilities when examining the relative significance of sensory and cognitive factors in age-related functional abilities.

Although extensive support exists that training can improve sensory and cognitive functioning of aging individuals in everyday tasks, little research has been conducted to provide evidence of training that improves the perceptual-cognitive skills necessary to perform in dynamic, physical tasks (i.e., sports). Given that perceptual skills underlie many daily and sport activities, perceptual-cognitive training that slows or ameliorates such deficits for older adults may maintain active physical lifestyles, which can have significant health benefits and improved independence and quality of living. If physical skills become more difficult to retain with age and improvements in perceptual-cognitive skills can compensate for those declines, further research is needed to examine the most effective perceptual-cognitive training programs to acquire and retain such skills and improve performance.

**Summary and Hypotheses**

In sum, the extant research training singular perceptual skills has rarely produced the levels of improvement necessary for recreational tennis players to compete successfully. Practical application and transference to *real-world, real-time competitive sports* requires perceptual-cognitive training protocols to foster improvements in response speed, response accuracy, and decision-making as well as increase performance outcomes. Comprehensive evaluation of perceptual-cognitive interventions are therefore needed to delineate the effectiveness of independent or collective contributions to these programs, as well as to assess the existence of functionally significant learning effects as opposed to merely transient performance effects. Evidence exists concerning the means by which *performance is maintained* and *improved* in *master* level athletes (Starkes,
Cullen, & MacMahon, 2004; Starkes, Weir, & Young, 2003); however, research is also needed to determine what aspects of training slow or even ameliorate cognitive effects on aging and improve competitive performance. Countless hours spent developing technical skills may not benefit senior athletes with respect to improved performance; however, the training of multiple perceptual and cognitive skills may prove key for aged athletes who compete in dynamic sports. I sought to determine what aspects of perceptual-cognitive skills training would most effectively improve such abilities and performance in older adult athletes with and without cognitive impairments.

The primary aim of the study, therefore, was to determine whether the use of multidimensional perceptual skill training (i.e., situation awareness, anticipation, and decision-making) or the traditional anticipation training used throughout extant research was more effective in improving the response speed, response accuracy, decision-making, and situation awareness of older adults during on-court performance. A secondary aim was to examine if multidimensional perceptual-cognitive skills training or traditional anticipation-only training would transfer to a higher percentage of points and games won during real-time, competitive singles matches when compared to a physical training program, including stroke and footwork development or no training. Three experimental groups, (1) multidimensional perceptual-cognitive skills training, (2) traditional anticipation-only training, and (3) technique-footwork training, along with a (4) control group receiving no training, were tested in on-court evaluations prior to and following intervention. In addition, all four groups were given a retention test 6-weeks following the on-court posttest evaluation to determine whether training would produce functionally significant learning effects. I hypothesized that senior tennis players trained
with multidimensional perceptual-cognitive skills training would respond faster, more accurately, and make more appropriate decisions during tennis match situations, as well as score higher in SA during posttest when compared to those provided with traditional anticipation-only, physical, or no training. Additionally, I hypothesized that senior tennis players trained with multidimensional perceptual-cognitive skills training would retain posttest improvements over a six-week retention interval. The final aim of this investigation was to assess the potential ameliorating effects of perceptual-cognitive training on mild levels of cognitive impairment in aged performers. I hypothesized that multidimensional perceptual-cognitive skills training would improve mild levels of cognitive impairments.
CHAPTER 2
REVIEW OF LITERATURE

Given the critical role perceptual-cognitive skills training plays in improving the anticipation and decision-making skills of performers, a review of the perceptual-cognitive skills training literature was necessary to determine potential limitations that exist in training perceptual-cognitive skills. By identifying those critical factors that may have limited the effectiveness of perceptual-cognitive skills training to date, further investigations can be planned and tested to alleviate existing limitations. Two cognitively based indirect conceptual accounts of perception and action, namely the information-processing approach (Norman, 1976; Wickens, 1992) and the theory of the perceptual cycle (Neisser, 1976), are discussed as a theoretical basis for perceptual skills training. Empirical work in perceptual skills is then chronologically summarized. Methodological limitations of extant perception research have been largely responsible for the conflicting and equivocal findings to date. As such, methodological shortcomings, including speed/accuracy trade-offs, the use of video-based, still photographs, and field-based training, and performance speeds, accuracy, and decisions in the laboratory versus requirements in real-time competitive environments, are addressed. Finally, future directions are proposed regarding the assessment, development, and maintenance of perceptual-cognitive skills across dynamic sports.

Theories of Perception and Action

For elite athletes in dynamic sports, the ability to efficiently and reliably perform complex skills despite the large amounts of available information separates them from
their less experienced counterparts. However, no single theory explains the link between perception and action or how these abilities are acquired. In an attempt to further understand how perception leads to action, two theories (the information-processing approach and the theory of the perceptual cycle) have been proposed to explain this link. Other direct and indirect theories and approaches, including the computational approach (Marr, 1982), connectionist models (Bruce et al., 1996), schema theory (Schmidt, 1975), the perceptual moment hypothesis (Whiting, 1968, 1969, 1970), the operational timing hypothesis (Tyldesley & Whiting, 1975), and the ecological approach (Gibson, 1979), account for aspects of perceptual and action. I have, however, chosen to focus solely on the indirect theories that most informed the perceptual-cognitive skills training program that was designed for this investigation. Although an in-depth review of these two theories goes beyond the scope of this paper, the most relevant constructs of the information-processing approach and summation of the theory of the perceptual cycle are discussed regarding their influence in perception and action in sport.

### Information-Processing Approach

Athletes make precise decisions on where to move from perceived stimuli of their opponents and/or the competitive environment. For perceptual-cognitive skills to be maintained, mental processes are required to be performed in coordination with an action sequence. The ability to perceive and act appropriately is therefore largely based on the efficiency and effectiveness by which a performer processes underlying constructs of the information-processing approach, including goals, preattentive processing, attention, working memory, long-term memory, and automaticity.

Perception directly influences decision-making and one’s actions. Therefore, it also plays a significant role in the goals of the athlete as well as the goals or outcomes of
the situation. In dynamic sport situations, more than one goal often exists and these multiple goals can frequently work in opposition to each other (e.g., maintaining energy levels throughout a five set tennis match while also keeping the ball in play). With regards to perception and the information-processing system, top-down processing and bottom-up processing are responsible for dictating or changing those goals according to the environmental cues being perceived. During top-down decision processing (Casson, 1983), an athlete’s goals and intentions direct preattentive processing and attention to designated informational cues and aspects of the environment. Concurrently, bottom-up processing draws on patterns being dictated by the environment, causing athletes to adapt to the current goals and intentions of their opponents.

Information processing researchers (see Norman, 1976; Wickens, 1992) have proposed that information from the environment is initially processed through preattentive sensory stores. *Preattentive processing* identifies specific properties, including spatial proximity, color, simple aspects of shapes, or movement (Treisman & Paterson, 1984). Because these properties provide important cues for focused attention, the most relevant characteristics significantly impact what an individual initially attends to. For performers, the most salient information exists in distinct regions of the opponents’ body, along with the opponents’ field/court positioning, and is initially processed through focused attention, thus initiating and aiding perception. Therefore, the saliency of relevant cues is realized during preattentive processing and forms the basis of perceptual skills. As will be discussed later, the ability to acquire relevant cues is known as Level 1 situation awareness.
A limiting factor in the perceptual process, attention can present restrictions on an athlete’s ability to perceive several items simultaneously. Selective attention is required to attend to relevant items and plays a significant role in decision-making and eventually performing an action sequence. However, dynamic sport environments often tax attentional capacities, causing relevant and irrelevant information to enter the information-processing stream, which overloads and negatively affects perception. To avoid exceeding these limited attentional capacities, pattern matching is used from long-term memory (Wickens, 1992) and working memory modifies attention to be directed towards goal-relevant information.

An athlete’s perception of goal-relevant information is stored in working memory, where the bulk of information processing occurs (Ericsson & Kintsch, 1995). As situations produce new information, existing knowledge of the environment is combined with newly acquired information allowing for a detailed understanding of performance outcomes. The ability to anticipate future tendencies and strategies as well as the subsequent decisions to counter these actions also resides in working memory (Endsley, 1995; Ericsson & Kintsch, 1995). As will be addressed later, the ability to comprehend informational cues and project that knowledge to future situations is known as Level 2 and Level 3 situation awareness, respectively. As such, working memory is vital to perception and the information-processing system. In dynamic situations, working memory is constantly occupied with the interaction of new and existing informational cues, anticipatory cues, interpreting and selecting responses, and programming the execution of corresponding actions (Endsley, 1995).
To overcome the limited capacity of working memory, expert performers use long-term working memory to quickly access past experiences and apply this knowledge to current situations (Ericsson & Kintsch, 1995). Long-term memory is based on three processes: encoding, storage, and retrieval. Experts encode information in long-term memory by using past experience, encoding specificity, and effective mnemonics. How relevant knowledge and acquired strategies are organized and stored in long-term memory has received multiple explanations, including episodic and semantic memory (Tulving, 2004), schemas (Mayer, 1983), and mental models (Rouse & Morris, 1985). Of these, schemas and mental models most directly relate to perception and action, and, more specifically, effective decision-making (Braune & Trollip, 1982; Rasmussen & Rouse, 1981; Schmidt, 1975). Schemas are considered generalized knowledge structures about objects, situations, and events (Mayer, 1983). According to Schmidt’s (1975, 1988) schema theory, the perceptual system works in coordination with generalized movement representations to direct behavior. The important aspect of Schmidt’s theory is that the “motor program is not provided a priori; it has to be written [rewritten] time and time again. Both external and internal conditions are taken into account, and opportunity is provided for feedback not only to correct for minor errors in the execution of the program but also to enable the organism to write better ones” (Meijer, 1988, p. 8). Rouse and Morris (1985) define mental models as “mechanisms whereby humans are able to generate descriptions of [environment] purpose and form, explanations of functioning and observed states, and predictions of future states” (p. 7). As schemas and mental models are developed through training and domain-specific experiences, both
provide direction of attention to critical cues, expectations of predictable and unpredictable future situations, and a direct link to perception and action.

Finally, as the attention, working memory, and long-term memory components of the information-processing system reach levels of expertise, automaticity of perception and action can be realized. Automatic processing allows perceptual abilities to be performed quickly, effortlessly, and sometimes unconsciously; however, a degree of conscious awareness remains necessary during the perception and action cycle. Although individuals may be unconscious of environmental perception, and may be unable to identify the process used to make a decision, the specific elements or cues in the environment to attend to still require a conscious level of awareness (Endsley, 1995). Those who enter a total state of perceptual automaticity may risk decreased response speed and accuracy during unexpected and unpredictable situations, which can cause deficits in the effectiveness of performance decisions.

Theory of the Perceptual Cycle

Relying heavily on information processing concepts, Neisser (1976) proposed an integration of perception and cognition with the theory of the perceptual cycle, and addressed the interrelationship between perception and knowledge. Generally speaking (Figure 2-1), Neisser (1976) argued that context specific knowledge, which is represented in schemas/mental models, directs attention and exploration of relevant information to the environment, objects, and individuals. Relevant information, in turn, further modifies context specific knowledge.
Figure 2-1. Neisser’s (1976) view of the perceptual cycle

However, Neisser (1976) expanded this view of the perceptual cycle (Figure 1b) to specifically explain the link between perception and action.

Figure 2-2. Modification of Neisser’s (1976) view of the perceptual cycle.
In the expanded model, the inner circle encompassed perception of the immediate environment, while the outer circle represented actions taken to enhance information that may not be present in the immediate environment. First, schemas have been more appropriately separated into *implicit* and *explicit focus*, which taps knowledge on an unconscious and conscious level, respectively. The combination of implicit and explicit focus reduces cognitive processing workload by improving working memory. On the outer ring, *long-term semantic memory* and *long-term episodic memory* support implicit and explicit focus, respectively. According to Tulving (2004), semantic memory is “characterized by the additional capability of internally representing states of the world that are not perceptually present,” while episodic memory “affords the additional capability of acquisition and retention of knowledge about personally experienced events and their temporal relations in subjective time and the ability to mentally ‘travel back’ in time” (p. 364). The ability to represent states not perceptually present and retain the spatio-temporal aspects of situational events allows an individual to project where to move in that environment more effectively. Ultimately, these mechanisms direct *locomotion and action* necessary for sports (Figure 2-2). The perception and action link is further modified and strengthened by *actual world information* preparing the athlete to perform in the future. Individuals can have a heightened sensitivity to surrounding information, which enhances perceptual mechanisms for picking up perceptually relevant information. This developed sensitivity may allow athletes rapid awareness of specific visual cues, which directly affects response times. Over the past 50 years, research has incorporated the information-processing approach and the theory of the perceptual cycle to develop training protocols to enhance the perception and action link.
From Past to Present: Training Perceptual-Cognitive Skills

Although a limited number of researchers have directly examined the effectiveness of training perceptual-cognitive skills, attempts to improve such behaviors began in the 1950s. The following timeline tracks the perceptual-cognitive skills assessed and methodologies used in these studies, as well as the limitations as applied to performing in dynamic sports.

The 1950s and 1960s

Initially, perceptual training research focused on developing the pattern recognition of athletes and how this skill improved the response speed and accuracy of an athlete. Training protocols incorporated two- and three-dimensional slide images, live on-field formations, flash cards, and motion pictures to enhance pattern recognition.

Damron (1955) proposed that recognition of different defensive formations in football could be developed through the training of specific recognition principles used during World War II. Two- and three-dimensional slide images with tachistoscopic training techniques were used to examine the effects of instructing high school football players on identifying eight defensive formations. Over 18 sessions, defensive formations were projected on a screen in one-minute intervals, while the advantages and disadvantages of that particular defense were discussed. During each training session, review slides were presented for ten seconds and then repeated at 1/100 sec. By flashing projected slide images on a screen, it was hypothesized that football players would learn how to quickly recognize these formations. Although no distinct advantages were found between two- and three-dimensional slides, high school football players viewing two-dimensional slides accurately identified 79.3% of projected slides, and all trained football players accurately recognized approximately 95% defenses using live players.
Although the recognition of defensive formations is an important first step for offensive players, the actual intentions of a defense may not be revealed until the play has commenced. In football, heightened awareness and rapid decisions are necessary and require higher-order cognitive processing that are not elicited through recognition of still formations. Furthermore, flashing projected slides at 1/100 sec does nothing for perception since the perception of vital cues and comprehension of those cues occurs throughout the movement action. In addition, no evidence of transference to real-time settings was provided. Although this study represents an encouraging beginning for perceptual training research, findings are limited to the training of pattern recognition in contrived football scenarios.

Haskins (1965) developed a response-recognition training film to assess the ability of tennis players to rapidly determine the direction of tennis shots. Training consisted of shots that were paused at the point-of-contact and other shots that were paused eight frames after impact, showing the ball approximately until it reached the net. Following a pilot investigation, two training sessions were determined to produce faster responses when compared to the effects of one training session. Prior to this film-based training, pretest filming was obtained for each participant and response times (i.e., the number of frames) were determined for movements in the correct direction. Although posttest response times were faster, initial movements were made after 8.84 frames. Consequently, the ball had already passed the net, making perceptual abilities less important. Tennis players need to be moving prior to the ball reaching the net to effectively cover the entire tennis court. Response times as slow as these may have been sufficient during the 1960s when players used wooden racquets; however, modern day
technology has drastically increased the pace with which shots are hit. Additionally, the lack of improvements across response times and accuracy scores limits the generalizability and potential effectiveness of this intervention as related to competitive settings.

As alluded to earlier, football aptitude relies heavily on the ability to quickly and accurately react to dynamic situations. Londeree (1967) argued that practice schedules might benefit from play recognition training for two reasons: (a) multiple game situations can be examined over a short period of time, and (b) more practice time is available for other training. Therefore, Londeree (1967) examined the differences between the play recognition of football players trained with motion pictures and those trained with flash cards. Play recognition training consisted of six offensive plays viewed from the perspective of the defensive end. The first three training sessions outlined each play and provided practice trials. In the next six sessions, plays were randomly displayed under reduced exposure time. During the final session, participants had a 10 min review followed by testing. Participants trained with motion pictures responded significantly faster than participants trained with flash cards; however, no differences in the number of correct responses were found. As Londeree (1967) admitted, however, this study had two major flaws. First, no baseline measures of perceptual abilities were taken, making improvements in perception difficult to assess. Secondly, participants were only tested on three trials. The lack of trials lessens the reliability of these results, since reduced variability may have occurred if multiple trails were used. Despite these limitations, this study provided initial evidence (i.e., faster responses) to support the benefits of two-dimensional video training.
In sum, the 1950s and 1960s provided evidence that still pictures and motion pictures could improve pattern recognition and anticipation skills. Although athletes made improvements in recognizing offensive and defensive football formations as well as the directions of tennis shots, dynamic situations require more than accurate responses. Furthermore, these research findings are limited to laboratory-based tasks, which fail to elicit the cognitive processing needed for live competition.

The 1980s and the Early 1990s

Approximately 20 years after Londeree’s (1967) work, training of a new set of perceptual and cognitive skills emerged, including pre-performance cues, anticipation, and decision-making, as well as a combination of these skills (e.g., anticipation and pre-performance cues). The 1980s and early 1990s provided new technology and training protocols to address the limitations found during the 1950s and 1960s. Still slides, video (slow-motion and real time), and viewing on-court play became the dominant vehicles through which perceptual skills were trained during this time period. In addition, new evidence of the effects of perceptual skills training with differing abilities, ages, and sports was provided.

Anticipation has been cited as a key component in tennis. Day (1980) emphasized that anticipation creates time for players to properly set up to hit a shot and provides more opportunities to utilize in-game strategies. He advocated that anticipation is built on the following information: (a) knowledge of an opponent’s game, (b) pre-performance cues prior to contact, and (c) the flight path of the ball. Unlike extant research on training perceptual abilities in tennis players, Day (1980) eliminated the flight path of the ball after impact to gain an accurate representation of the perceptual abilities of the participants. The purpose of the study was to examine the effectiveness of video-based
anticipation training in advanced junior tennis players. Participants were tested under a laboratory film-based condition as well as an on-court condition both pre- and post-training. During the ten-week training program, 10 sets of 20 film clips were viewed. Importantly, participants were shown the flight path of the ball after point-of-contact. Results indicated that improvements were made in the accuracy of responses during film-based testing; however, no improvements were found in on-court testing. When considering the fact that film-based testing consisted of only ten clips and no measure of reaction time was calculated, these findings have limited practical application. Although not specifically stated, anticipation training failed to provide improvements in on-court play, which raises an important question. Has the lack of transference to real-time on-court situations resulted from the type of training or insufficient testing protocols? As will be discussed later, the lack of transference may be due to both. Although tennis and football had traditionally been the focus of research in perceptual training, the 1980s provided new evidence of the effects of perceptual skills training in other dynamic sports, including baseball, soccer, and ice hockey.

Thiffault (1980) provided ice hockey players with decision-making training in offensive situations where shooting, passing, or skating with the puck was required. During laboratory testing with slide show pictures, players decreased verbal reaction times; however, when observing wooden mannequins set up in offensive and defensive positions on the ice, only moderate correlations were found between performance on the on-ice transfer task and decision speeds. Although this research design was innovative at that time, the use of wooden mannequins does not represent the high speed, dynamic situations that exist on the ice. Clearly, accounting for the complexity of actual
perception and action requirements is a difficult yet critical consideration when designing and assessing training research of this nature (Thiffault, 1980).

When one considers that the speed of baseball pitches ranges between 65 mph for a curve ball and 100 mph for a fastball (29.1 m s\(^{-1}\) and 44.7 m s\(^{-1}\), respectively), batters have less than a half of a second to determine the type of pitch being thrown and then make contact with the ball. Because hitting a baseball relies heavily on perception and action, Burroughs (1984) evaluated the effectiveness of different film-based visual simulation approaches on enhancing the pitch recognition (i.e., straight and breaking pitches) and location skills of collegiate baseball batters. After pilot testing the effectiveness of film simulation training, 36 collegiate baseball players were randomly assigned to a slow-motion film training group (Group 1), a real time film training group (Group 2), or a combination slow-motion and real time film training group (Group 3). All participants took part in four to six training sessions, each lasting approximately 45 min. They were then tested with the Visual Interruption System (V.I.S.), which allowed them to see only the first third of each pitch (approximately 14-20 ft.). Although no differences were found in the recognition of pitches (i.e., straight and breaking pitches), participants trained with slow motion film (Group 1) and real time film (Group 2) enhanced their ability to accurately locate pitches from pre- to posttest. No differences were found in the location scores of participants trained with combinational slow motion and real time film (Group 3) when compared to the other groups. The effectiveness of V.I.S and film-based training was promising for future research; however, results would have been strengthened if this type of training improved batting percentages during the competitive season.
In addition to her ice hockey studies, Lindley (1987) examined the effectiveness of perceptual training on shooting, passing, or dribbling in basketball situations. Advanced junior players were randomly assigned to perceptual training via slides or video, or a control group. After a total of 90 min of training over 4 days, improved pre- to posttest voice reaction times were found in the slide and video training groups; however, no differences were found in accuracy of decisions. Both slide and video training groups were then tested in an on-court transfer test with actual players arranged in stationary positions. No increases in the speed and accuracy of decisions were found in on-court situations.

Christina, Barresi, and Shaffner (1990) emphasized that football linebackers must perceive relevant cues generated by specific offensive players and use that information to respond appropriately in dynamic situations. Although previous research had used video- and film-based perceptual skills training designed from the point-of-view of the player, the effectiveness of this type of training had yet to be determined in the sport of football. The study was designed to determine if video-based perceptual skills training from the viewpoint of an outside linebacker enhanced response selection accuracy and speed in a laboratory simulation task. A senior outside linebacker on The Pennsylvania State University football team was selected to participate in a 4-week training program by the football coaching staff who noticed deficiencies in the player’s ability to accurately respond in game situations. During 16 training sessions (i.e., 8 practice and 8 test days were alternated), the participant received feedback after each practice consisting of response time, response error, and response correction, and was tested on 40-videotaped offensive plays each test day. No improvements were made in the speed of responses;
however, accuracy of responding improved over the 16 days of training. Christina et al. (1990) concluded that response selection accuracy could be improved significantly in a laboratory simulation as a result of video-based perceptual training. The fact that only one NCAA Division I outside linebacker with seven years of football experience achieved improvements does not clearly indicate training effectiveness. Moreover, repeating the same 20 plays twice during training and testing most likely represents learning effects, or even pure memorization, rather than effective training of perceptual skills. As with past research, evidence of the effectiveness of this perceptual skills training protocol for improving in-game performance would have strengthened these findings.

Starkes and Lindley (1991) conducted a video-based perceptual training experiment with female high school and university basketball players. Players receiving video perceptual training had faster posttest voice reaction times during video testing, and, unlike past research, had more accurate decisions. Starkes and Lindley (1991) evaluated varsity players performing live offensive sequences to determine if this type of training would transfer back to game situations. Upon predetermined moments, players would “freeze” their positions, allowing participants to make decisions on whether to shoot, pass, or dribble. As with prior on-court transfer tests, no improvements were made with regard to reaction times and accuracy of decisions. The lack of transference may have been due to the fact that participants were not involved in the on-court performance and only observed from the sideline, which may provoke declarative, but not procedural knowledge. Experts have developed greater declarative (i.e., context-specific knowledge) and procedural knowledge bases over many years of domain specific
experience (Starkes & Lindley, 1994). Declarative and procedural knowledge allows for more efficient access and retrieval of information from long-term memory. Video training that closely resembles real-life performances will increase procedural knowledge, but the problem lies in transference to real-time game play, which may only occur when the training elicits the same cognitive processes required in live competition (Starkes & Lindley, 1994). Therefore, transference may have less to do with how perceptual-cognitive skills are trained and tested and more about what perceptual-cognitive skills are being trained.

When one considers that the last two women’s World Cup Soccer Championships were decided by overtime penalty shoot-outs, it becomes readily obvious that the training of perceptual skills in goalkeepers is important. Williams and Burwitz (1993) proposed that goalkeepers use pre-performance cues provided during the opponent’s angle of approach and body orientation when addressing the ball to anticipate ball direction on penalty shots. A temporal-spatial filmed occlusion paradigm was used to evaluate how experienced \( n = 30 \) and inexperienced \( n = 30 \) soccer players anticipate ball direction. Experienced soccer players responded appropriately during earlier occlusion periods of 120 ms and 40 ms prior to impact compared to their inexperienced counterparts. Although the angle of approach, the arc of the leg approaching the ball, and the angle of the kicking foot and hip prior to contact were found to be important pre-performance cues, the most important cues were hip position and the lean of the trunk. A follow-up experiment determined whether the training of these pre-performance cues could enhance anticipation in beginner soccer players. Following approximately 90 min of video-based anticipation training, response accuracy improved across both response categories (i.e.,
shot direction and ball height). Although Williams and Burwitz (1993) concluded that
goalkeepers could make use of the pre-performance cues found in Experiment 1 and that
these behaviors of interest could be enhanced through video-based anticipation training,
findings were limited to the accuracy of goalkeepers’ movements, not the speed with
which they moved.

Extant research (Bard & Fleury, 1981; Goulet, Bard, & Fleury, 1989; Shank &
Haywood, 1987) has revealed that during reactive sport situations, expert athletes glean
the most relevant information from anticipatory cues when compared to novice athletes.
In tennis, Goulet, Bard, and Fleury (1989) found that expert tennis players predominantly
focused on the arm and racquet of their opponents, while novices fixated primarily on the
ball. Early research examining the effectiveness of training perception claimed
improvements in response selections. However, Singer et al. (1994) argued that training
protocols based solely on repeated exposure to pertinent task stimuli was insufficient
because better anticipation consisted of attending to relevant cues as well as
understanding the meaning behind those cues. Accordingly, they investigated whether
the training of tennis-specific anticipatory cues was more effective in predicting an
opponent’s intentions than simple exposure to repeated tennis situations. Male and
female beginning/intermediate tennis players were randomly assigned to “mental
quickness” training (i.e., experimental group) or “physical quickness” training (i.e.,
control group). Training consisted of three 20-min laboratory-based training sessions and
six 20-min on-court training sessions. The “mental quickness” group received feedback
on video-based training of serves, groundstrokes, and match play situations as well as
practiced appropriate decision making in a split-step movement task, while the “physical
quickness” group watched the same video with no feedback. During on-court training, the “physical quickness” group participated in agility drills and experimental participants were given formal instruction. Results revealed that the “mental quickness” trained participants made faster serve decisions than the “physical quickness” trained participants in laboratory assessment, and also improved their accuracy in predicting serve type and location from pretest to posttest. No differences were found in on-court evaluations. Future recommendation called for valid “real-time” assessment of perceptual training. However, the development of “real-time” assessments may not provide the answers to transferring improved laboratory-based perceptual training to live competition. Because these improvements failed to improve live performance, questions still arise with regards to the appropriateness of what is being trained and how to train it.

To determine whether attentional strategies could enhance the speed and accuracy of shuttlecock placement in novice badminton players, Taylor, Burwitz, and Davids (1994) attempted to train specific perceptual cues in both laboratory and field settings. Although experimental ($n = 8$) and control ($n = 8$) participants received equal durations of training (60 min), only the experimental group was taught which variables provided the most important information with regards to smashes, drop-shots, and drives. Laboratory conditions included video of an expert performer executing each shot, while field conditions consisted of participants viewing stroke-play performance by a “live” model. Results indicated improvements in movement initiation time (MIT) and accuracy posttest scores for the experimental group only. Significant differences in the MIT of perceptually trained participants existed in the field condition, but not in the laboratory setting. Taylor et al. (1994) suggested that the use of a “live” model performing in real-
time playing situations could be a viable method for training perceptual strategies. However, these data were limited in two primary ways: (1) no evidence toward improved on-court performance due to the fact that participants merely watched others performing during field conditions, and (2) the small sample size did not provide the power required to confirm the hypotheses.

In sum, the 1980s and early 1990s provided more elaborate methodologies, including an expansion of the type of perceptual skills trained and the environment in which they were trained. However, few studies produced improvements in response speed and accuracy (Singer et al., 1994; Starkes & Lindley, 1991), and the effectiveness of perceptual skills training remained inconclusive when applied to live competition.

The Late 1990s to the Present

Contemporary researchers have more specifically examined the differences between experts and non-experts as well as the transference of perceptual training to live, real-time performances. Unfortunately, the types of perceptual skills (e.g., pre-performance cues and anticipation) and the methodologies used to training these skills (e.g., video) have minimally advanced. As reviewed next, findings suggest that training pre-performance cues and anticipation may not elicit the appropriate and necessary perceptual-cognitive processes required in live dynamic sport competition.

Adolphe, Vickers, and Laplante (1997) evaluated on-court training of selective attention in elite volleyball players from an earlier study (Vickers & Adolphe, 1997) as well as the long-term (i.e., three years post training) effects of the training program on performance in international competitions. For visual attention to be altered, an individual must be able to “control the allocation of attention during performance of the skill, …[have] difficulty in fulfilling this potential, …[and show the capacity to]
overcome or diminish these difficulties with proper training” (Gopher, 1993, p. 299).

Adolphe, Vickers, and Laplante (1997) provided both expert and non-expert Team Canada volleyball receivers with a six-week visual attention training program to determine if improvements could be made in tracking and passing accuracy. After receiving video feedback and specific training of gaze behavior when receiving serve, five on-court training sessions were used to facilitate early detection and tracking of the ball. On-court training consisted of the following drills:

- Tracking and passing a tennis ball thrown over the receiver’s head off a wall.
- Tracking and detecting numbers and/or letters placed on the volleyball during ball flight.
- Tracking and detecting serves hit from behind a barrier.
- Tracking and detecting a serve after starting with their back to the court.
- Tracking, detecting, and accurately passing the volleyball to the setter.

Posttest was completed a month after training, and all participants improved from pre- to posttest in early tracking onset, longer tracking duration, and later tracking offset. After three years of international competitions, the Team Canada players assessed by Adolphe et al. (1997) improved their accuracy each year (1992, $M = 65\%$; 1993, $M = 69\%$; 1994, $M = 72\%$) compared to eight other international receivers (1992, $M = 65\%$; 1993, $M = 68\%$; 1994, $M = 61\%$) selected from the top-20 in the world. Although Adolphe et al. (1997) had limitations with regards to the influence of external factors, including different team coaches, amount of deliberate practice, and the number of competitions over the three years, and a small sample size, important training techniques lent correlational evidence to enhanced performance in real world settings. Video
feedback of gaze behaviors and the use of on-court visual attention training improved the attentional skills of these elite players, though performance improvement was mainly indexed by response accuracy, not response speed. Clearly, with greater deception in serving strategy (i.e., variations in speed, spin, and direction), receivers will require both faster and more accurate movements to respond effectively. To address this deception, research examined soccer penalty shots where players used deception to their advantage.

Franks and Harvey (1997) initially examined 138 penalty shots taken during FIFA World Cup competitions from 1982 to 1994. Expert goalkeepers only saved 14.5% of shots. More importantly, goalkeepers correctly predicted the direction of shots a mere 41% of the time, which is worse than chance suggesting the advantage is to the kicker who can misdirect and disguise shots. These findings initiated further analysis of penalty kicks in order to identify reliable response cues, which could be used to improve save percentages. Pre-performance cues consisted of starting position, angle of approach, forward and backward lean of the trunk, placement of the non-kicking foot, inward or outward knee rotation of the kicking leg prior to contact, and the point of contact with the striking foot (Franks & Harvey, 1997). Of these cues, placement of the non-kicking foot provided over 80% reliability of shot direction and provided goalkeepers with the longest amount of time (150ms to 200ms) to react after detection of foot placement. Franks and Harvey (1997) used the data obtained in their initial analysis to determine whether experienced soccer players and coaches trained with this information could accurately predict the direction of penalty shots. Participants (N = 18) were randomly assigned to an experimental group or a control group. During pre-testing, all participants viewed 100 penalty shots projected on a 4x6 ft screen. Video clips were occluded just prior to the
point of contact and reaction times and accuracy of responses were recorded. Both groups were then provided with 10 penalty kicks with no occlusion of shot direction; however, only the experimental group was trained on the importance of the placement of the non-kicking foot. Immediately following the intervention, all participants were post-tested on the same 100 penalty kicks. Results indicated that the experimental group improved in response accuracy from pre- to posttest; 63% to 77%, respectively. As for the speed of response, reaction times decreased for the control group, but increased for the experimental group. This finding is consistent with the amount of time allowed to react after detecting the trained cue (i.e., placement of non-kicking foot) causing the experimental group to respond slower. Although these findings lend evidence of the effectiveness of training pre-performance cues for predicting the direction of penalty shots, many dynamic sports require the perception and comprehension of more than one performance cue.

The need for fast and timely anticipation is best understood when considering the pace at which tennis professionals, like Andy Roddick, regularly serve. At only 23.77 m away, a serve traveling 193.1 km/h (120 mph) will take 0.58 s to cross the opponent’s baseline. Currently, Roddick holds the record for the fastest serve, set at 246.2 km/h (153 mph), giving fellow tour players 0.45 s to hit a return. Within that time, tennis players require at least 0.25 s to effectively and accurately choose between three possible service directions (e.g., down the center at the “T”, down the middle at the receiver, or out wide) (Abernethy, 1991). Furthermore, serves that require a player to move his or her body a considerable distance (e.g., serves hit down the center or out wide) call for even faster and more accurate responses.
Farrow, Chivers, Hardingham, and Sachse (1998) examined whether beginner tennis players could improve perceptual abilities through anticipation training. To examine the effects of anticipation training on physical performance in an ecologically valid testing environment, participants performed return of serve motions in front of a life-size video simulation of a player serving. Novice tennis players ($N = 24$), with no competitive experience, were randomly assigned to one of three groups (perceptual training, placebo, or control), and then pre-tested on 7 flat serves, 7 top-spin serves, and 7 slice serves. The perceptual training group and placebo group received two training sessions each week for four weeks. However, the perceptual training group viewed temporally occluded video while being training on specific anticipatory cues, whereas the placebo group viewed video tapes of professional tennis matches. Post-testing was completed with the same 21 serves used during the pre-test, but the video clips were re-ordered. The perceptual training group responded faster on post-test serves when compared to the placebo and control groups. As for response accuracy, no differences were found from pre- to post-test or between groups.

Farrow et al. (1998) proposed that “temporal occlusion coupled with only a verbal confirmation of the result may promote a bias towards decision speed at the expense of directional accuracy” (p. 240). Furthermore, their findings question the training potential of perceptual skills and the type of perceptual skills needed for dynamic, fast-paced sports. Improvements in response speed, while significant, were minimal (i.e., 3.27 s to 3.19 s), and more importantly, such response speeds would be too slow for serves hit at 64 and 120 km/h (40-75 mph: approximately 1,250 to 900 ms to cross the opponents baseline). Second, perceptually trained participants actually reduced their directional
accuracy during posttesting by over 23%. For perceptual training to prove effective in real-time events, improvements are needed in response speed and accuracy (see Ward et al., in press; Williams et al., 1999). One without the other provides little to no benefit to recreational athletes, not to mention elite athletes. Finally, findings may indicate that the type of training is not the problem, but the perceptual skills being trained (i.e., anticipation) are not those that limit the realization of expert performance in fast-paced sports.

Experts performing in dynamic sports rely heavily on perceptual skills to maximize their performance. Although researchers have delimited expert-novice differences in perceptual abilities, extensive research is required to determine the effectiveness of training these attributes and the effects that training has on competitive performance. Stine, Arterburn, and Stern (1982) emphasized that the value of perceptual training is threefold: (1) improvements in the sport of interest must directly relate to enhanced perceptual abilities; (2) training programs must improve specific perceptual skills and provide alternatives to physical practice; and (3) perceptual training must translate to improvements in real time performance.

When examining past perceptual training programs, Abernethy, Wood, and Parks (1999) argued that extant research contained methodological errors, which limit the application of these findings. Limitations consisted of the lack of placebo groups, the testing of speed and accuracy of responses causing a tradeoff and mixed results, and the lack of transference to real time sport settings. They addressed the first two limitations by examining whether novice athletes could develop anticipatory skills with a combination of video- and knowledge-based training, that are apparent in expert athletes.
Novice athletes ($N = 30$) with no competitive experience in any racquet sports were randomly assigned to one of three groups. The perceptual training group received 4 weeks of perceptual (four days per week) and motor (one day per week) training. Perceptual training consisted of specific anticipatory strategies while motor training focused on practicing the forehand drive in tennis. The placebo group received the same amount of training as the perceptual training group; however, training consisted of reading coaching manuals and watching past professional tennis matches. The control group was given only one training session each week on the forehand drive in racquetball. After responding to the same 160 video clips from pre-testing, results indicated that perceptual trained participants improved their prediction of stroke direction and stroke depth when compared to the placebo and control groups. Abernethy et al. (1999) revealed that under sound methodological designs, perceptual training (i.e., anticipation) could improve performance in video-based testing. Their recommendations echoed the need for validating on-court, live performance enhancements as well as reducing the speed-accuracy trade-off. Novices may have more room for improvement, but may be difficult to test in live performance due to their ability to express such procedural skills during competitive play.

Extant research examining the perceptual abilities of goalkeepers (Franks & Harvey, 1997; Williams & Burwitz, 1993) suggests that utilization of advanced cues allows for reliable prediction of penalty kicks. Pursuant to this mission, James and Hollely (2002) examined how alternate training of penalty kicks would affect goalkeeper’s abilities to predict penalty shots from differing visual cues. Video was taken of penalty kicks from four advanced soccer players. These players then received
two 60 min training sessions to develop a standardized penalty kick pattern, and were filmed again. The testing video consisted of 64 penalty shots (which included pre- and post-training kicks) with half occluded 200 ms prior to contact and the other half occluded at the point of contact. Participants included expert goalkeepers (n = 6) and outfield players with no goalkeeping experience (n = 6). Accuracy of response was the primary dependent measure.

James and Hollely (2002) found that the accuracy of prediction decreased from pre- to post- penalty kick training for both experts and outfielders. Thus, the alternate penalty kick training improved player’s ability to disguise the typically reliable advanced cues used by goalkeepers. In addition, findings revealed that the response accuracy of expert goalkeepers decreased from 50% to 37.5% on penalty shots occluded 200 ms prior to the point of contact. These findings lend further evidence to the fact that the perceptual skills and cognitive strategies that are necessary during externally paced sports must extend beyond training of single cues or anticipation alone. If the angle of approach, forward and backward lean of the trunk, or placement of the non-kicking foot will provide goalkeepers with over 80% reliability on shot direction (Franks & Harvey, 1997), it is inevitable that soccer players and coaches will train alternate techniques to hide or deceive goalkeepers. As such, future training must include perceptual-cognitive strategies that include more than training pre-performance cues only.

Although the training of perceptual skills has grown significantly over the past decade, Williams, Ward, Knowles, and Smeeton (2002) indicated that limited knowledge exists as to the underlying mechanisms of anticipation skills. To examine the measurement, training, and transference of anticipation skills, Williams et al. (2002)
examined the critical characteristics of anticipation and how those characteristics differed in skilled and less skilled tennis players (Experiment 1), and then used that information to develop a systematic training program with the intention of improving anticipation in less skilled players (Experiment 2).

In Experiment 1, eight skilled ($M = 23.0$ years, $SD = 7.3$) and eight less skilled ($M = 27.2$ years, $SD = 4.4$) male tennis players were required to perform simulated forehand and backhand groundstrokes (to four locations on the court) in response to a life-size image of an opponent hitting groundstrokes. The test film and procedures of this investigation followed the guidelines used by Singer et al. (1994); however, eye movements were recorded during the simulated test film. Participants received six practice and 16 test trials (8 forehand and 8 backhand), and the groundstrokes and locations of the opponents’ shots were randomized. Results of the anticipation test indicated that skilled players responded significantly faster (3,817 ms) than their less skilled counterparts (3,954 ms). No significant differences were found between groups in response accuracy (68.4% and 64.5%, respectively). As for the visual search behaviors, skilled tennis players spent significantly more time fixating on the head-shoulder and trunk-hip regions of the body when compared to the less skilled tennis players, who viewed more peripheral areas of the body. Skilled players also used these fixations more successfully, as indicated by less alternation of gaze between regions of interest. No significant differences were observed between groups in the average number of locations fixated, average number of fixations, and mean fixation duration per trial. These findings supported past visual search studies in tennis (e.g., Jones & Miles, 1978; Rowe & McKenna, 2001; Singer et al., 1996).
With the knowledge obtained from Experiment 1, Williams et al. (2002) examined the effectiveness of training the anticipatory strategies used by skilled players in less skilled performers. Similar to the less skilled group in Experiment 1, 32 recreational male tennis players were recruited for Experiment 2 and randomly assigned to one of the following four groups: (1) *explicit instruction*, which consisted of a 45 min video-based and 45 min field-based perceptual training outlining the specific advanced cues and their relationship to eventual shots (followed guidelines proposed by Abernethy et al., 1999 and Singer et al., 1994), (2) *guided discovery*, which followed the training set forth in the explicitly trained group; however, these participants were only directed to attend to the important cues, (3) *placebo*, which included a 45 min video on technical skills, or (4) *control*, which provided participants with no training. Participants were tested in the video-based laboratory assessment used in Experiment 1 as well as a field-based test against a male recreational tennis player.

Results of the laboratory test indicated a significant posttest difference in response accuracy for explicit instruction and guided discovery ($M = 72.1\%, \ SD = 15.6$) when compared to the placebo and control groups ($M = 58.9\%, \ SD = 14.0$). No significant differences were found in the decision times between the two experimental groups and the two control groups. Furthermore, no significant differences were observed in the decision times or response accuracy of explicitly trained participants against the guided discovery participants or between the placebo and control groups on the posttest. As for the field-based test, significant posttest differences were found in the decision times for explicit instruction and guided discovery ($M = 2,001, \ SD = 163.3$) when compared to the placebo and control groups ($M = 2,186, \ SD = 198.5$). No significant differences were
found in response accuracy between the two experimental groups and the two control groups. Similar to the laboratory findings, no significant differences were observed in the decision times or response accuracy of explicitly trained participants against the guided discovery participants or between the placebo and control groups on the posttest.

Williams et al. (2002) concluded perceptual skills training programs are effective, and that these skills developed in the laboratory are transferable to live environments. However, it should be emphasized that improvements were made in either decision times or response accuracy, and those improvements were minimal ($\leq 200$ ms faster and $\leq 6\%$ more accurate). Furthermore, improvements such as these cannot be considered “superior anticipatory performance” (p. 262, Williams et al., 2002) or the necessary “development of the underlying knowledge structures and skills” (p. 267, Williams et al., 2002) that will facilitate performance in real-world competitive situations given the extremely slow decision times (laboratory: $M = 3,870$ ms, field: $M = 2,006$ ms) in the experimental groups, and the response accuracy levels of control participants, which either matched or exceeded those of the experimental group (i.e., guided discovery). Finally, the lack of a follow up retention test makes it impossible to ascertain whether the improvements observed for the experimental groups were functionally significant learning effects or merely transient performance effects.

Farrow and Abernethy (2002) contested that the lack of clear evidence for the effectiveness of perceptual skills training in natural performance contexts, as well as several methodological issues (i.e., true experimental designs, ecological approaches that maintain the perception and action link, and training that improves sport performance), currently limits the applicability of perceptual training. Based on these concerns, Farrow
and Abernethy (2002) examined whether the cue sources used by expert athletes could be trained in less skilled individuals and retained over a 32 day unfilled interval. Intermediate junior tennis players \((N = 32)\) were randomly assigned to an explicit learning, implicit learning, placebo, or control group. Explicit perceptual training consisted of temporally occluded video-based footage of professional tennis players hitting serves. The relationship between specific advanced cues and the direction of the serve was explicitly trained according to previously identified expert visual search behaviors. Implicitly trained participants received the same temporally occluded video clips; however, were only asked to estimate the speed in which the opponent was serving. No indication was provided regarding specific informational sources. The placebo group watched professional tennis matches, and were asked to evaluate why a player was winning and within circumstance shot selections. The control group consisted of only weekly physical practices. Results indicated that implicitly trained participants significantly improved response accuracy from pre- to posttest; however, these improvements were not maintained on the 32 day retention test. The explicit, placebo, and control groups made no significant improvements following the intervention. Findings lend evidence to the potential effectiveness of implicit perceptual skills training, and the need for training that produces meaningful learning effects.

Extensive research examining the development of sport expertise has revealed the importance of motor development and perceptual and cognitive skills in high-level performance (Ericsson, 1996; Starkes & Ericsson, 2004). According to Williams, Ward, and Chapman (2003), key issues concern whether acquisition of perceptual and cognitive skills in sport can be facilitated through instructional techniques and practice. As cited in
prior research (Abernethy et al., 1999), limiting factors, such as methodological errors, the use of appropriate perceptual skills that develop expert performance, and suitable transfer tests to determine whether training improves real time competitive performance, warrant future empirical evaluation before perceptual training can be considered an effective, practical tool for coaches.

Accordingly, Williams et al. (2003) sought to determine if video-based anticipation training on a field hockey penalty flick could improve the on-field performance of field hockey goalkeepers. Participants were recruited from local and university field hockey teams. Outfield players \(N = 24\) with no goalkeeping experience (8.5 years, \(SD = 2.2\) of field hockey experience) were classified as novice participants. Participants who were randomly assigned to the training group received one on one instruction during one 45 min session. During this time, participants viewed videotape of 20 penalty flicks and were trained on the most vital cues underpinning anticipation (e.g., orientation of the stick face and foot placement). In addition, participants were required to indicate penalty flick direction on 10 video clips that were temporally occluded six frames after ball contact and on 10 video clips that were occluded at the point of contact. The placebo group received the same duration of training; however, participants watched an instructional video on goalkeeping skills. The control group received no instruction. Upon completion of training, participants were tested in a laboratory- and field-based assessment of anticipatory performance. The laboratory test included a life-sized video image of four female national level players performing 20 penalty kicks. Dressed in full gear, participants were instructed to respond as quickly and accurately as possible to each video clip while a camera recorded their performance. In the field test, the same four
national players attempted 20 “live” penalty flicks on each participant. Again, each performance was recorded for analysis of response speed and accuracy. Results indicated that only the training group reduced reaction times in both the laboratory- and field-based tests. No improvements in accuracy were made in any group and in either condition. Williams et al. (2003) concluded that the anticipatory skills developed in the laboratory with video simulation training effectively transferred to “live” on-field performance for novice field hockey goalkeepers. However, the pace of the game is considerably higher for experts. Thus, improvements need to be achieved in both response speed and accuracy. Future research should determine how to design, implement, and evaluate such programs.

Williams, Ward, Smeeton, and Allen (2004) have shown the use of in situ perceptual skills training as a means of improving live, on-court anticipation skills in young adult tennis players ($M_{\text{age}} = 21.7$, $SD = 1.5$ years). Through established on-court measures involving frame-by-frame video analysis (Williams & Grant, 1999; Williams, Ward, & Chapman, 2003), perception-action and perception-only trained participants received 45 min of on-court anticipation skills training, which followed the same protocols set forth by Abernethy et al. (1999) and Singer et al. (1994). The only differences between these two experimental groups were that the perception-action participants physically moved to intercept serves while perception-only participants verbally indicated where the serve was hit in the service box (e.g., left or right). Perception-action and perception-only groups recorded significantly faster response times when compared to the technical training group. Although the experimental groups significantly improved response initiation times from pre- to posttest (pretest: 1,437 ms,
posttest: 998 ms and pretest: 1,492 ms, posttest: 1163 ms, respectively), no improvements were made in response accuracy across all groups. Williams et al. (2004) concluded that anticipation skills could be improved with the use of perception and action as well as using perceptual judgment only, and “…perceptual training should be specific to the functional demands placed upon the visual system in the performance context” (p. 358).

Smeeton, Williams, Hodges, and Ward (2005) also found significant laboratory- and field-based improvements in anticipation skills by incorporating video-based perceptual skills training similar to that used by Singer et al. (1994). Junior tennis players ($M$ age = 10.6, $SD$ = 1.1 years) receiving explicit or guided discovery perceptual training improved decision times quicker than discovery trained participants; however, during anxiety laden situations, explicitly trained participants showed significant declines in decision times when compared to those in the guided discovery and discovery groups.

Most recently, Ward et al. (in press) reviewed the similarities and differences between the perceptual-cognitive and decision skills training research being conducted in the fields of sport psychology, expert performance, human factors, and military psychology. Although the ability to efficiently and reliably gather, sort, and process massive amounts of information and respond appropriately under changing situations is critical to performance outcomes in all dynamic sport and military environments, Ward et al. (in press) emphasized that little to no cross examination has been conducted on how to train these skills. Moreover, the perceptual-cognitive skills trained in military research have lacked the evidence-based practice approach to training, which has been the hallmark of the sport psychology literature (Williams & Ward, 2003).
According to Ward et al. (in press), military psychology and human factors researchers have incorporated multiple skills (e.g., operator decision-making, situation awareness, critical thinking, and stress- and event-based training) to develop the perception and cognition of individuals performing in dynamic situations; however, few of these studies have utilized objective assessments, evaluation, or validation of such training in “real-world” environments. In an attempt to inform military research, Ward et al. (in press) suggested that future research should move beyond training content knowledge and empirically examine training that improves such behaviors causing improvements in real-time competitive situations. Furthermore, the most appropriate factors that enhance both response speed and accuracy needed to be determined.

In accord with Ward et al. (in press) and after examining past perceptual-cognitive training protocols, Caserta and Singer (in press) proposed that dynamic sport situations required more than any singular factor (e.g., anticipation, pattern recognition, or decision-making) could provide. In an effort to most effectively train perceptual-cognitive skills in tennis match play situations, the most relevant perceptual constructs from military psychology were combined with those from the field of sport psychology. By merging the recommendations of these related bodies of literature, Caserta and Singer (in press) developed a combinational intervention, including situation awareness, anticipation, and decision-making, to provide empirical evidence of the effects of perceptual-cognitive skills training in dynamic situations.

Human factors researchers have focused significant effort toward understanding how fighter pilots, challenged by similar dynamic environments to those encountered in sport, efficiently process potentially massive amounts of information in air combat and
reliably respond under these conditions. The development of a multidimensional concept, namely situation awareness, provided direction towards explaining, measuring, and training this perceptual-cognitive skill. Situation awareness is defined as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley, 1988, p. 97). In sport competitions, situation awareness includes being prepared for events that may occur predictably or even unpredictably with time to react while understanding the benefits and/or costs of actions decided upon (Endsley & Garland, 2000). When age-related declines occur in physical capabilities, temporal pressures are increased, causing older athletes to rely more heavily on perceptual and cognitive skills. Otherwise stated, the need to perceive and program appropriate responses quickly must be maximized among older athletes to counter the inevitable slowing of physical response capabilities that occurs due to aging. Indeed, one could argue that efficiency of perception and response selection is therefore most critical to high-level performance among aging athletes relative to younger competitors.

Endsley (1995) developed a model of situation awareness (Figure 2-3) as a means of depicting the most influential factors that exist in dynamic settings and the role situation awareness plays in those environments. The state of the environment constantly provides performers with relevant information, which forms the basis of situation awareness. Based on relevant cues, levels of situation awareness directly affects appropriate decisions and, in turn, drives performance outcomes. Each experience produces a feedback loop that advances the knowledge base of situation awareness. The
outer layer of the core has several specific factors that directly influence situation awareness, decision-making, and performance.

Figure 2-3. Model of situation awareness in dynamic decision-making. Adapted from Endsley, M. (1995). Toward a theory of situation awareness in dynamic systems. Human Factors, 37, 32-64.

Individual differences exist in the ability to acquire situation awareness given the functional levels of information-processing mechanisms, which are directly influenced by one’s abilities, experience, and training. In addition, the goals, objectives, and expectations of a performer affect the interpretation of the environment and assist in forming situation awareness and decision-making. Finally, the workload, stress, and complexity of the environment may play a role in affecting situation awareness, decision-making, and performance outcomes (Endsley, 1995).
Researchers examining complex environments where situation awareness is essential to peak performance (e.g., flying a plane, surgery, and air traffic control) have identified three levels of situation awareness (Endsley, 1988). Level 1 consists of the perception of essential cues. Large amounts of available information require individuals to learn how to inhibit the processing of irrelevant cues so as to efficiently identify and respond to only the most relevant ones. More specifically, individuals must become adept at visually determining what cues are present, the absolute and relative location of these cues, as well as the speed in which the cues are moving (i.e., temporal-spatial aspects). Problems in perception have been traced to problems with cognitive processes. The lack of this fundamental perceptual ability has been found to produce 76% of situation awareness errors in pilot performance (Jones & Endsley, 1996).

Level 2 situation awareness deals with comprehension, which encompasses how individuals combine, interpret, store, and retain perceived information. By combining and interpreting the most relevant information, individuals develop a heightened awareness of expected and, more importantly, unexpected decisions made by an opponent. Every dynamic situation has key leverage points that allow an individual to take control of a situation. Leverage points are temporally and spatially defined within dynamic environments, and are a key function in expertise. Attaining Level 2 situation awareness enhances responsiveness to these leverage points. For a fighter pilot, the leverage points are the opportunity to seize control of a dogfight with a perfectly timed tactical maneuver. For a tennis player, the leverage points are the shots that players attack hitting down-the-line to pressure their opponent. Jones and Endsley (1996) found that 20% of situation awareness errors among pilots occur at the comprehension level.
These errors are about a consequence of a lack of understanding of what to do with the cues that have been recognized.

Finally, Level 3 situation awareness, the highest level of understanding, consists of the propensity to predict future situation events and dynamics. The ability to *project* from past knowledge to current and future situations impacts the temporal-spatial aspects of the performance, including the timing of situation-specific actions and the decisions that are made under duress. Although future events and outcomes remain highly unpredictable, expert performers who tap into this third level of situation awareness have a distinct advantage over the competition. Ultimately, the third level of situation awareness appears to be where elite level performers in any domain are distinguished from others.

Caserta and Singer (in press) used situation awareness training in a video-based simulation to examine the effectiveness of multidimensional perceptual training on tennis match play situations. Unlike previous research, multiple perceptual-cognitive strategies were combined to train these skills. Intermediate male and female tennis players were recruited from university undergraduate tennis classes as well as local area tennis clubs, and were provided only 30 min of training. Experimental participants were provided with situation awareness and anticipation training or situation awareness, anticipation, and decision-making training, whereas the control group received general information regarding NCAA I, II, and III as well as NAIA collegiate tennis. The results indicated that participants trained with combinational situation awareness, anticipation, and decision-making training had significantly faster response times, and on average, 10% more accurate scores than all other participants across both singles and doubles.
situations. When examining the response speed of experimental groups, response speeds were the fastest in participants trained with situation awareness, anticipation, and decision-making, who averaged 1,563 ms, compared to participants who received situation awareness and anticipation training or general information regarding collegiate tennis, who averaged 1,845 ms and 2,302 ms, respectively. The fast response speed of participants trained with situation awareness, anticipation, and decision-making provided support for training situation awareness as well as multiple cognitive training strategies, which may contain all the factors necessary in dynamic sports. The effectiveness of this type of training also provided empirical evidence for the use of military-based perceptual skills in combination with those from the sport psychology literature; however, continued research is needed to provide further support for the effectiveness of combinational perceptual-cognitive skills training towards improving live on-court situations.

**Conclusions and Future Directions**

In this paper, I have attempted to provide a comprehensive review of the perceptual training research in sport. The training of perceptual skills in sport was humbly initiated in 1955 where training principles were adopted from strategies used during World War II. The last 50 years has seen advancement in sport specific perceptual training, but sport scientists interested in perceptual training are now combining their efforts with those in the military psychology community to identify the most effective means of training perceptual-cognitive skills. Clear documentation of the most appropriate perceptual-cognitive skills to enhance the response speed, accuracy, and decisions of dynamic sport athletes remains necessary and elusive. That being the case, my review of the perceptual training literature has revealed the following:
**Speed vs. accuracy.** Perceptual training has improved response speed or directional accuracy, but rarely (Singer et al., 1994; Starkes & Lindley, 1991) has it improved both. While the speed/accuracy trade-off is inevitable, training insufficient (or the incorrect) perceptual skills may cause improvements to be limited to only faster or more accurate responses. Research on expert and non-expert performers across multiple sports would seem to support this explanation. Future perceptual-cognitive skills training should focus on improving both response speed and accuracy;

**Video vs. photographs vs. life models.** Video-based training of perceptual skills has been more effective in increasing performance on laboratory tests when compared to still photographs and life models. Video-based training or dynamically moving life models may provide the perception-action coupling that is required during open-skills;

**Laboratory vs. field.** Significant improvements in perceptual skills (e.g., pre-performance cues, anticipation, attention) have been typically found during laboratory-based tests of perception, while few field-based tests have been able to recreate these results. Although developing ecologically valid laboratory-based tests have proven difficult for researchers, the perceptual training programs have followed similar designs to the laboratory tests. Perceptual training that was similar to laboratory testing may have been susceptible to learning effects due to the same video clips being used. In addition, the field-based tests used to test transference have poor ecological validity since static situations have been employed;

**Speed vs. real-time settings.** Response speeds gathered during posttests may reveal significant training effects; however, these speeds are often slower than the pace of even recreational sport situations. Improvements must be contextualized and considered
based on their importance in real-life sport contexts, and as previously stated, may require both decreased response speeds while increasing response accuracy;

**Methodological errors.** Research designs have not included appropriate placebo and control groups, making it difficult to attribute significant findings to effective training. The lack of retention tests also makes it difficult to determine whether training produced significant learning effects or merely transient performance effects. In addition, studies have often included small samples, and have yielded small effect sizes;

**Unidimensional constructs.** To date, perceptual training interventions have only included single cognitive strategies. Training only unidimensional constructs, such as pattern recognition, anticipation, or visual cues, limits the complexity of perception and the potential efficiency of the information processing systems, particularly among experts. Additionally, the use of procedural tasks where the responses to the cues are more realistic (i.e., move-to-return) would be more advantageous for mapping into real responses as well as improved learning and memory. Training multiple perceptual skills would likely lead to greater improvements in speed and accuracy (see Caserta & Singer, in press) as well as transference to real-time performance, as compared to those training standards used to date.

From past research examining the skilled-based differences in anticipation and decision-making, Williams et al. (1999) summarized the following characteristics of expert performers: (1) pattern recognition during play is faster and more accurate; (2) quick and accurate recognition of the most relevant performance cues; (3) accurate prediction of opponents actions through the use of pre-performance cues; (4) enhanced knowledge of situational probabilities and player tendencies; (5) freed attentional
processing improves tactical decisions; (6) complex knowledge-base of procedural matters; and (7) enhanced self-monitoring skills. Perceptual-cognitive training programs must be developed to foster all of these characteristics and with various levels of participants.

Future research should be directed to examining the most appropriate perceptual-cognitive strategies that most effectively enhance perceptual abilities, and, more importantly, transfer to improved performance in real-time, competitive situations. Furthermore, support is needed for training that improves both the speed and accuracy of responses (see Caserta & Singer, in press; Ward et al., in press; Williams et al., 1999). Finally, previous researchers have focused their training efforts mostly on young adult, novice populations. Considerations need to be given toward understanding how such training affects different age groups and ability levels, specifically older adults who are less likely to benefit from or dedicate time to physical development. Because cognitive declines typically occur with aging, the benefits of perceptual-cognitive skills training may extend sport involvement and influence the health and quality of life of older adults.
CHAPTER 3
METHOD

Participants

Intermediate/advanced skilled senior male ($M = 68.38$ years old, $SD = 6.13$) and female ($M = 60.21$ years old, $SD = 7.51$) tennis players over the age of 50 were recruited from local tennis clubs in Central Florida and prescreened on the Mini-Mental State Examination (MMSE) prior to participating in this study. Players were required to compete on a regular basis in local, club, or United States Tennis Association (USTA) sanctioned leagues, events, or tournaments and have a National Tennis Rating Program (NTRP) certified rating. The NTRP is a definitive skill rating system used by the USTA. Ratings range from 1.0 (novice) to 7.0 (tour player) and increase in 0.5 increments. The average experience level of the participants ranged between 3.5 and 4.0, which categorized them as intermediate to advanced tennis players. The project was approved by institutional IRB and written informed consent was obtained prior to participation.

Materials and Measures

Video Camcorder

To accurately analyze data and reduce the gross error rates produced by consumer grade video camcorders, a production quality, professional digital video camcorder (Canon GL2; Jamesburg, NJ) with a shutter speed of 1/15,000 sec (performing at a capture rate of 201.5 Hz) was used to record pre- and posttest matches as well as retention test matches. The sample rate of the camera was accurate to within ± 2.5 ms. Such minimal error allowed for heightened measurement accuracy.
Mini-Mental State Examination (MMSE)

The MMSE (Folstein, Folstein, & McHugh, 1975) is a brief standardized screening test that quantitatively assesses severity of cognitive impairment (i.e., mild, moderate, and severe). Considered to be the gold standard, the MMSE has been used extensively with geriatric patients, and consists of 11 questions assessing orientation, registration, attention, recall, and language, which can be easily administered in approximately 10 min. Although the MMSE should not be used as a stand-alone diagnostic tool for identifying dementia, validity and reliability analyses show excellent sensitivity to cognitive impairments without differing across gender. Concurrent validity of the MMSE was significantly correlated with the Wechsler Adult Intelligence Scale Verbal IQ (Pearson $r = 0.776, p < 0.0001$) and Performance IQ (Pearson $r = 0.660, p < 0.001$), and scores were not significantly different when examining 24 hr or 28 day test-retest reliability (Pearson $r = 0.827$; Pearson $r = 0.980$, respectively) by single or multiple examiners (Folstein, Folstein, & McHugh, 1975).

Situation Awareness Global Assessment Technique (SAGAT)

Developed to assess each component of SA (e.g., Level 1 SA, Level 2 SA, and Level 3 SA), the SAGAT (Endsley, 1987) is an objective tool that queries performers during a full spectrum of simulated events. The SAGAT assesses the perceptions of dynamic performers in real-time rather than making post hoc inferences from behavioral observations or subjective self-ratings, and provides an immediate, detailed understanding of SA and the qualities that positively or negatively affect performance. The effectiveness of this technique lies in the development of queries; however, such queries must be based on the aspects that are most vital to the SA of a performer. To
determine these aspects, a goal-directed task analysis (see Table 3-1) was necessary to define the SA requirements for a particular situation.

**Table 3-1. Format of Goal-Directed Task Analysis**

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<thead>
<tr>
<th>Goal</th>
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<tr>
<td>Sub-goal</td>
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<tr>
<td>Decision</td>
</tr>
<tr>
<td>Level 3 SA – Forecast Future Situation Events</td>
</tr>
<tr>
<td>Level 2 SA – Comprehension and Integration of Cues</td>
</tr>
<tr>
<td>Level 1 SA – Perception of Pertinent Cues</td>
</tr>
</tbody>
</table>

In general, the analysis consists of the major goals of the task along with identifying the sub-goals that support these major goals. Each sub-goal is achieved through appropriate decision-making, which is supported by all three levels of SA. These analyses have been created for a variety of performers, including air traffic controllers, fighter pilots, bomber pilots, commercial airline pilots, and aircraft mechanics; however, such analyses have yet to be developed for athletes. Therefore, Table 3-2 provides a specific outline of the goal-directed task analysis that will be used to create the queries for senior tennis players performing in singles match play situations.

**Table 3-2. Goal-Directed Task Analysis for Singles Tennis Matches**

<table>
<thead>
<tr>
<th>Groundstrokes</th>
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<tbody>
<tr>
<td>Maintain rally</td>
</tr>
<tr>
<td>Controlling the point</td>
</tr>
<tr>
<td>• Play conservative</td>
</tr>
<tr>
<td>• Attack down-the-line</td>
</tr>
<tr>
<td>• Open up the court</td>
</tr>
<tr>
<td>• Induce unforced errors</td>
</tr>
<tr>
<td>• Level 3-Type of shot selection hit in specific situations</td>
</tr>
<tr>
<td>• Level 3-Direction of shot selection hit in specific situations</td>
</tr>
<tr>
<td>• Level 2-Cue zone speed and amount of rotation</td>
</tr>
<tr>
<td>• Level 2-Early or late point-of-contact</td>
</tr>
<tr>
<td>• Level 1-Playing side trunk-shoulder region and point-of-contact</td>
</tr>
</tbody>
</table>
Table 3-2. Continued

Approach Shots
Approach and effectively cover the net
Dictate play
• Approach down-the-line
• Approach deep or short
• Attack opponent’s weak side
  • Level 3-Type of shot selection hit in specific situations
  • Level 3-Direction of shot selection hit in specific situations
    • Level 2-Cue zone speed and amount of rotation
    • Level 2-Early or late point-of-contact
  • Level 1-Playing side trunk-shoulder region and point-of-contact

Volleys
Reduce the time and ability to cover the court
Dictate play and shorten points
• Use angles
• Hit short or deep
• Hit behind the opponent
  • Level 3-Type of shot selection hit in specific situations
  • Level 3-Direction/depth of shot selection hit in specific situations
    • Level 2-Cue zone speed and amount of rotation
    • Level 2-Early or late point-of-contact
  • Level 1-Playing side shoulder and point-of-contact

The goal-directed task analysis for singles tennis matches was specifically developed relative to the video-based simulation used to assess each level of SA. An expert in perceptual-cognitive skills training and tennis confirmed the relevance and appropriateness of these goal-directed tasks (i.e., groundstrokes, approach shots, and volleys) during a previous study in which the current video-based simulation was effectively used to assess perceptual-cognitive skills training (Caserta & Singer, in press).

Implementation. The SAGAT was administered through a video-based simulation presented on an 867 Mhz PowerBook G4 with 640 MB of DDR SDRAM. A total of 36 video clips was selected from NCAA Division I tennis matches, as they illustrate
technically correct strokes, effective decisions, and rallies that last longer than three shots. To accurately assess the SA of a participant during groundstrokes, approach shots, and volleys, each of the three levels were tested in four match play situations across each of the shot types. The 36 video clips were viewed in random order for the pretest, posttest, and retention test. Each video clip was recorded from behind the baseline, and was play for a random number of shots. Detail instructions were provided regarding how to use the video-based simulation, the temporal “freezing” of video clips, and how to answer each query. Participants were individually tested and three practice clips were used to clear up any questions about answering the queries. As recommended by Endsley (1987), participants received one point for a correct response and no points for an incorrect response.

**Posttest Questionnaire**

A posttest questionnaire was used to acquire general demographic information, including gender, age, number of years in tennis, NTRP rating, and visual acuity. Also, questions were included to address participant’s confidence in their ability to make quick and accurate decisions as well as their ability to adapt to changing match situations when competing in singles tennis matches.

**Tennis Log**

Participants were given a tennis log to track the number of days and total hours played (excluding training for the study) during the intervention and the 6-week retention interval. As a means to increasing statistical control and improving internal validity, the tennis log was examined for group differences to be used as a covariate. By partialing out the effects of independent practice, more specific understanding may be gained regarding the effectiveness and retention of the training protocol.
**Procedure**

**Prescreening**

To specifically examine the effects of perceptual-cognitive skills training on older athletes with cognitive impairments, all participants were prescreened on the MMSE prior to participating in the study to identify those with cognitive impairments and to determine the severity of such impairments. Participants scoring 25 points and higher were classified as non-cognitively impaired, those scoring between 20 and 24 points were classified with mild cognitive impairments, and those scoring 19 points and lower were classified with moderate/severe cognitive impairments, which are the standard criteria for the MMSE according to Folstein, Folstein, and McHugh (1975). Participants then played against an independent tennis professional for approximately 10 min. To confirm NTRP ratings and experience, two independent tennis professionals assessed each participant during this time. Following prescreening, participants were randomly assigned according to gender, ability, and level of cognitive impairment to one of the following four groups: (1) multidimensional perceptual-cognitive skills training (MPCT), (2) traditional anticipation-only training (AT), (3) technique-footwork training (TFT), or (4) control. Each of the four groups initially included four men and ten women.

<table>
<thead>
<tr>
<th>Table 3-3. Final Participant Characteristics According to Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>MPCT</strong></td>
</tr>
<tr>
<td>(n = 12)</td>
</tr>
<tr>
<td><strong>AT</strong></td>
</tr>
<tr>
<td>(n = 12)</td>
</tr>
<tr>
<td><strong>TFT</strong></td>
</tr>
<tr>
<td>(n = 13)</td>
</tr>
<tr>
<td><strong>Control</strong></td>
</tr>
<tr>
<td>(n = 13)</td>
</tr>
</tbody>
</table>

* No impairment (25-30); Mild Impairment (20-24) as determined by the MMSE.
Although an equal number of participants were randomly assigned to each of the training groups, six participants voluntarily dropped out of the study due to time constraints. A power analysis indicated an adequate sample size for this investigation. The final participant characteristics are outlined in Table 3-3.

Pretest

Participants were told that the study was designed to examine how well senior tennis players compete in singles tennis matches, and then provided with detailed instructions for responding to the SAGAT. Participants were individually tested on the SAGAT and responses were recorded in written form. Upon completion of the SAGAT, each participant was individually pretested in a 4-game singles match. Previous research with senior tennis players (Caserta, Young, & Janelle, in press) confirmed the use of a 4-game match primarily because many tennis players in this population play a limited amount of singles and often suffer from physical ailments, making it difficult to sustain quality play for more than 4 games. Each 4-game match was played against one of the control participants of equal ability and experience. The control participants had no prior knowledge of the training provided within each group or participant group affiliation, which ensures objectivity of testing. Competing against an opponent of equal ability also provided consistency and reliability of performance across matches, assured that each match was competitive, and increased the ecological validity of the experiment. The video camcorder was setup near the back fence in the middle of the tennis court behind the participant to provide the optimal viewing angle for data analysis.

Experimental Treatment

Following the pretest, the researcher met with each participant individually to provide group specific training. Group-specific, standardized instructions were provided
to the participants on-court in a one-on-one setting to help maximize the effects of training. The MPCT, AT, and TFT participants met for training during five consecutive sessions. Participants unable to meet on consecutive training days were not allowed more than one day between meetings. All instructions were presented through video and on-court demonstrations and drills with the researcher. Specifics on the training protocols used with each of the four groups follows.

**Multidimensional Perceptual-Cognitive Skills Training (MPCT)**

On the first day of training, MPCT participants learned what situation awareness is, how vital situation awareness is to rapidly changing situations specifically for tennis, and information about the three levels that make up situation awareness. Specifically, they were told that Level 1 situation awareness consists of attending to the cue zone, which represents the most important cues or relevant information during a point. The cue zone consists of the opponents’ body alignment (hip, trunk, and shoulder region), racquet angle at the point-of-contact, and court positioning. Next, the instructor explained that Level 2 situation awareness creates meaning of the cue zone as well as the situation in regards to personal goals for winning the point. For example, when the playing side hip, trunk, and shoulder regions rapidly move through the hitting zone causing the point-of-contact to be ahead of the body, shots are hit crosscourt. Conversely, delaying or slowing the hip, trunk, and shoulder regions causes the point-of-contact to be late and dictates a shot hit down-the-line (straight) or inside out. Finally, participants learned how Level 3 situation awareness consists of the ability to use this information to predict the opponent’s intended shots in the future as if automatically.

On Day 2, after a brief review of situation awareness, participants received tennis specific instruction on these three levels. For Level 1 situation awareness, participants
were instructed on how to direct attention to the cue zone when the opponent was hitting starting with court positioning and body alignment, and concluding with the racquet angle at the point of contact. Because the cue zone varies slightly for groundstrokes, approach shots, volleys, and serves, practice was provided for all four areas. Participants were then provided with on-court rallying to develop cue utilization aptitude. Training to comprehend what these cues mean in relation to the situation (i.e., Level 2 situation awareness) then followed. Level 2 training included learning how to interpret the opponent’s court positioning, body alignment before contact, timing of cue zone, and the racquet angle at the point-of-contact. The remainder of Day 2 consisted of crosscourt, down-the-line drills with the understanding that the development of better situation awareness begins as a conscious process, but with continued practice becomes an automated process that utilizes Level 3 situation awareness to project to future situations.

Day three consisted of combining anticipation with situation awareness. Instructions were designed to prepare participants for singles match play situations as well as anticipate opponent cues that typically indicate tendencies and intentions. For example, participants learned how to determine the strengths and weaknesses of their opponent, attend to situations where their opponent prefers to hit passing shots or lobs, attack down the line or crosscourt, and how to anticipate deception. In addition, training emphasized avoiding over anticipation by relying on situation awareness to guide the anticipation process.

On the fourth day of training, performance-based decision-making was emphasized. Instructions explained how situation awareness is the precursor to accurate decision-making, and that decisions made without situation awareness would be similar
to random selection. The objective was to create decisions that allow participants to dictate play and conserve energy. By learning what performance decisions to make as to the best shots to hit in specific situations, participants increase their ability to control play, cover the court, and win points. For example, hitting an approach shot down-the-line, as opposed to crosscourt, allows a player to more easily cover passing shots and conserves energy while placing pressure on the opponent to create openings and cover more court. In addition, participants learned what performance decisions can exploit the weaknesses of their opponents as well as how to use deception to take advantage of ineffective perceptual and decision-making skills. To achieve this, baseline, approach shot/volley, and serve/return drills were used to recreate singles match play situations. Following each drill, both appropriate and inappropriate decisions were discussed with regards to dictating play, conserving energy, and winning points. Participants were informed that the outcome of each decision made allows for greater understanding of where to go, what to do when they get there, and ultimately what decisions will provide them with the most success in the future. Further explanation was provided on how expert players process the most relevant information quickly and accurately as well as execute the best decisions out of the available options as if automatically.

Finally, Day 5 included review of situation awareness, anticipation, and decision-making strategies as well as preparing to use these newly acquired strategies in singles match play situations. Strategic breakdown of practice points, in terms of situation awareness, anticipation, and decision-making, ensured that each participant was applying these skills to their game. Questions about situation awareness, anticipation, and decision-making strategies were answered at the end of each training session.
Traditional Anticipation-Only Training (AT)

Extant research examining the effectiveness of perceptual skills training has focused on the development of anticipation skills. To accurately train anticipatory skills and maintain the qualitative integrity of past training, AT was structured according to the guidelines and procedures implemented by Abernethy et al. (1999), Singer et al. (1994), and Williams et al. (2004). Strict adherence to the aforementioned protocols was vital to assessing the differences between multidimensional and traditional perceptual-cognitive programs with regards to the effectiveness of improving perceptual-cognitive skills and increasing successful performance outcomes.

As with the MPCT, AT was conducted during on-court and video-based training over 5 consecutive sessions. The use of on-court perceptual skills training has been shown to improve anticipation as well as promote a perception and action link (e.g., Singer et al., 1994; Williams et al., 2002; Williams et al., 2004). Formal instruction consisted of anticipation skills training designed specifically for tennis, and was based on the following key components: (a) training on the biomechanics of the forehand and backhand groundstrokes, approach shots, volleys, and serves, specifically the proximal-to-distal development of stroke kinematics (see Abernethy et al., 1999; Williams et al., 2004); (b) training on visual search patterns and cue detection as well as expert-novice differences with regards to these skills (see Abernethy et al., 1999; Singer et al., 1994; Williams et al., 2004); (c) practice in focusing on informational cues and verbally responding to subsequent response requirements in on-court situations (see Abernethy et al., 1999; Williams et al., 2004); (d) practice in focusing on informational cues as well as deciding quickly what will happen in temporally occluded video clips (see Abernethy et al., 1999; Singer et al., 1994); and (e) practice anticipating and physically returning shots.
in live on-court point play as opposed to verbally responding. The five components were trained, respectively, one each lesson over five half hour lessons. The AT video clips were selected from NCAA Division I tennis matches and consist of groundstroke, approach shot, and volley situations. Each video clip was temporally occluded at the point of contact at which time three choices were displayed where the opponent could potentially hit the ball. Feedback was provided throughout the intervention, and questions regarding anticipation strategies were answered at the end of each training session.

**Technique-Footwork Training (TFT)**

TFT participants were trained on multiple stroke techniques as well as the corresponding on-court footwork used to increase the physical skills and movement required to compete in singles match play. When compared to MPCT and AT, the TFT had similar quantity and duration of training. During the TFT, instructions were provided to improve forehand and backhand groundstrokes, approach shots, volleys, overheads, and serves as well as the corresponding footwork that complement each stroke.

On the first and second days of training, TFT participants learned how to improve the consistency of forehand and backhand groundstrokes through faster preparation. Participants were instructed that early racquet preparation should occur prior to the ball passing the net. To further improve stroke consistency and power, participants learned the appropriate point-of-contact on all groundstrokes, which is slightly in front of the leading foot on the forehand and one-handed backhand and even with the leading foot on the two-handed backhand. Finally, the corresponding footwork required for groundstroke rallies included recover steps following forehand and backhand groundstrokes and
utilizing open stance footwork to conserve energy and more effectively cover the court in singles match play.

On Day 3, participants received advance training on approach shots. Along with reiterating the importance of early preparation and the appropriate point-of-contact, TFT participants learned how to drive and slice forehand and backhand approach shots. After developing the technical skills necessary to hit such shots, participants also learned where to split-step to optimally cover the net on passing shots. The corresponding footwork included learning how to avoid running through the hitting zone as well as incorporating a carioca step on slice approach shots. For volleys, participants were taught how to use a continental grip to hit both forehand and backhand volleys, which according to the USPTR curriculum not only simplifies volleying, but also dramatically improves overall effectiveness and efficiency at net. Footwork consisted of seven techniques that allow players to react to all possible net exchanges. These techniques included no footwork at all, a quick side step, a crossover step, a side/crossover step combination, a small side step with the opposite foot, right foot behind, and stepping into the ball.

On the fourth day of training, the focus was on developing advanced serve and return of serve techniques. TFT participants learned the most effective grip, point-of-contact, leg drive, and follow through for the flat serve and the slice serve as well as how to increase the pace and directional accuracy of both serves. As for return of serves, both the drive and chip return were explained for forehand and backhand shots. Footwork again focused on the recovery steps following a return of serve.

Finally, Day 5 included a review of any stroke and/or footwork technique, and most importantly, practice games assisted participants with transferring these newly acquired
skills to live singles play. No mention of situation awareness, anticipation, or decision-making was included in these instructions.

**Control**

Participants received no training or instruction; however, they were allowed to play and/or compete during the time between pretest and posttest.

**Posttest**

All training lasted approximately 30 min per session. Within one day following the five training sessions, each participant was posttested on the SAGAT and in another 4-game singles match against the same previously assigned control group participant from the pretest. At the conclusion of the 4-game match, participants completed the MMSE and posttest questionnaire.

**Retention Test**

Following the six-week retention phase, participants were tested a third time on the SAGAT, played another 4-game singles match against the same control group participant from the pretest and posttest, and completed the MMSE one final time. A long-term retention test, as opposed to an abbreviated interval (i.e., 24 hrs), was used to determine the extent to which functional learning of perceptual-cognitive skills could be maintained. Farrow and Abernethy (2002) have made the only previous attempt to determine the extent to which acquired perceptual skills have actually been retained over time. They incorporated a long-term unfilled retention interval (32 day). I therefore included an extended retention period so as to reasonably compare my findings to theirs.

**Data Reduction**

Relevant data were extracted from pretest, posttest, and retention test video analysis, which was conducted by two experts on perceptual-cognitive skills who also
had extensive background in the game of tennis. Each 4-game singles match was initially examined to eliminate irrelevant points that did not exhibit the need for perceptual-cognitive skills, which included double faults and missed returns. In addition, points where either player was inside the service line (e.g., net points and most approach shots) were excluded due to the discrepancies in distance when compared to serves and groundstrokes. Upon determining the points to be analyzed, the two experts individually coded response speed, response accuracy, and performance decision-making according to the predetermined set of criteria (see description of dependent measures). To ensure that the differences in response speeds were due to training and not the speed in which players were hitting the ball, the duration from the point-of-contact to the ball intersecting the net was calculated to determine differences in speed of play across groups. These values were calculated during the video analysis, and were determined by the relative distance between the baseline and the net. Because only one video camera was used, a potential error of $+0.066 \text{ ms}$ may have occurred. If differences in the speed of play existed, the duration from the point-of-contact to the ball intersecting the net was used as a covariate to partial out these effects on the response speeds of participants. If differences existed in the total number of hours practiced over the intervention or 6-week retention intervals, independent practice was also used as a covariate. An intraclass correlation (ICC) was used to assess the inter-rater reliability scores of the two raters across response speed, response accuracy, and performance decision-making. An ICC $>.80$ was considered outstanding inter-rater reliability.

Dependent measures of interest included the following:
Response Speed

Response speed was operationalized as the time period from the point-of-contact to the initiation of the participants’ first step in the correct direction of the ensuing shot. For example, the first response time was calculated from the point-of-contact of the opponents’ serve and conclude upon the initiation of the participants’ first step in the correct direction to properly return the serve. The next response time was calculated from the point-of-contact of the opponents’ ensuing shot (e.g., groundstroke) and again concluded upon the initiation of the participants’ first step in the correct direction to properly return this shot. Response speeds were analyzed using Final Cut Pro video editing software, which when combined with the production quality video provided response times accurate to ± 2.5 ms. Perceptual-cognitive skills often afford tour tennis players with the ability to move in the correct direction before their opponent has even made contact with the ball. For this reason, movements made prior to the point-of-contact were analyzed as a negative time.

Response Accuracy

Response accuracy consisted of the percentage accuracy of on-court movement in relation to tracking toward the ensuing shot hit by the opponent. Participants were given one point for correctly moving in the appropriate direction and no points for moving in the wrong direction. For example, the first response accuracy point was given if the participants moved in the correct direction to properly return the opponents’ serve. After returning serve, the participant received another point for moving in the correct direction for the opponents’ ensuing shot (e.g., groundstroke). Furthermore, participants received no points for starting in the wrong direction and then correcting this error or movements that were initiated 1,000 ms after the point-of-contact regardless of direction. Corrected
movements are not related to effective use of perceptual-cognitive skills, and these skills of interest are not necessary after the ball has traveled past the net (1,000 ms and up is typical of this ability level).

Performance Decision-Making

Performance decision-making was operationalized as the appropriateness of the participants’ shot selections according to court positioning, percentages, situation, and shot hit by the opponent. For senior tennis players, maintaining physical stamina by controlling the point is essential to the outcome of matches, especially during singles matches. High-level performance decision-making allows players to dictate points causing their opponents to expend greater energy throughout the match. Participants received one point for choosing appropriate performance decisions and no points for inappropriate performance decisions. Appropriate decisions were operationalized as shots hit by the participant that dictate play, promote efficiency of court coverage, and increase the percentage of winning points.

Statistical Analysis

Cognitive Functioning Analyses

First, a mixed model 2 x 4 x 3 (Cognitively Impaired, Non-Cognitively Impaired x MPCT, AT, TFT, Control x Pretest, Posttest, Retention) multivariate analysis of variance (MANOVA), with repeated measures on the third factor, was conducted to examine if the cognitive functioning of participants differed in group-specific training during pretest, posttest, and retention test when examining the total score as well as the five subscale scores (i.e., orientation, registration, attention, recall, and language) of the MMSE. Significant main effects for the Group factor were followed by Tukey’s HSD procedures.
to specify the locus of the effects. Simple effects tests with Bonferroni corrected alpha levels were used to evaluate significant interactions.

**Performance Analyses**

To determine the relative similarity of groups prior to the primary performance analyses, separate one-way independent groups ANOVAs were conducted to determine if group differences existed in the speed of play and the total number of independent practice hours.

Next, a mixed model 2 x 4 x 3 (Cognitively Impaired, Non-Cognitively Impaired x MPCT, AT, TFT, Control x Pretest, Posttest, Retention) MANOVA, with repeated measures on the third factor, was conducted to examine if the cognitive functioning of participants across group-specific training differed in response speed, response accuracy, and performance decision-making during pretest, posttest, and retention test. Significant main effects for the Group factor were followed by Tukey’s HSD procedures to specify the locus of the effects. Simple effects tests with Bonferroni corrected alpha levels were used to evaluate significant interactions.

A second mixed model 2 x 4 x 3 (Cognitively Impaired, Non-Cognitively Impaired x MPCT, AT, TFT, Control x Pretest, Posttest, Retention) MANOVA, with repeated measures on the third factor, was conducted to examine if the cognitive functioning of participants across group-specific training differed in the total scores on the SAGAT as well as Levels 1, 2, and 3 SA during pretest, posttest, and retention test. Significant main effects for the Group factor were followed by Tukey’s HSD procedures to specify the locus of the effects. Simple effects tests with Bonferroni corrected alpha levels were used to evaluate significant interactions.
Finally, a third mixed model 2 x 4 x 3 (Cognitively Impaired, Non-Cognitively Impaired x MPCT, AT, TFT, Control x Pretest, Posttest, Retention) MANOVA, with repeated measures on the third factor, was conducted to examine if the cognitive functioning of participants across group-specific training differed in the percentages of points and games won during pretest, posttest, and retention test singles match play situations. Significant main effects for the Group factor were followed by Tukey’s HSD procedures to specify the locus of the effects. Simple effects tests with Bonferroni corrected alpha levels were used to evaluate significant interactions. The critical p-value was set at .05.
Cognitive Functioning

Determining initial differences in cognitive functioning across group training was necessary to evaluate the influence training had on such deficits. A mixed model 2 x 4 x 3 MANOVA was conducted to determine if cognitively impaired and non-cognitively impaired participants in the four training groups differed across the five subscales and total score on the MMSE during pretest, posttest, and retention test. Significant main effects for cognitive functioning (Wilks’ $\lambda = .36, F(5, 38) = 13.54, p < .001, \eta^2 = .64$) and pre/post/retention test (Wilks’ $\lambda = .24, F(9, 34) = 12.07, p < .001, \eta^2 = .76$) emerged. Important to note, no significant main effect was found between MPCT, AT, TFT, and control participants with respect to their total scores on the MMSE (Wilks’ $\lambda = .59, F(5, 40) = 1.48, p > .05$). Therefore, each group had an equal representation of cognitively and non-cognitively impaired participants. The main effects, however, were superceded by a significant cognitive functioning x group training interaction (Wilks’ $\lambda = .51, F(5, 40) = 1.96, p < .03, \eta^2 = .20$) and a significant cognitive functioning x pre/post/retention test interaction (Wilks’ $\lambda = .44, F(9, 34) = 4.74, p < .001, \eta^2 = .56$).

Follow-up univariate simple effects tests, for the cognitive functioning x group training interaction, confirmed significant mean differences for the overall level of cognitive functioning (total score on the MMSE) between those with and without cognitive impairments (MPCT: $F(1, 42) = 13.72, p < .001$; AT: $F(1, 42) = 34.11, p <$
.001; $TFT: F(1, 42) = 21.88, p < .001$; $Control: F(1, 42) = 30.79, p < .001$) as well as in the level of attention ($MPCT: F(1, 42) = 7.80, p < .008$; $AT: F(1, 42) = 14.75, p < .001$; $TFT: F(1, 42) = 21.02, p < .001$; $Control: F(1, 42) = 19.60, p < .001$). With regards to overall level of cognitive functioning and levels of attention, non-cognitively impaired participants scored significantly higher than those who where cognitively impaired across all four groups. Furthermore, follow-up univariate simple effects tests, for cognitive functioning x pre/post/retention test, confirmed significant mean differences for the overall level of cognitive functioning (total score on the MMSE) between those with and without cognitive impairments ($Pretest: F(1, 42) = 97.65, p < .001$; $Posttest: F(1, 42) = 9.23, p < .004$; $Retention test: F(1, 42) = 19.80, p < .001$) as well as in the level of attention ($Pretest: F(1, 42) = 61.01, p < .001$; $Retention test: F(1, 42) = 6.85, p < .01$). During pretest, posttest, and retention test, non-cognitively impaired participants had significantly higher overall cognitive functioning than those who where cognitively impaired. For level of attention, non-cognitively impaired participants scored significantly higher than those who where cognitively impaired during pretest and retention test (see Table 4-1).

**Performance**

Controlling for the speed of play and amount of independent practice was necessary for analyzing and interpreting the performance findings. Matches in which players are rallying at different speeds directly influence response speed, response accuracy, and performance decision-making. For example, faster play may promote the need to respond faster and negatively affect the accuracy of that response while limiting the ability to choose the best decision available. In addition, the amount of independent practice can affect learning and retention.
Table 4-1. Pretest, Posttest, and Retention Test Mean Scores and Standard Deviations for Scores on the MMSE as a Function of Cognitive Impairment

<table>
<thead>
<tr>
<th>Group</th>
<th>Total</th>
<th>Orientation</th>
<th>Registration</th>
<th>Attention</th>
<th>Recall</th>
<th>Language</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Pretest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Cognitively Impaired (n = 34)</td>
<td>*26.85 (1.52)</td>
<td>9.06 (1.01)</td>
<td>3.00 (0.00)</td>
<td>*4.03 (1.29)</td>
<td>2.38 (0.78)</td>
<td>8.38 (0.60)</td>
</tr>
<tr>
<td>Cognitively Impaired (n = 16)</td>
<td>*22.56 (1.15)</td>
<td>8.50 (0.97)</td>
<td>3.00 (0.00)</td>
<td>*1.25 (0.86)</td>
<td>2.06 (1.00)</td>
<td>7.75 (0.68)</td>
</tr>
<tr>
<td>Posttest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Cognitively Impaired (n = 46)</td>
<td>**27.83 (1.22)</td>
<td>9.04 (0.79)</td>
<td>3.00 (0.00)</td>
<td>4.80 (0.65)</td>
<td>2.61 (0.65)</td>
<td>8.37 (0.68)</td>
</tr>
<tr>
<td>Cognitively Impaired (n = 4)</td>
<td>**22.50 (1.29)</td>
<td>8.25 (0.50)</td>
<td>3.00 (0.00)</td>
<td>1.75 (0.96)</td>
<td>2.00 (1.41)</td>
<td>8.00 (0.82)</td>
</tr>
<tr>
<td>Retention Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Cognitively Impaired (n = 47)</td>
<td>*27.47 (1.76)</td>
<td>9.43 (0.74)</td>
<td>3.00 (0.00)</td>
<td>**4.04 (1.43)</td>
<td>2.68 (0.63)</td>
<td>8.32 (0.78)</td>
</tr>
<tr>
<td>Cognitively Impaired (n = 3)</td>
<td>*20.67 (1.53)</td>
<td>7.00 (1.00)</td>
<td>3.00 (0.00)</td>
<td>**0.67 (0.58)</td>
<td>2.67 (0.58)</td>
<td>7.33 (0.58)</td>
</tr>
</tbody>
</table>

Note. Non-Cognitively Impaired = no impairment (25-30); Cognitive Impairment = mild impairment (20-24) as determined by the MMSE; Total = 30 total points; Orientation = 10 total points; Registration = 3 total points; Attention = 5 total points; Recall = 3 total points; Language = 9 total points; * p < .001; **p < .01.
Accordingly, separate one-way independent groups ANOVAs examining group differences in the speed of play and the total number of independent practice hours yielded no significant differences between MPCT, AT, TFT, and control participants with respect to the speed of play (Pretest: \( F(3, 46) = 1.12, p > .05 \); Posttest: \( F(3, 46) = 2.47, p > .05 \); Retention test: \( F(3, 46) = .97, p > .05 \); Overall: \( F(3, 46) = 1.91, p > .05 \)) and the amount of independent practice (Week of Training: \( F(3, 46) = .83, p > .05 \); 6-Week Retention Period: \( F(3, 46) = .33, p > .05 \)). Therefore, the speed of play and the total number of independent practice hours were not used as covariates (see Tables 4-2 and 4-3).

Table 4-2. Pretest, Posttest, Retention Test, and Total Mean Scores and Standard Deviations for the Speed of Play (ms) as a Function of Training

<table>
<thead>
<tr>
<th>Group</th>
<th>Pretest M (SD)</th>
<th>Posttest M (SD)</th>
<th>Retention Test M (SD)</th>
<th>Total M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPCT (n = 12)</td>
<td>520 (23.11)</td>
<td>515 (14.05)</td>
<td>517 (22.21)</td>
<td>517 (17.32)</td>
</tr>
<tr>
<td>AT (n = 12)</td>
<td>504 (22.49)</td>
<td>502 (13.13)</td>
<td>509 (23.43)</td>
<td>505 (14.72)</td>
</tr>
<tr>
<td>TFT (n = 13)</td>
<td>516 (28.06)</td>
<td>513 (16.87)</td>
<td>516 (23.56)</td>
<td>515 (18.31)</td>
</tr>
<tr>
<td>Control (n = 13)</td>
<td>508 (21.89)</td>
<td>504 (13.60)</td>
<td>503 (24.36)</td>
<td>505 (16.26)</td>
</tr>
</tbody>
</table>

Note. MPCT = multidimensional perceptual-cognitive skills training; AT = anticipation-only training; TFT = technique-footwork training.

Prior to examining group differences in response speed, response accuracy, and performance decision-making, an intraclass correlation (ICC) was used to assess the inter-rater reliability scores of the two raters. ICC values were > .80 (response speed = .913, response accuracy = .917, and performance decision-making = .878) indicating outstanding inter-rater reliability and limited variance in video analysis. To evaluate differences in the effectiveness of the respective training protocols, a mixed model 2 x 4
MANOVA yielded significant main effects for group training (Wilks’ $\lambda = .06$, $F(3, 42) = 23.45$, $p < .001$, $\eta^2 = .61$) and pre/post/retention test (Wilks’ $\lambda = .19$, $F(6, 37) = 26.61$, $p < .001$, $\eta^2 = .81$). More importantly, a significant group training x pre/post/retention test interaction (Wilks’ $\lambda = .10$, $F(6, 39) = 7.63$, $p < .001$, $\eta^2 = .55$) was observed.

<table>
<thead>
<tr>
<th>Group</th>
<th>Week of Training $M (SD)$</th>
<th>6-Week Retention Period $M (SD)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPCT ($n = 12$)</td>
<td>6.71 (5.90)</td>
<td>27.25 (15.83)</td>
</tr>
<tr>
<td>AT ($n = 12$)</td>
<td>4.35 (4.22)</td>
<td>26.52 (14.15)</td>
</tr>
<tr>
<td>TFT ($n = 13$)</td>
<td>4.85 (3.89)</td>
<td>22.30 (9.85)</td>
</tr>
<tr>
<td>Control ($n = 13$)</td>
<td>4.07 (4.05)</td>
<td>27.84 (20.62)</td>
</tr>
</tbody>
</table>

*Note.* MPCT = multidimensional perceptual-cognitive skills training; AT = anticipation-only training; TFT = technique-footwork training; Week of Training = time period during 5 training sessions.

Follow-up univariate simple effects tests confirmed significant mean differences for response speed (*Posttest:* $F(3, 46) = 78.36$, $p < .001$; *Retention test:* $F(3, 46) = 53.18$, $p < .001$), response accuracy (*Pretest:* $F(3, 46) = 3.20$, $p < .05$; *Posttest:* $F(3, 46) = 87.72$, $p < .001$; *Retention test:* $F(3, 46) = 75.89$, $p < .001$), and performance decision-making (*Posttest:* $F(3, 46) = 111.68$, $p < .001$; *Retention test:* $F(3, 46) = 42.96$, $p < .001$). During pretest, the control group responded significantly more accurately than the AT and TFT group. For posttest and retention test, the MPCT significantly improved response speed, response accuracy, and performance decision-making (see Table 4-4) when compared to AT, TFT, and no training (see Figure 4-1, 4-2, and 4-3). Important to note, no significant cognitive functioning x pre/post/retention test interaction was found, which ensured that
no preexisting differences influenced the performance findings. Specifically, no significant differences were found between levels of cognitive impairment with respect to response speed, response accuracy, and performance decision-making during pre/post/retention test.

![Graph showing response speed](image1)

**Figure 4-1.** Mean ($\pm$ SE) response speed (ms) as a function of training group and pre/post/retention test.

![Graph showing response accuracy](image2)

**Figure 4-2.** Mean ($\pm$ SE) response accuracy (%) as a function of training group and pre/post/retention test.
To specifically examine the improvements in situation awareness and evaluate the differences/similarities of situation awareness and anticipation, a second mixed model 2 x 4 x 3 MANOVA was conducted to determine if cognitively impaired and non-cognitively impaired participants in the four training groups differed in the total scores on the SAGAT as well as Levels 1, 2, and 3 during pretest, posttest, and retention test. Significant main effects for group training (Wilks’ $\lambda = .13$, $F(3, 42) = 14.32$, $p < .001$, $\eta^2 = .50$) and pre/post/retention test (Wilks’ $\lambda = .19$, $F(6, 37) = 26.95$, $p < .001$, $\eta^2 = .81$) emerged. The main effects, however, were superceded by a significant group training x pre/post/retention test interaction (Wilks’ $\lambda = .15$, $F(6, 39) = 5.71$, $p < .001$, $\eta^2 = .47$).
Table 4-4. Pretest, Posttest, and Retention Test Mean Scores and Standard Deviation for Measures of Perceptual-Cognitive Ability as a Function of Training

<table>
<thead>
<tr>
<th>Group</th>
<th>Response Speed (s)</th>
<th></th>
<th>Response Accuracy (%)</th>
<th></th>
<th>Performance Decision-Making (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
<td>Retention</td>
<td>Pretest</td>
<td>Posttest</td>
<td>Retention</td>
</tr>
<tr>
<td></td>
<td>$M$ ($SD$)</td>
<td>$M$ ($SD$)</td>
<td>$M$ ($SD$)</td>
<td>$M$ ($SD$)</td>
<td>$M$ ($SD$)</td>
<td>$M$ ($SD$)</td>
</tr>
<tr>
<td>MPCT ($n = 12$)</td>
<td>.949 (.06)</td>
<td><strong>.621 (.06)</strong></td>
<td>**.651 (.06)</td>
<td>.40 (.06)</td>
<td><strong>.91 (.08)</strong></td>
<td>**.89 (.05)</td>
</tr>
<tr>
<td>AT ($n = 12$)</td>
<td>.972 (.08)</td>
<td>.938 (.09)</td>
<td>.919 (.05)</td>
<td>.34 (.14)</td>
<td>.39 (.10)</td>
<td>.44 (.08)</td>
</tr>
<tr>
<td>TFT ($n = 13$)</td>
<td>1.021 (.08)</td>
<td>.979 (.06)</td>
<td>.928 (.09)</td>
<td>.33 (.09)</td>
<td>.36 (.12)</td>
<td>.42 (.11)</td>
</tr>
<tr>
<td>Control ($n = 13$)</td>
<td>.963 (.07)</td>
<td>.941 (.06)</td>
<td>.910 (.05)</td>
<td>*.44 (.10)</td>
<td>.39 (.09)</td>
<td>.37 (.13)</td>
</tr>
</tbody>
</table>

Note. MPCT = multidimensional perceptual-cognitive skills training; AT = anticipation-only training; TFT = technique-footwork training; Response Speed = seconds; Response Accuracy = %; Performance Decision-Making = %; * $p < .05$; **$p < .001$. 
Follow-up univariate simple effects tests confirmed significant mean differences for overall SA \((\text{Posttest}: F(3, 46) = 59.78, p < .001; \text{Retention test}: F(3, 46) = 43.15, p < .001)\), Level 1 SA \((\text{Posttest}: F(3, 46) = 58.90, p < .001; \text{Retention test}: F(3, 46) = 38.33, p < .001)\), Level 2 SA \((\text{Posttest}: F(3, 46) = 3.51, p < .05)\), and Level 3 SA \((\text{Posttest}: F(3, 46) = 6.59, p < .001; \text{Retention test}: F(3, 46) = 4.60, p < .01)\) (see Figure 4-4, 4-5, 4-6, and 4-7, respectively). With regards to overall SA, the MPCT and AT group had significantly higher SA than the TFT and control group during both post- and retention tests; however, the MPCT group had significant higher SA when compared to all other groups during those two time periods. For Levels 1 and 3 SA, similar results occurred during posttest and retention test. Finally, the MPCT and control groups had significantly higher Level 2 SA when compared to the AT group.

![Figure 4-4. Mean (± SE) overall level of situation awareness, according to the SAGAT, as a function of training group and pre/post/retention test.](image)

Figure 4-4. Mean (± SE) overall level of situation awareness, according to the SAGAT, as a function of training group and pre/post/retention test.
Figure 4-5. Mean (± SE) level 1 of situation awareness, according to the SAGAT, as a function of training group and pre/post/retention test.

Figure 4-6. Mean (± SE) level 2 of situation awareness, according to the SAGAT, as a function of training group and pre/post/retention test.
Previous perceptual skills training studies have failed to examine whether improved perceptual skills effectively translated to a higher percentage of winning. Improving perceptual-cognitive skills is important; however, increasing sport performance outcomes is vital to such intervention-based investigations. Therefore, group differences in the percentage of points and games won were examined. The final mixed model 2 x 4 x 3 MANOVA yielded significant main effects for group training (Wilks’ $\lambda = .69, F(3, 42) = 2.84, p < .02, \eta^2 = .17$); however, more importantly, a significant group training x pre/post/retention test interaction (Wilks’ $\lambda = .43, F(4, 41) = 3.20, p < .001, \eta^2 = .24$) emerged. Follow-up univariate simple effects tests confirmed significant mean differences for the percentage of points won (Posttest: $F(3, 46) = 4.25, p < .01$; Retention test: $F(3, 46) = 12.90, p < .001$), and the percentage of games won (Retention test: $F(3, 46) = 17.29, p < .001$). Participants in the MPCT group won a significantly higher percentage of points than participants in the TFT group during posttest; however,
participants in the MPCT and AT groups won a significantly higher percentage of points when compared to participants in the TFT and control groups during the retention test. With regards to games won, participants in the MPCT and AT groups also won a significantly higher percentage of games when compared to participants in the TFT and control groups during the retention test (see Figure 4-8 and 4-9).

Figure 4-8. Mean (± SE) points won (%) as a function of training group and pre/post/retention test.

Figure 4-9. Mean (± SE) games won (%) as a function of training group and pre/post/retention test.
CHAPTER 5
DISCUSSION

Extant research has provided clear evidence that perceptual skills (i.e., pre-performance cues and anticipation) are trainable; however, these studies have focused solely on training perceptual-cognitive skills in junior and young adult athletes and only one study has examined whether the training of such skills produced functionally transferable and enduring learning effects (Farrow & Abernethy, 2002). Although these investigations have examined different methods to develop anticipatory skills, few have assessed the effectiveness of alternative perceptual-cognitive skills and how such skills influences performance outcomes. Therefore, the purpose of this investigation was to examine the training and maintenance of perceptual-cognitive skills in senior tennis players, specifically in real-time, live competitive environments where the transference of these skills has been difficult to replicate. The use of a multidimensional perceptual-cognitive skills training program, which included situation awareness, anticipation, and decision-making, was compared to the traditional anticipation-only training to delineate the importance of independent or combinational efforts. A six-week retention test was used to determine the degree to which acquired skills were learned. Beyond development and maintenance of the skills of interest, I determined whether a multidimensional perceptual-cognitive, an anticipation-only, or a technique/footwork development approach would more effectively increase performance outcomes in aged athletes.
Perceptual-Cognitive Training and Performance Outcomes

As hypothesized, senior tennis players trained with multidimensional perceptual-cognitive skills improved in the speed of their responses (Pretest: 949 ms, Posttest: 621 ms), the accuracy of their movements (Pretest: 40%, Posttest: 91%), and the appropriateness of their decisions (Pretest: 32%, Posttest: 83%) during live on-court singles matches, when compared to players receiving anticipation-only training, technique-footwork training, or no training. Importantly, the performance levels attained by individuals in the multidimensional training group far surpassed the speed (Posttest: 938 ms), accuracy (Posttest: 39%), and decisions (Posttest: 38%) of those trained with anticipation only. Considering that players at this ability level are hitting groundstrokes between 64 and 120 km/h (40-75 mph), allowing between 1,250 to 900 ms to cover the court, the aforementioned response speeds provide a distinct advantage. Most notably, the speed, accuracy, and decisions in which MPCT players attained following training remained over a six-week retention period (Response speed: 651 ms, Response accuracy: 89%, Decision-making: 74%) indicating functional learning effects occurred from the multidimensional based perceptual-cognitive training program.

To more specifically evaluate the processes responsible for these performance improvements, overall SA as well as each individual level of SA was assessed with the SAGAT. Although senior tennis players trained with AT had higher overall levels of awareness than those receiving TFT or no training, players trained with MPCT achieved higher overall awareness than all other groups. When examining Levels 1, 2, and 3 SA, the MPCT players attained a greater ability to selectively attend to vital cues (Level 1) and project from current experiences to future dynamic situations during the match (Level 3) compared to all others. MPCT also produced slightly greater comprehension of
vital cues and responsiveness to leverage points (Level 2) when compared to players in the AT. Although not the main purpose of the study, the direct assessment of SA provides insight into the effectiveness of training and how future studies may utilize the SAGAT. Alternate forms of the SAGAT (i.e., life-size video simulation, 3D simulation, or field-based measurements) are necessary to better understand Levels 1, 2, and 3 SA. Testing participants on a laptop may have limited the potential comprehension of vital cues (Level 2 SA) and projection of that information to future situations (Level 3 SA).

As for the performance outcomes, players provided with MPCT won a greater percentage of points (83%) immediately following training when compared to those receiving technique/footwork training (57%). However, following the six-week retention period, both the MPCT and AT players won a greater percentage of points (90% and 82%, respectively) as opposed to their TFT and control counterparts (60% and 53%, respectively). With regard to the percentage of games won, players receiving MPCT and AT again won a greater percentage of games (81% and 69%, respectively) when compared to those receiving TFT or no training (33% and 19%, respectively) following the six-week retention period. Although no significant differences existed between MPCT and AT, the multidimensional perceptual-cognitive approach produced 12% more games won. Important to note, the performance measures indicated gross improvements in the response speed, response accuracy, and performance decision-making of MPCT participants and no improvements for the AT group. However, the outcome measures indicated a higher percentage of points and games won for both perceptually trained groups. The following two reasons may have contributed to this finding: (1) outcome percentages may have been simply due to the participants assigned to the MPCT and AT
groups, or (2) the game determining points were when perceptually trained participants responded quickly and accurately due to heightened attention focus. Yet, the speed and accuracy of the MPCT as well as the heightened decision-making may have allowed for the slightly higher overall winning percentages.

The current findings replicate recent work that has demonstrated the effectiveness of training perceptual-cognitive skills (Abernethy, Woods, & Parks, 1999; Caserta & Singer, in press; Farrow et al., 1998; Grant & Williams, 1996; Scott et al., 1998; Singer et al., 1994; Smeeton et al., 2005; Williams & Ward, 2003; Williams et al., 2002; Williams et al., 2004), especially with aged athletes (Caserta, Young, & Janelle, in press). However, our results extent the existing database in novel and noteworthy ways. First, robust evidence for the effectiveness of multidimensional perceptual-cognitive training was provided over singular based strategies (e.g., anticipation) with this population. As with previous research examining the perceptual-cognitive skills training of senior tennis players (Caserta et al., in press), improvements in speed, accuracy, and decision-making were made during real-time, live tennis matches; however, the current players responded, on average, 53 ms slower. The higher average age recruited for this study (Male: $M = 68.38$ years old, $SD = 6.13$; Female: $M = 60.21$ years old, $SD = 7.51$), as compared to those recruited by Caserta et al. (in press) (Male: $M = 62.50$ years old, $SD = 8.44$; Female: $M = 56.59$ years old, $SD = 8.53$), may have contributed to the slower response speeds. The combined SA and anticipation training in the MPCT again produced drastic improvements in both response speed and accuracy. Although there may be times where the speed/accuracy tradeoff is more important to the situation, tennis players in this
population will benefit most from moving quickly and accurately due to the enhanced court coverage and extra time permitted to make the best performance decisions.

To date, only Farrow and Abernethy (2002) have examined whether the training of cue sources in tennis players could be retained over time. Implicit training improved response accuracy; however, these improvements were not maintained on the 32 day retention test. Farrow and Abernethy (2002) contested that the lack of clear evidence for the effectiveness of perceptual skills training in natural performance contexts, as well as several methodological issues (i.e., true experimental designs, ecological approaches that maintain the perception and action link, and training that improves sport performance and produces meaningful learning effects), currently limits the applicability of perceptual training and thereby contributed to the lack of retention. Our data, however, lend strong evidence that perceptual-cognitive skill based performance improvements can be retained over a six-week period if the training integrates important aspects of SA training.

Researchers (e.g., Abernethy, 1987 and Williams et al., 1992) have long argued that although multiple variables (i.e., physical endurance, quickness, execution, technical skill) influence the outcome of dynamic sports, the key to success may lie in the level of perceptual-cognitive expertise. Our findings lend clear evidence that higher levels of perceptual-cognitive expertise were a critical determining factor in the successful performance of senior tennis players, especially when considering that random assignment was based on ability and level of cognitive impairment and those players receiving MPCT won 81% of the games in which they played. This success may be attributed to the three levels of SA and the decision-making component of the
multidimensional approach, which provides a comprehensive set of perceptual tools necessary to compete and succeed in dynamic sports.

**Effects on Cognitive Aging**

An additional aim of this investigation was to determine whether perceptual-cognitive skills training provided ameliorating effects on age-related declines in cognitive functioning. Cognitively impaired and non-cognitively impaired participants differed in *overall cognitive functioning* during pre-, post-, and retention test and in *attention* during pre- and retention test. Out of the five subscales on the MMSE (e.g., orientation, registration, attention, recall, and language), the *attention* subscale provides direct information on the ameliorating effects perceptual-cognitive training has on age-related cognitive functioning. Furthermore, results indicated that participants receiving MPCT were the only group in which all members scored in the non-cognitively impaired range on *overall cognitive functioning* and *attention* during posttest and retention test.

Recently, interest has grown regarding how aged athletes retain expert perceptual-motor performance (Starkes, Cullen, & MacMahon, 2004; Starkes et al., 1999, 2003; Weir et al., 2002) as well as acquire or enhance perceptual-cognitive skills (Caserta et al., in press). However, by focusing on the perceptual-cognitive domain, important links can be made to the cognitive functioning of older adults and how the development and retention of such skills can influence dynamic life activities. Although previous findings (Caserta et al., in press) showed the potential of training these skills in senior tennis players with mild cognitive deficits, my current findings lend specific evidence to the potential ameliorating effects of perceptual-cognitive training on attentional deficits. As with previous cognitive training research (Ball et al., 2002; Kramer, Larish, & Strayer, 1995; Roenker et al., 2003; Sifrit et al., 2001; Wood et al., 2005), the improvement and
retention of response speed, response accuracy, and decision-making in MPCT participants showed an increased ability to perform multiple tasks, increased cognitive processing speed, and heightened selective attention to relevant cues. By improving the perceptual-cognitive skills necessary to perform in any dynamic physical task, older adults may maintain and benefit from such active lifestyles through transference of these skills to other activities of daily living.

Summary and Future Directions

In summary, multidimensional perceptual-cognitive skills, specifically situation awareness and decision-making, were beneficial to improving the speed and accuracy of movement as well as the performance decisions of senior tennis players in real-time, competitive tennis matches. Current findings lend evidence to the importance of what perceptual-cognitive skills are being trained. The response speeds attained (Posttest: 621 ms) by MPCT participants provide distinct advantages for this age group (overall age: $M = 62.82$ years old, $SD = 8.02$) and ability level (NTRP 3.5 to 4.0). However, senior tennis players who are older or younger than this group and have NTRP ratings above 4.0 or below 3.5 may require distinctive response speeds relative to these factors. Moreover, the improvements attained in response accuracy become most valuable especially when physical declines begin to hinder quick, altering movements on the tennis court.

Although the importance of improved response speed and/or accuracy have been documented throughout the extant literature, the performance decisions that players make during points may ultimately determine the outcome of matches. By executing the best decisions, players were able to dictate play, control more points, and force their opponents to expend more energy. Older adults trained with situation awareness, anticipation, and performance decision-making not only improved these skills with five,
30 min sessions, but also retained these performance levels over a long-term retention period. Notable findings also include the transference of improved perceptual-cognitive skills to winning more games relative to other training protocols. The retention of perceptual-cognitive skills training and increased win percentages have never been shown through previous investigations, and I echo the sentiments offered by Farrow and Abernethy (2002) that meaningful learning effects and training that transfers to increased performance outcomes are needed in future perceptual training research across varying age groups and ability levels. Finally, the multidimensional approach also alleviated age-related declines in cognitive functioning, specifically attention.

The use of multidimensional perceptual-cognitive skills training, as opposed to traditional anticipation-only training, has brought forth several questions to be answered. Additionally, examining the development of these skills in older adults as well as the ameliorating effects on cognitive aging deficits provides rich avenues for future research.

1. This is the first study to show the benefits of a combinational approach to perceptual-cognitive training as opposed to singular based strategies, and, therefore, requires further exploration and support of these findings. Exploring other senior, young adult, and junior populations as well as varying ability levels within those populations would advance the science and the game of tennis. Furthermore, investigating the potential benefits of multidimensional perceptual-cognitive training in other dynamic sports (i.e., baseball, soccer, volleyball, football) is necessary. Although the current findings lend strong evidence for senior tennis players, many senior athletes compete in other dynamic sports. The
development of sport specific, perceptual-cognitive training protocols is needed to
determine the effectiveness and generalizability of this training.

2. With regards to specific aspects of the multidimensional perceptual-cognitive
skills, further examination of how MPCT training benefits the individual
components of situation awareness would explain how increased learning of each
level influences performance. Focusing solely on the individual levels of
situation awareness and their influence on performance can produce
improvements in the training protocol for each of the three levels. Most
importantly, greater insight can be attained regarding how Level 3 situation
awareness is developed and possibly trained. This could be accomplished by
randomly assigning participants to and provide training in only one of the three
levels of situation awareness, along with the global strategy.

3. For the first time in the sport psychology literature, the SAGAT was used to
assess perceptual skills, specifically situation awareness, which provided more
traditional laboratory based testing. Although not the main focus of this study,
the use and development of the SAGAT for dynamic sport environments needs
further construct validation. In the future, researchers will be best served by
including both traditional laboratory testing and field-based, ecological
approaches that maintain the perception and action link.

4. One possible limitation of this study was use of one individual to administer
group-specific training to MPCT, AT, and TFT participants. Important aspects of
the training and how the training should be administered may be realized when
multiple individuals are administering the training. This can be accomplished by
assigning different individuals to administer group-specific training or by developing computer-based, participant initiated training.

5. Finally, several issues could be addressed with regards to improving cognitive functioning and the effectiveness of this multidimensional approach in dynamic life activities (i.e., driving). Beyond sport, older adults may find the greatest benefits from this training for dynamic life activities as such protocols must be developed and tested. For example, similar training of situation awareness, anticipation, and performance decision-making and assessment of response speed, response accuracy, and decision-making could be conducted in a driving simulation in which older adults were required to respond in familiar and unfamiliar situations. Further research will provide a better understanding of how older adults benefit from improved perceptual-cognitive skills and their long-term influence on executive functioning.

In conclusion, the current findings addressed several issues that have been raised over the past 50 years of perceptual skills training research. Multidimensional perceptual-cognitive training produced the following results: (1) improved speed and accuracy, (2) improved perceptual-action coupling with on-court training and testing, (3) response speeds equivalent to and often better than the pace of play during real-time competitive matches, (4) functionally significant learning effects, and (5) increased performance outcomes. I hope that these seminal findings can be replicated across different populations, ability levels, and dynamic environments, so as to solidify guidelines for the development of comprehensive domain specific perceptual training.
tools that can benefit the broader community while also advancing the science of perceptual expertise.
APPENDIX A
MINI-MENTAL STATE EXAMINATION

Participant # _____

Orientation

1. What is the…
   Year __________ 1 point
   Season __________ 1 point
   Date __________ 1 point
   Day __________ 1 point
   Month __________ 1 point

2. Where are we?
   State __________ 1 point
   County __________ 1 point
   Town/City __________ 1 point
   Tennis Club __________ 1 point
   Street __________ 1 point

Registration

3. I’m going to name 3 objects. When I’m finished I’d like you to repeat them back to me.

   WINDOW  APPLE  CHAIR

   __________  __________  __________  (1 point for each correct answer)

Attention and Calculation

4. Starting at 100, please count backwards by sevens. (93, 86, 79, 72, 65)

   __________  __________  __________  __________  __________  __________

   (1 point for each correct answer)
Recall

5. What were the 3 objects you named a few minutes ago?

_________ _________ _________ (1 point for each correct answer)

Language

6. Name each object as I point to it. (Point to a PEN & then a WATCH)

_________ _________ (1 point for each correct answer)

7. Repeat after me: “No ifs, ands, or buts.” (1 point)

8. I’m going to tell you 3 things I want you to do. When I’m finished, please do those 3 things:

“Take a paper in your right hand. Fold the paper in half. Put the paper on the floor.”

_________ _________ _________ (1 point for each correct answer)

9. I’m going to show you a written command. Please read it and do what it says to do.

CLOSE YOUR EYES (1 point)

10. Please write a simple sentence of your choice.

____________________________________________ 1 point

11. Copy the design shown below.

________ 1 point
### APPENDIX B
### POSTTEST QUESTIONNAIRE

Participant Number: ______________________________

1. Please indicate your gender.

- [ ] Female
- [ ] Male

2. What is your age?

3. How many years have you played tennis?

____________________                                  ______________________________

4. How acute is your vision (e.g., 20/20, 20/40, 20/60…)? _____________________________

Please list any eye/vision problems or illnesses.
_____________________________________________________________________________

Mark an “x” in only one of the numbered boxes on a 1 – 5 scale.

5. How would you rate your skill level as a tennis player?

| Beginner | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5+
|----------|-----|---|-----|---|-----|---|-----|---|

6. How confident were you in your ability to make quick and accurate decisions throughout the singles match?

<table>
<thead>
<tr>
<th>Totally Unsure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Very Confident</th>
<th>5</th>
</tr>
</thead>
</table>

7. How confident were you in your ability to adapt to different match situations and still make successful decisions?

<table>
<thead>
<tr>
<th>Totally Unsure</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Very Confident</th>
<th>5</th>
</tr>
</thead>
</table>

8. What helped guide you in making your decisions?

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
9. Did your approach stay the same or change during the singles match?
☐ Same   ☐ Changed

10. If your approach changed, why did you decide to make this change? What did you change?
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
APPENDIX C
TENNIS LOG

Participant #__________

Please indicate the number of days and total number of hours played each week.

**Week of training:**

<table>
<thead>
<tr>
<th>Number of Days Played (Excluding Training for Study)</th>
<th>Total Number of Hours Played (Excluding Training for Study)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Weeks following training:**

<table>
<thead>
<tr>
<th></th>
<th>Number of Days Played</th>
<th>Total Number of Hours Played</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 3</td>
<td></td>
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<tr>
<td>Week 4</td>
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<tr>
<td>Week 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX D
SITUATION AWARENESS GLOBAL ASSESSMENT TECHNIQUE

SAGAT Queries for Singles Tennis Matches

1. Where are you looking right now?
2. Where will your opponent hit this shot, 1, 2, or 3?
3. Where are you looking right now?
4. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
5. Where are you looking right now?
6. Where will your opponent hit this shot, 1, 2, or 3?
7. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
8. Where are you looking right now?
9. Where will your opponent hit this shot, 1, 2, or 3?
10. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
11. Where are you looking right now?
12. Where will your opponent hit this shot, 1, 2, or 3?
13. Where are you looking right now?
14. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
15. Where are you looking right now?
16. Where will your opponent hit this shot, 1, 2, or 3?
17. Where will your opponent hit this shot, 1, 2, or 3?
18. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
19. Where are you looking right now?
20. Where will your opponent hit this shot, 1, 2, or 3?
21. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
22. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
23. Where will your opponent hit this shot, 1, 2, or 3?
24. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
25. Where are you looking right now?
26. Where are you looking right now?
27. Where will your opponent hit this shot, 1, 2, or 3?
28. Where are you looking right now?
29. Where will your opponent hit this shot, 1, 2, or 3?
30. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
31. Where are you looking right now?
32. Where will your opponent hit this shot, 1, 2, or 3?
33. Where will your opponent hit this shot, 1, 2, or 3?
34. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
35. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
36. Where would you hit this shot, and from that position, where would your opponent hit the next shot?
LIST OF REFERENCES


BIOGRAPHICAL SKETCH

Ryan J. Caserta was born in Bridgeport, Connecticut, on May 29, 1974. After training in Florida with the world’s top tennis players, he received a full scholarship to Belmont Abbey College (Belmont, North Carolina). During his four years at Belmont Abbey College, Ryan was twice named to Who’s Who Among Students In American Universities and Colleges, named the Outstanding Business Student of the Year, and was a GTE Academic All-American in tennis. In 1997, Ryan graduated cum laude with a Bachelor of Science in business administration and a dual minor in psychology and economics. After working in finance and corporate management for three years, he went on to Springfield College (Springfield, Massachusetts) to pursue his love of sport psychology. In 2002, he received a Master of Science in sport psychology, and then went on to the University of Florida (Gainesville, Florida) to continue his graduate work in sport and exercise psychology. Under the guidance of Dr. Robert N. Singer and Dr. Christopher M. Janelle, Ryan received Presidential Recognition for Outstanding Achievement during his first year, won the Graduate Student Teaching Excellence Award, and received the Leighton Cluff Award for Research in Aging. Ryan received his Doctor of Philosophy Degree in May of 2007 with concentrations in sport and exercise psychology as well as cognitive psychology.