

Old Dogs, New Tricks: Training the Perceptual Skills of Senior Tennis Players

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The purpose of the study was to determine whether multidimensional perceptual-cognitive skills training, including situational awareness, anticipation, and decision making, improves on-court performance in older adults when compared with a physical training program, including stroke and footwork development. Senior tennis players ($N = 27$) were randomly assigned to one of three groups: perceptual-cognitive skills training, technique-footwork training, or no training. Results indicated that participants receiving perceptual-cognitive skills training had significantly faster response speeds, higher percentage of accurate responses, and higher percentage of performance decision making in posttest match situations. Findings provide clear evidence that perceptual-cognitive skills can be trained in aged individuals. Implications and suggestions for future research are offered.

Key Words: situational awareness, anticipation, decision making, aging, cognitive impairment, intervention

For senior athletes, a number of physical barriers impede or prevent competing in dynamic sports. Deterioration in muscle size and strength, bone density, joint and muscular flexibility, and aerobic capacity can force aged competitors to consider less demanding, closed skill sports such as golf (Kirkendall & Garrett, 1998; Rogers & Evans, 1993; Ruegsegger, Durand, & Dambacher, 1992). Athletes who push through the physical pain and discomfort associated with these physical declines often incur serious injuries, which can permanently sideline them. Even though physical abilities decline with age, Starkes, Cullen, and MacMahon (2004) propose that “adaptations within perceptual-cognitive [skills] can ‘make up’ for losses within perceptual-motor [skills]” (p. 271).

Beyond the physical decay, age-related declines also occur in cognitive functioning. Cognitive declines in conscious memory accelerate significantly after the age of 50, including impairment of new memory formation and recall of detailed information (Salloway, 1997). As adults approach the age of 70, deficits begin to occur in attention, visual perception, hearing acuity, and verbal memory (Salloway, 1997). In addition to the aforementioned cognitive aging effects, declines exist in the capacity to hold information in working memory and to perform multiple tasks

simultaneously (Navon, 1984; Salthouse, 1985, 1988) as well as general slowing of processing speeds and response execution (Birren, 1970; Cerella, 1994; Salthouse, 1985). As a means to assess these age-related declines, the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) has been used extensively over the past 30 years to test the severity of cognitive impairment (i.e., mild, moderate, and severe) in geriatric patients. Given the fact that these cognitive deficits are an inevitable part of the aging process, loss in conscious memory, processing resources, attention, and visual perception may directly influence the adaptability of aged individuals to perceptual-cognitive skills training.

Although less obvious than physical impediments, cognitive obstacles can substantially affect performance. Clearly, such declines directly influence perception, which many consider the key component to the outcome of dynamic sport competitions (e.g., Abernethy, 1987; Williams et al., 1992). For athletes to be successful regardless of age, they must have the ability to efficiently and reliably gather, sort, and process massive amounts of information while responding appropriately under rapidly changing sport situations. Minimal research has examined whether training perceptual-cognitive skills influences sport performance in older athletes and whether aging effects in cognition can be slowed or even ameliorated in such athletes. However, researchers examining the effects of cognitive training with aged individuals have found that interventions can significantly improve specific cognitive abilities, including processing speed, reasoning, and memory (e.g., Ball et al., 2002; Baltes & Baltes, 1990; Baltes & Lindenberger, 1988; Roenker, Cissell, Ball, & Edwards, 2003; Schaie & Willis, 1986).

Perceptual Expertise and Perceptual Skills Training

Researchers examining perceptual expertise have advocated the training of perceptual-cognitive skills, including anticipation and decision making (Abernethy, Woods, & Parks, 1999; Farrow, Chivers, Hardingham, & Sachse, 1998; Grant & Williams, 1996; Scott, Scott, & Howe, 1998; Singer et al., 1994; Smeeton, Williams, Hodges, & Ward, 2005; Williams & Ward, 2003; Williams, Ward, Knowles, & Smeeton, 2002; Williams, Ward, Smeeton, & Allen, 2004). As a means for improving performance across youth and young adult athletes, investigations have used laboratory-based simulations to train and test the acquisition of perceptual-cognitive skills (Farrow et al., 1998; Franks & Hanvey, 1997; McMorris & Hauxwell, 1997; Scott et al., 1998; Singer et al., 1994; Starkes & Lindley, 1994; Williams, Ward, & Chapman, 2003). Video-based and occlusion training have been used to highlight key preperformance cues allowing participants to learn and receive feedback on these skills in a controlled environment. Ensuing laboratory-based perceptual-cognitive skills testing has resulted in significant improvements in response speed and/or response accuracy for these age groups.

Although few perceptual interventions have successfully transferred laboratory-based improvements to the field (e.g., Adolphe, Vickers, & Laplante, 1997; Williams et al., 2003), most recent evidence by Williams et al. (2004) has supported the use of in situ perceptual skills training as a means of improving live, on-court anticipation skills in young adult tennis players (M age = 21.7, SD = 1.5 years). Through established on-court measures involving frame-by-frame video analysis (Williams & Grant, 1999; Williams et al., 2003), perception-action and perception-only trained

participants significantly improved response initiation times from pre- to posttest. However, no improvements were made in response accuracy. In addition, Smeeton et al. (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 with those in the guided discovery and discovery groups. Similar to past perceptual training studies, these improved decision times were not accompanied by a higher percentage of accurate responses.

The improvement in *both* response speed and accuracy may be less important for younger athletes; however, when one considers the physical and cognitive declines that occur with age, greater emphasis exists on improving both areas for older athletes to effectively maximize their performance. In addition, further consideration is required regarding the number of perceptual-cognitive skills being trained because multiple cognitive deficits influence the functioning of aged individuals (e.g., deficits in fluid intelligence, inhibition, amount of processing resources, and processing speeds).

Situational Awareness

Human factors researchers have focused significant effort toward understanding how fighter pilots, challenged by dynamic environments similar to those encountered in sport, efficiently process information in air combat and reliably respond under these conditions. The development of a multidimensional concept, namely *situational awareness*, has provided direction toward explaining, measuring, and training this perceptual-cognitive skill, which is directly linked to information-processing mechanisms, long-term working memory, and automaticity. *Situational 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, situational 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 owing to aging. 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.

Researchers examining complex environments where situational awareness is essential to peak performance (e.g., flying a plane, surgery, and air traffic control) have identified three levels of situational 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 situational awareness errors in pilot performance (Jones & Endsley, 1996).

Level 2 situational 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 situational 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. An example of leverage points for a tennis player would be the shots that players attack hitting down-the-line to pressure the opponent.

Finally, Level 3 situational 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 affects 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 situational awareness have a distinct advantage over the competition. Ultimately, the third level of situational awareness appears to be where elite performers in any domain are distinguished from others.

Recent findings (Caserta & Singer, 2007) lend evidence to the effectiveness of training these three levels of situational awareness in sport along with the importance of combining situational awareness with anticipation and decision-making training. Effective situational analysis should increase the probability of anticipating events that may occur. In turn, such appropriate situational awareness behaviors should enhance the probability of making better decisions/actions in such situations.

In sum, extant research on perceptual-cognitive skills training has provided no evidence of the effectiveness of this training with senior athletes as well as the transference of these skills in real-time performance. Producing significant improvements in perceptual-cognitive skills during field-based training may improve the performance of coaches and senior recreational athletes. Owing to the number of physical and cognitive barriers that hinder competing in dynamic sports, the effective development of both response speed and response accuracy as well as decision-making skills are necessary for seniors to successfully compete. Therefore, a multidimensional perceptual-cognitive intervention was used to address these limitations. Although evidence exists concerning *performance maintenance* and *performance improvement* in master-level athletes (Starkes et al., 2004; Starkes, Weir, & Young, 2003), whether perceptual skills training strategies can slow or even ameliorate cognitive effects on aging remains unknown. Therefore, the main purpose of the study was to determine whether multidimensional perceptual-cognitive skills training (i.e., situational awareness, anticipation, and

decision making) improved on-court performance in older adults when compared with a physical training program (i.e., stroke and footwork development). Three experimental groups provided with (1) perceptual skills training, (2) physical skills training, and (3) no training, respectively, were tested in on-court evaluations before and after intervention. We hypothesized that senior tennis players trained with situational awareness, anticipation, and decision making would demonstrate enhanced perceptual-cognitive skills (i.e., respond faster and more accurately as well as make more appropriate decisions during tennis match situations) when compared with those provided with physical or no training. In light of past findings examining the effects cognitive interventions have on the processing speed, reasoning, and memory of aged individuals, we hypothesized that perceptual-cognitive skills would improve regardless of cognitive impairments.

Method

Participants

Participants included senior male ($n = 10$, $M = 62.50$ years old, $SD = 8.44$) and female ($n = 17$, $M = 56.59$ years old, $SD = 8.53$) tennis players over the age of 50 who were recruited from three local tennis clubs in North Central Florida. The rationale for this age cutoff followed that of senior sports tours (e.g., Senior PGA, senior master events). Players competed regularly in United States Tennis Association (USTA) league tournaments; thus, each had a National Tennis Rating Program (NTRP) certified rating. The NTRP is a definitive skill rating system, which provides an easy, nonexclusive means of achieving parity in competition and on-court compatibility. Ratings range from 1.0 (novice) to 7.0 (tour player), and they increase in increments of 0.5. The average skill level of the participants, according to the NTRP, was 3.17 ($SD = .50$). Informed consent was obtained before administering the pretest.

Materials and Measures

Video Camcorder. A production-quality professional digital video camcorder (Canon GL2; Jamesburg, NJ) with 3 CCD sensor and 20 \times optical zoom was used to record each pre- and posttest match. With new shutter speed technology, the GL2 has a shutter speed of 1/15,000 s performing at a capture rate of 201.5 Hz. This produced an error rate of only ± 2.5 ms, which was vital to the accuracy of the data. The camcorder was setup at the fence in the middle of the tennis court on the same side as the tennis professional. The participants remained in the far court for the four-game match, which provided the optimal viewing angle for data analysis.

Mini-Mental State Examination (MMSE). The MMSE (Folstein et al., 1975) is a brief standardized screening test that quantitatively assesses the severity of cognitive impairment (i.e., mild, moderate, and severe). Used extensively over the past 30 years with geriatric patients, the MMSE consists of 11 questions assessing orientation, registration, attention, recall, and language and 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. Specifically, 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 et al., 1975).

Posttest Questionnaire. The posttest questionnaire provided general demographic information, including gender, age, number of years in tennis, NTRP rating, and visual acuity as well as questions regarding the confidence of utilizing perceptual-cognitive skills during singles tennis matches.

Procedures

Pretest. Participants were told that the study was designed to examine how senior tennis players perform during singles tennis match situations. Before training, each participant was administered the MMSE to test for cognitive impairments and then individually pretested in a four-game singles match against a PTR-certified tennis professional. The PTR tennis professional had over 17 years of teaching experience, and he was a collegiate All-American. Using a tennis professional of this caliber for each pretest match provided consistency and reliability of performance across participants. In addition, the tennis professional assured that each match was competitive and that points would challenge the participant from a perceptual-cognitive basis. Participants had no previous matches, lessons, contact, or playing of any kind with the PTR tennis professional.

Experimental Treatment. Following the pretest, the researcher met with each participant individually to provide group-specific training over five consecutive days. Participants were randomly assigned (irrespective of MMSE scores) to one of the following three groups: (1) perceptual-cognitive skills training (PCST), (2) technique-footwork training (TFT), or (3) control. Group-specific, standardized instructions were provided to the participants on-court in a one-on-one setting to help maximize the effects of training. All training sessions, regardless of group assignment, lasted approximately 40 min. The PCST and TFT participants met on five consecutive days, whereas the control participants met only twice (for pre- and posttesting). Participants unable to meet on consecutive training days were not allowed more than 1 day between meetings. All instructions were presented through video or on-court demonstrations and drills.

Perceptual-Cognitive Skills Training (PCST). On the first day of training, PCST participants learned what situational awareness is, how vital situational awareness is to rapidly changing situations—originally for fighter pilots, but now more specifically for tennis—and how the following three levels make up situational awareness: (Level 1 situational awareness) attending to the most important cues, or relevant information, during a point; (Level 2 situational awareness) making meaning of those cues as well as the situation in regards to personal goals for winning the point; and (Level 3 situational awareness) the ability to use this information to predict the opponent's intended shots in the future.

On Day 2, participants received tennis-specific instruction on the three levels of situational awareness. For Level 1 situational awareness, participants were instructed on the cues that provide the most useful information with regards to where a shot will be hit for ground strokes, approach shots, volleys, and serves. Participants were then provided with on-court drills designed to develop optimal cue utilization. Drills consisted of cross-court and down-the-line rallies for each of the aforementioned shots, with the exception of serving. In this case, the instructor hit serves from the service line to improve response speed and accuracy. Training to begin comprehending what these cues meant in relation to the situation (i.e., Level 2 situational awareness) followed. This included learning about opponent's court positioning, body alignment before contact, the racquet angle at the point of contact, and what these configurations represented. The same on-court drills were repeated to further develop the first two levels of situational awareness allowing participants to attend to important cues and the outcome of those cues. The remainder of Day 2 consisted of rallying, with the understanding that this begins as a conscious process, but with deliberate practice will become an unconscious process that utilizes Level 3 situational awareness to project onto future situations.

The third day of training consisted of combining situational awareness with anticipation. Instructions prepared participants for tennis play situations, and opponent cues that might be available as to intentions. During general on-court rallying and practice points, the cost/benefit ratio for determining where to move on the court to cover the opponent's shot was explained. Participants in this group were informed of the importance of understanding within point circumstances, the tendencies of an opponent, and that comprehension of what to expect of an opponent in a particular situation would be vital to improving their game on the tennis court.

On the fourth day of training, decision-making strategies were presented. Instructions explained how deciding on the best places to move to return a shot or the best places to hit a shot depend in large part on situational awareness and anticipation capabilities. Participants were trained on the importance of developing the ability to quickly interpret, process, and integrate the most situation-relevant information during a point in order to make effective decisions as to where to move and how to respond effectively to the opponent's intentions. The objective was to be aware of what was happening during the point, what decision the opponent might make, and what to decide when that moment came. Participants were informed that the outcome of each decision made allowed for greater understanding of where to go, what to do when they got there, and ultimately what decisions would provide them with the most success in the future. Further explained was how expert players process the most relevant information quickly and, more importantly, accurately as well as execute the best decisions out of the available options as if automatically. Again, the use of on-court rallying and practice points were provided to improve the decision-making skills of participants in specific tennis situations and teach them to control points and conserve energy.

Finally, Day 5 included review of situational 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 situational awareness, anticipation, and decision making, ensured that participants were correctly applying these skills to their game. Following each drill, rally, and/or practice point, participants were provided with feedback regarding the effectiveness of using each skill or lack thereof. Questions about situational awareness, anticipation, and decision-making strategies were also answered at the end of each training session.

Technique-Footwork Training (TFT). Participants in the TFT group were trained on specific stroke techniques and on-court footwork drills used to increase the effectiveness and efficiency of movement during singles match play. Over the five consecutive days of training, technique was provided to improve forehand and backhand ground strokes, approach shots, volleys, overheads, and serves as well as the corresponding footwork that complemented each stroke. Groundstroke instruction included the importance of early preparation, the appropriate point of contact for the forehand and the one/two-handed backhand, and the most effective ways for returning deep and short hit shots. The techniques used with ground strokes were transferred to approach shots; however, participants also learned where to split-step to optimally cover the net on passing shots. For volleys, participants were taught how to use a continental grip to hit both forehand and backhand volleys. This technique not only simplified this shot, but also dramatically improved overall effectiveness and efficiency at net. Last, the serve and overhead were trained together owing to the continuity of movement. Preparation, balance, point of contact, and the use of the nondominant hand were all addressed. Instructions describing the importance of good footwork were provided along with a demonstration of correct footwork. After completing the demonstration of techniques and footwork, participants in the TFT group were required to practice these skills during on-court drills. The quantity and duration of TFT equaled that of the PCST group. As with the PSCT group, feedback was provided regarding the effectiveness of executing each skill, or lack thereof, following each drill. Questions about technique and/or the corresponding footwork were also answered at the end of each training session. No mention of situational 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. On average, control participants played 2 hours a day, 3 days during the week.

Posttest. Immediately following the 5 days of training, each participant was posttested in another four-game singles match against the same PTR-certified tennis professional (Figure 1). By using the same tennis pro, consistency was maintained across playing style, pre- to posttesting analysis, and participants. Although all matches had an equal chance of being one-sided, the PTR professional was instructed to match the ability level of each participant. Because the participants were of similar skill level, variance was minimized in the speed of play, and the type of shots hit remained consistent across participants and pretest/posttest matches. The ability to have each participant play against all other participants in a round robin format for pre- and posttesting was not feasible owing to participant scheduling conflicts or time restrictions and the number of participants. More importantly, the lack of experimental control inherent in highly variable dynamic tennis match

play would have rendered this arrangement less than ideal for the purpose of maintaining consistency between sessions, among situations, and among participants. Although the PTR tennis professional did have prior knowledge as to the group assignment of each participant, a postinvestigation video analysis was conducted with two tennis professionals to determine the objectivity of the PTR tennis professionals' playing in each match. The two independent tennis professionals had no knowledge as to the purpose of the study or the group assignment. A postinvestigation questionnaire and video analysis indicated 100% objectivity with regards to matching the ability level of each participant, maintaining the competitiveness of each match, and equally challenging each participant from a perceptual-cognitive basis. In addition, two coders were used for data analysis and interrater reliability scores were analyzed to determine the consistency across video analysis (see Data Reduction subsection). Following the four-game posttest, participants completed the posttest questionnaire.

Data Reduction

First, irrelevant data (e.g., double-fault and missed return of serves requiring no movement) were extracted from the pre- and posttest video analysis (average of 4 points per four-game set). Upon eliminating irrelevant data, the first author and a second expert (who was blind to group assignment), who had background in perceptual-cognitive skills training and the game of tennis, individually coded response speed, response accuracy, and performance decision making according to the predetermined set of criteria (see dependent measures, as follows) for each four-game singles match. The total of 60 trials were analyzed for each participant across pre- and posttest, with each trial producing a response speed, response accuracy, and performance decision-making score. Interrater reliability scores for the points examined, across response speed, response accuracy, and performance decision making, were 98%, 99%, and 99%, respectively. Any discrepancies in coding were discussed and agreed upon prior to statistical analysis. The scores on the MMSE were reduced according to the predetermined criteria set by Folstein et al. (1975). Participants scoring between 20 and 24 points were considered to have mild levels of cognitive impairment and those scoring 25 points or higher were considered not cognitively impaired.

Dependent measures of interest included the following.

Response Speed. Response speed was considered to be the time period from the point of contact by the opponent to the completion of the participants' first step in the correct direction of the ensuing 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. Elite-level perceptual-cognitive skills afford 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. Based on the accuracy of movement, participants were given 1 point for correctly moving in the appropriate direction and no points for moving in the wrong direction. Participants

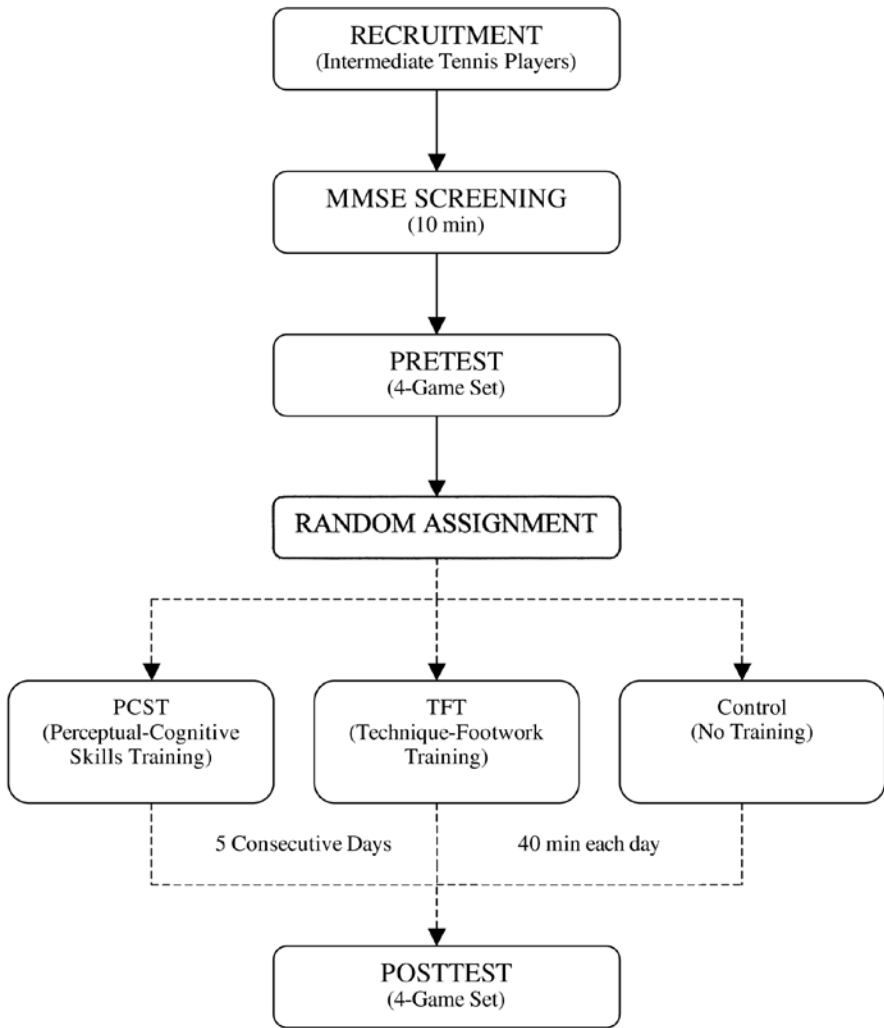


Figure 1 — Experimental design.

also 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 because individuals will have seen where the shot has been hit. Furthermore, the perceptual cognitive skills of interest are not necessary after the ball has traveled past the net (1,000 ms and up).

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 1 point for choosing appropriate performance decisions and no points for inappropriate performance decisions. For example, participants would receive a point for appropriately attacking down the line even if the ball was hit into the net, wide of the singles line, or beyond the baseline. Thus, this variable was based solely on choosing the most appropriate decision and was not influenced by technical skill execution. Making the correct decision and executing the shot are clearly separate skills.

Statistical Analysis

First, levels of cognitive impairment were analyzed with a one-way independent groups MANOVA to determine whether differences existed between participants who displayed cognitive impairments and those with no cognitive impairments across the five subscales (i.e., orientation, registration, attention, recall, and language) on the MMSE. In addition, a mixed model 2×2 (Cognitive Impairment, No Impairment \times Pretest, Posttest) MANOVA with repeated measures on the second factor, was undertaken to determine whether participants with cognitive impairments as opposed to those without cognitive impairments (as determined by the MMSE) differed in response speed, response accuracy, and decision making during pre- and posttest singles match play situations. Simple effects tests with Bonferroni-corrected alpha levels were used to evaluate significant interactions. Furthermore, a separate one-way independent groups ANOVA was then conducted to determine whether group differences existed across scores from the MMSE. Finally, a mixed model 3×2 (Group: PCST, TFT, control \times Pretest, Posttest) MANOVA with repeated measures on the second factor, was conducted to determine whether the participants in the three groups differed in response speed, response accuracy, and decision making during pre- and posttest 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.

Results

Participant Characteristics

The one-way independent groups MANOVA yielded a significant main effect for levels of cognitive impairments, Wilks's $\lambda = .16$, $F(3, 5) = 1.64$, $p < .05$, $\eta^2 = .31$, observed power = .78. Scores on the *attention* and *recall* subscales were significantly different between participants with cognitive impairments as opposed to those without impairments (Table 1). No significant differences were found between levels of cognitive impairment with respect to scores on the orientation, registration, and language subscales.

As for the 2×2 mixed-model MANOVA, a significant main effect for pre/posttest was found in the PCST participants, Wilks's $\lambda = .003$, $F(3, 5) = 570.70$,

Table 1 Mean Scores and Standard Deviations for MMSE Point Scores as a Function of Cognitive Impairment and Training

Group	Total (30 pts.)		Orientation (10 pts.)		Registration (3 pts.)		Attention (5 pts.)		Recall (3 pts.)		Language (9 pts.)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Cognitive impairment (<i>n</i> = 14)												
PCST (<i>n</i> = 3)	23.67	.58	8.00	1.00	3.00	.00	3.00*	1.00	1.67*	1.15	8.00	.00
TFT (<i>n</i> = 5)	22.80	1.10	8.00	.71	3.00	.00	2.80*	.84	1.20*	.45	7.80	.45
Control (<i>n</i> = 6)	23.33	1.03	8.50	.55	3.00	.00	2.67*	1.86	1.83*	.75	7.83	.41
No cognitive impairment (<i>n</i> = 13)												
PCST (<i>n</i> = 5)	26.80	.84	8.80	.45	2.60	.89	4.40*	.55	3.00*	.00	8.00	.00
TFT (<i>n</i> = 4)	26.50	.58	8.50	.58	3.00	.00	4.25*	.96	2.25*	.96	8.25	.50
Control (<i>n</i> = 4)	26.50	1.00	8.25	.50	3.00	.00	4.75*	.50	2.00*	1.15	8.25	.50

Note. Cognitive impairment = mild impairment (20–24 pts.) as determined by the MMSE; PCST = perceptual-cognitive skills training; TFT = technique-footwork training.

**p* < .05.

p < .001, $\eta^2 = .99$, observed power = 1.00. However, no significant main effects were found for pre/posttest across TFT participants, Wilks's $\lambda = .61$, $F(3, 4) = .84$, *p* > .05, and control participants, Wilks's $\lambda = .71$, $F(3, 5) = .67$, *p* > .05. Moreover, no significant main effects were found for levels of cognitive impairment across PCST participants, Wilks's $\lambda = .86$, $F(3, 5) = .27$, *p* > .05; TFT participants, Wilks's $\lambda = .76$, $F(6, 8) = .19$, *p* > .05; and control participants, Wilks's $\lambda = .17$, $F(6, 10) = 2.41$, *p* > .05, participants (Table 2).

Separate one-way independent groups ANOVA indicated no significant differences between PCST, TFT, and control participants with respect to their scores on the MMSE, $F(2, 24) = .61$, *p* > .05.

Performance

The mixed-model 3 × 2 MANOVA yielded significant main effects for group, Wilks's $\lambda = .07$, $F(6, 44) = 21.48$, *p* < .001, $\eta^2 = .75$, observed power = 1.00, and pre/posttest, Wilks's $\lambda = .06$, $F(3, 22) = 116.58$, *p* < .001, $\eta^2 = .94$, observed power = 1.00. Follow-up Tukey's HSD indicated that although PCST and TFT participants responded significantly faster than control participants, the PCST participants responded the fastest when compared with all groups. In addition, the PCST group produced a significantly higher percentage of accurate responses and performance decisions when compared with the TFT and control groups.

More importantly, a significant Group × Pre/Posttest interaction, Wilks's $\lambda = .03$, $F(6, 44) = 39.44$, *p* < .001, $\eta^2 = .84$, observed power = 1.00, was also observed. Follow-up univariate simple effects tests confirmed significant mean differences for

response speed, $F(2, 24) = 183.09, p < .001$; response accuracy, $F(2, 24) = 182.67, p < .001$; and performance decision making, $F(2, 24) = 105.23, p < .001$. Participants receiving PCST training significantly improved response speed, response accuracy, and performance decision making from pre- to posttest (Table 3) when compared with those receiving TFT or no training (Figure 2).

Table 2 Pre- and Posttest Mean Scores and Standard Deviations for Measures of Perceptual-Cognitive Ability as a Function of Cognitive Impairment and Training

Group	Response speed (milliseconds)				Response accuracy (%)				Performance decision making (%)			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Cognitive impairment ($n = 14$)												
PCST	1,038*	55.82	534*	17.05	32.23*	6.93	87.77*	10.20	32.23*	5.10	81.10*	11.70
TFT	1,163	138.77	1,229	122.83	22.00	8.37	20.67	4.33	30.00	6.23	27.33	5.47
Control	1,263	53.19	1,317	65.98	13.90	3.27	13.90	9.03	25.00	10.90	23.33	11.73
No cognitive impairment ($n = 13$)												
PCST	1,059*	43.20	589*	76.45	30.67*	11.87	88.00*	9.00	36.00*	5.47	80.67*	5.47
TFT	1,122	81.93	1,153	88.97	22.50	13.70	22.50	15.97	31.67	6.93	31.67	10.37
Control	1,241	36.62	1,241	51.86	21.67	1.93	15.83	3.20	26.67	11.87	26.67	9.80

Note. PCST = perceptual-cognitive skills training; TFT = technique-footwork training; cognitive impairment = mild impairment as determined by the MMSE.

* $p < .001$.

Table 3 Pre- and Posttest Mean Scores and Standard Error for Measures of Perceptual-Cognitive Ability as a Function of Training

Group	Response speed (milliseconds)				Response accuracy (%)				Performance decision making (%)			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE
PCST ($n = 8$)	1,051*	.03	568*	.03	31.33*	2.99	87.89*	3.09	34.59*	2.82	80.80*	3.13
TFT ($n = 9$)	1,145	.03	1,196	.03	22.22	2.82	21.47	2.91	30.69	2.65	29.28	2.96
Control ($n = 10$)	1,254	.02	1,287	.03	17.00	2.68	14.67	2.76	25.67	2.52	24.67	2.80

Note. PCST = perceptual-cognitive skills training; TFT = technique-footwork training.

* $p < .001$.

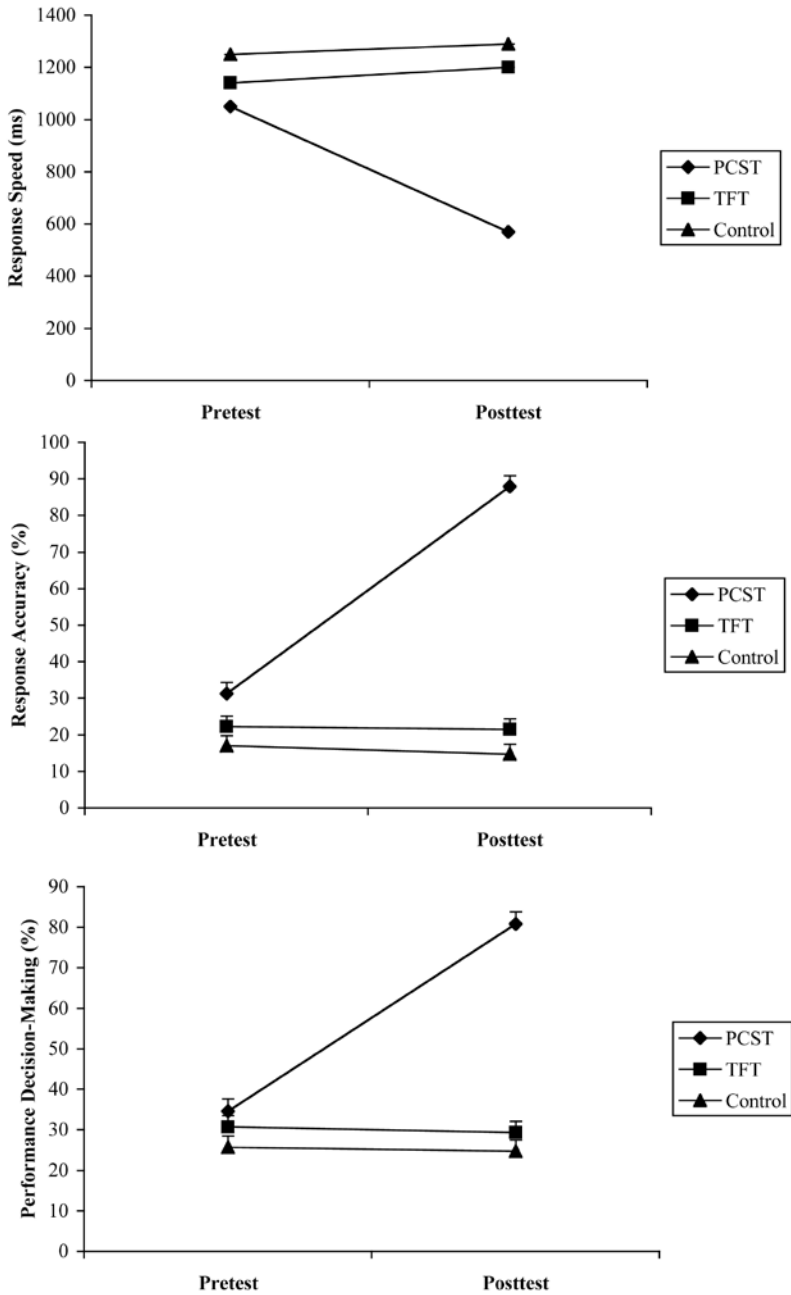


Figure 2 — (a) Mean ($\pm SE$) response speed (ms), (b) response accuracy (%), and (c) performance decision making (%) as a function of training group and pre/posttest. *Note.* PCST = perceptual-cognitive skills training; TFT = technical-footwork training.

Discussion

We designed this investigation to determine whether perceptual-cognitive skills training or technical footwork training would improve on-court performance in senior tennis players relative to a “no training” control condition. Response speed, response accuracy, and performance decision-making measures were taken during on-court match play to study the effects of these training programs during real-time singles points. As hypothesized, results indicated that players, even those with cognitive impairments, who received perceptual skills training responded faster and more accurately to shots hit during posttest competitive singles matches relative to their pretest scores. The PCST participants also made a higher percentage of appropriate decisions regarding the type and direction of shots hit when compared with the placebo (i.e., technique and footwork training) and control groups. On average, PCST participants improved their response speed by nearly a half-second (pretest: 1,050 ms, posttest: 568 ms), and their faster responses occurred with enhanced response accuracy (pretest: 31%, posttest: 88%). In addition, those players who were provided with PCST more than doubled the number of correct decisions (pretest: 35%, posttest: 81%) during live on-court singles matches.

Although no significant within-group differences were found between participants with cognitive impairments and those without cognitive impairments, PCST participants with impairments made noteworthy progressions. The PCST senior participants with mild-to-moderate impairments made the second greatest improvements in response speed, with a difference of 536 ms (pretest: 1,079 ms, posttest: 543 ms), the second greatest improvements in response accuracy with a difference of 67% (pretest: 30%, posttest: 97%) of those tested, and the greatest improvements in performance decision-making capabilities with a difference of 57% (pretest: 37%, posttest: 94%). The significant improvement in situational awareness and dynamic performance decision making during singles matches indicates that multidimensional perceptual training potentially improves the availability of processing resources and overall cognitive processing speed. Influential effects may have also occurred from improved inhibition of irrelevant information, which improves selective attention to free up working memory (Hasher & Zacks, 1988). Future research is necessary to determine whether age-related cognitive limitations, such as fluid intelligence, disinhibition, processing resources, and general cognitive slowing, can be partially or substantially compensated for with perceptual-cognitive training and continued practice.

Our findings provide strong support for the efficacy of training multidimensional perceptual-cognitive skills over physical skills (e.g., stroke technique and footwork) in older tennis players. More importantly, the data lend evidence to the transference of this specific type of perceptual skill training to real-time, dynamic tennis situations. These results, however, would have been strengthened by the combination of more traditional laboratory-based tests along with these field-based measures. Much of the past research examining perceptual skill acquisition in youth and young adult athletes has provided support for improvements during laboratory-based tasks but cannot be generalized to competitive play or older athletes (Abernethy et al., 1999; Christina, Baressi, & Shaffner, 1990; Farrow et al., 1998; Franks & Hanvey, 1997; Haskins, 1965; James & Hollely, 2002; McMorris & Hauxwell, 1997; Williams & Burwitz, 1993). Attempts have been made to measure

the transference of laboratory-based training back to real-world, game situations. Of these studies, several have produced significant improvements in either response *speed* or response *accuracy* (Adolphe et al., 1997; Burroughs, 1984; Scott et al., 1998; Smeeton et al., 2005; Tayler et al., 1994; Williams et al., 2002, 2003, 2004), whereas others have yielded nonsignificant findings (Day, 1980; Londerlee, 1967; Singer et al., 1994; Starkes & Lindley, 1994). Clearly, this investigation is unable to partition out the effects of multidimensional perceptual-cognitive training programs as opposed to more traditional training programs employed in previous literature. However, we have initiated a follow-up investigation to examine this issue so as to determine which strategies (or components of them) are most effective, and we encourage other independent efforts to delineate these important independent or collective contributions.

Upon consideration of the various demands placed on sport competitors, the dynamic nature of tennis mandates refined anticipation skills. The spatial-temporal pressures that exist in singles tennis competitions emphasize equal importance on player speed and accuracy as well as performance decisions that allow players to control (or even dictate) seemingly unpredictable situations. Although participants provided with PCST heightened these abilities over a 1-week period, the lack of a follow-up retention test makes it difficult to ascertain whether the improvements observed for the PCST group are functionally significant learning effects or merely transient performance effects. The potential benefits of extended training periods and continued practice incorporating these training principles of interest are certainly merited and may allow continued participation and success for a variety of senior athletes. Because age-related physical deterioration (e.g., muscles, joints, balance, coordination) makes it more difficult to correct inaccurate movements or make-up slow response speed with “fast feet,” a small “fountain of youth” may exist in multidimensional training of perceptual-cognitive skills. When considering that intermediate tennis players typically hit shots 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 (Brody, 2003), improvements in both response speed and accuracy becomes vital to enhancing performance. Although there are times during a tennis match when speed or accuracy may have greater importance, on average, senior tennis players (indeed, all players) will significantly benefit from improved mental quickness and accuracy. This is especially the case for aging athletes with cognitive impairments, not to mention those who suffer from physical setbacks. However, for those investigations that have struggled with analyzing both response speed and accuracy, future studies may consider whether participants are responding accurately during a specified time window that is deemed key to the successful performance on any particular trial.

In sum, our findings (a) support the use of multidimensional perceptual-cognitive skill acquisition with senior tennis players; (b) demonstrate the transference of perceptual skills training to real-time, competitive singles match play; and (c) lend support for the compensatory effects of perceptual training on mild, age-related declines in cognitive functioning. Extant research on cognitive aging indicates that even healthy older adults suffer compromised cognitive functioning (Birren, 1970; Cerella, 1994; Hasher & Zacks, 1988; Horn & Cattell, 1966; Layton, 1975; Navon, 1984; Rabbitt, 1993; Salthouse, 1985, 1988). Our findings provide initial indications that inevitable cognitive deficits can be minimized or overcome through

multidimensional perceptual-cognitive training. Further, we are optimistic that our results may possibly be extended beyond sport to other performance settings. Older adults may find such training beneficial in various work environments (e.g., medical doctors, police officers, firemen, financial analyst/stock broker), at home (e.g., cooking, caring for infants, making home repairs), and during everyday activities (e.g., driving, crossing a busy street, dealing with inclement weather).

Future research examining perceptual-cognitive skills training and cognitive aging should consider exploration of the relative effectiveness of extended situational awareness training protocols as well as older adults' ability to maintain such skills. Such findings may allow practitioners to produce more appropriate, individualized training programs that enhance areas of extreme cognitive decline. In addition, further evidence is needed regarding the training effects across elderly with mild, moderate, and severe levels of cognitive impairment. Finally, the possible transference of such perceptual-cognitive skills in general life activities may prove to be a critical component to maintaining a high quality of life throughout later adulthood.

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