THE ROLE OF THE QUIET-EYE PERIOD AND THE BEREITSCHAFTSPOTENTIAL IN AROUSAL REGULATION AND MOTOR PREPARATION FOR PERFORMANCE OF A SELF-PACED MOTOR SKILL

By

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To the memory of my mom (August 10, 1947 to October 4, 1997). Without her love, support, and sacrifice this journey would not have been possible!

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Given the robust empirical support for and practical implications of the quiet-eye (QE) period, it was my objective to assess the role of the QE period in emotion regulation and motor preparation. The concurrent exploration of the BP and QE period under varying levels of anxiety was designed to assess the principal mechanisms responsible for the psychomotor differences between expert and near-expert performers. Twenty golfers were classified by their USGA handicap rating as either a high handicap (HH; near-expert) or low handicap (LH; expert) to permit skill-based inferences. Participants completed 45 trials in both low and high anxiety conditions during which cognitive anxiety, somatic anxiety, heart rate, QE duration, BP activity, and putting performance were recorded.

Results indicated that the LH golfers are more accurate and less variable in their performance than the HH group, as revealed by measures of radial error, bivariate variable error, and group centroid radial error. Systematic differences in QE duration and BP were also observed, with experts exhibiting a prolonged quiet eye period and greater cortical activation in the right-central region compared to non-experts. A significant association between cortical activation and QE duration was also noted. Despite performing under high and low anxiety

conditions, QE duration and cortical activation did not fluctuate across conditions. Taken together, the results of this investigation lend primary support to the motor programming/motor preparation function of the QE period. Practical and theoretical implications are presented and suggestions for empirical work provided.

CHAPTER 1
INTRODUCTION

> One of the most challenging putts I've ever faced was the one I had on the final green of the 1999 Bob Hope Chrysler Classic. It wasn't the length or the break that made it hard, of course. The putt was only about seven feet, with a little tail at the end…. It was an eagle putt to win the tournament. And it was for a score of 59, which would be the first sub-60 score anyone on the PGA Tour had ever shot in a final round. I knew that I might never have another chance to set that record. The circumstances surrounding the putt challenged my mind. And putting, I've learned, is all about your mind and your attitude.
>
> --David Duvall

Anyone who has ever stood over a golf putt with the slightest of importance can easily relate to the anxiety, trepidation, and uncertainty that faced David Duval that day. The game of golf is replete with indelible moments in which players have managed to coordinate both the mind and body through volition to achieve. Ever so prevalent, however, are those missed opportunities in which the athlete succumbs to the performance pressures of arguably the simplest stroke in golf.

The golf putt, which accounts for approximately 43 percent of the game's strokes (Pelz, 2000) is a simple, self-paced, closed task that requires minimal athleticism. It is perhaps these superficial aspects of the golf putt that yield such a quandary for both athlete and sport scientist alike. Although motorically simple, the difficulty of the golf putt lies in the golfer's ability to synchronize sensory information with the mechanisms necessary to prepare, produce, and control motor behavior (Craig, Delay, Greely, & Lee, 2000; Pfurtscheller & Neuper, 2003). For example, successful performance mandates that the golfer attend to cues related to distance, direction, and speed; elements that are directly influenced by a multitude of environmental conditions (e.g., slope, grain direction). Accordingly, the visual system must attend to the most salient perceptual cues necessary to ascertain both distance and direction information, while working memory is called upon for matching stroke tempo with the requisite speed of the impending stroke.

An extensive body of evidence suggests that the visual system is the dominant perceptual system by which all other perceptual systems are attuned (Abernethy, 1996; Janelle, Hillman, & Hatfield, 2000; Posner, Nissen, & Klein, 1976; Van Wynsberghe, Noback, & Carola, 1995). The inability to coordinate the visual and motor systems while regulating affective states may confound the mechanical elements of the golf putt, rendering it a difficult and often frustrating task. As such, the ability to attain, master, and demonstrate performance proficiency of motorically simple tasks under varying contextual conditions (e.g., high pressure) can prove demanding even for the most skilled athletes (Singer, 2000), suggesting that optimizing attentional processes during the preparatory period immediately preceding task execution for a self-paced task is of paramount importance (Hillman, Apparies, Janelle, & Hatfield, 2000).

Given that the visual system is the dominant perceptual system, researchers have dedicated considerable effort to addressing the visual search characteristics and gaze behaviors accounting for the attentional factors that preclude the expert advantage. Mann, Williams, Ward, and Janelle (2006) conducted a meta-analysis encompassing nearly three decades of work, examining the many performance metrics and indices of attentional allocation differences of experts and non-experts. The results provide further support for the role of visual attention in the expert advantage, revealing that experts consistently exhibit fewer *fixations* ($\bar{r}_{pb}$ = 0.26) of longer *duration* ($\bar{r}_{pb}$ = 0.23). Such visual search characteristics index an individual's point of interest and relative attention allocation. The longer the eye remains fixated on a given target, the more information is thought to be extracted from the display, permitting detailed information processing. Additionally, the number of visual fixations during a given period provides an index of the search characteristics representative of the most pertinent cues extracted from the environment, thereby facilitating the decision making process. Given the typically dynamic

context of sport, researchers have interpreted visual search strategies involving fewer fixations of longer duration as more efficient, permitting more time for more detailed information extraction (Williams, Davids, & Williams, 1999).

Researchers (i.e., Janelle, Hillman, & Hatfield, 2000; Vickers, 1992, 1996a, 1996b) have turned their attention to additional gaze behavior indices that may reveal expert-novice differences. Of these indices, a promising and robust observation is that experts exhibit an extended *quiet-eye* period relative to non-experts. According to Vickers (1996a), the quiet-eye (QE) is a temporal period when task relevant environmental cues are processed and motor plans are coordinated for the successful completion of an upcoming task. Specifically, the QE period is defined as the elapsed time between the last visual fixation to a target and the initiation of the motor response (Vickers, 1996a). As such, the QE appears to functionally represent the time needed to organize the neural networks and visual parameters responsible for the orienting and control of visual attention (Vickers, 1996a). Collective analysis of the extant literature reveals that experts exhibit longer quiet eye periods ($\bar{r}_{pb} = 0.62$) when compared to less skilled performers (Mann et al., 2006). Furthermore, intragroup variability has also been reported, suggesting that longer quiet eye periods correspond with increased accuracy (Harle & Vickers, 2001; Janelle et al., 2000; Vickers, 1996a, 1996b; Vickers & Adolphe, 1997).

Despite its promise, the underlying mechanism(s) responsible for the robust QE findings remain in question. From a pure visuo-motor perspective, the QE may serve to maximize cerebral efficiency, as reflected in cortical patterns indicative of elite performance (Janelle, Hillman, & Hatfield, 2000; Janelle, Hillman, Apparies, Murray, Meilli, Fallon, & Hatfield, 2000). That is, previous research has consistently reported cortical quieting in visuospatial and motor coordination tasks in the left hemisphere as compared to the right hemisphere at temporal,

mid-frontal, occipital, and parietal regions (e.g., Crews & Landers, 1993; Haufler et al., 2000). Although counter intuitive, a prolonged QE period may be related to this cortical quieting and subsequent notion of expert efficiency. As previously stated, experts in sport generally make fewer fixations of longer duration, suggesting a level of information processing efficiency that permits more time spent on task relevant cues and less time in search of these cues. As such, a prolonged QE may permit a similar advantage; as task-salient cues are efficiently acquired, less effort is spent on the acquisition and processing of such cues, permitting the re-allocation of cortical resources away from the information processing stages of performance and toward the motor programming and execution stages.

Alternatively, researchers (Janelle, Hillman, & Hatfield, 2000; Vickers et al., 1999) have suggested that the QE period may serve an emotion regulation function to maintain processing efficiency (Eysenck & Calvo, 1992) and the effective use of relevant perceptual cues (Easterbrook, 1959), sparing attentional resources necessary for task execution. The following section addresses the two potential mechanisms that may moderate the relationship between the QE period and performance, namely sensorimotor integration and emotion regulation.

Expertise Related Differences in Cortical Activity

Vickers (1996a, 1996b) has relied heavily on basic cognitive neuropsychological evidence to postulate the cognitive architecture that underlies the QE period. In doing so, she cited the work of Posner and Raichle (1991), who proposed a three-component network for visual attention including the orienting, executive, and vigilance networks. The orienting network provides for shifts in attention, while the executive network serves to recognize the most pertinent cues relative to goal directed behavior. The vigilance network, however, serves to maintain focused attention by facilitating the orienting system and suppressing the processing of irrelevant stimuli. A residual effect of the vigilance network may also be the reorganization of

the neural networks responsible for increased visual-spatial processing and the recruitment of the requisite motor program.

To better understand the covert psychological indices of the expert advantage, researchers have made extensive use of electroencephalography (EEG) and spectral analysis techniques to investigate cortical activation and hemispheric specialization during the preparatory period of self-paced closed motor skills such as golf putting (Crews & Landers, 1993), archery (Salazar, Landers, Petruzzello, & Han, 1990), and shooting (Deeny, Hillman, Janelle, & Hatfield, 2003; Hatfield, Landers, & Ray, 1984, 1987; Hillman, Apparies, Janelle, & Hatfield, 2000; Janelle, Hillman, & Hatfield, 2000). Analysis of EEG spectral power, in particular, has revealed that the effectiveness and efficiency of expert performance has a cortical signature that differs from that of non-experts (Deeny et al., 2003; Hatfield et al., 1984; Haufler et al., 2000; Janelle, Hillman, & Hatfield, 2000; Landers et al., 1994). That is, as individuals progressively become more skilled, the cognitive strategies employed during the planning and execution of movement become more routine, demanding fewer cortical resources (Fitts & Posner, 1967; Smith, McEvoy, & Gevins, 1999), resulting in a demonstrable increase in left hemisphere alpha power (i.e., decrease in cortical activity) and performance. The comparison of cortical activation across hemispheres at corresponding reference sites permits an index of hemispheric asymmetry.

Within the psychomotor literature, researchers have demonstrated relatively stable cortical activation across hemispheres in the novice performer, where as the expert reliably demonstrates a pronounced asymmetrical ratio, characterized by a relative increase in left hemisphere to right hemisphere alpha power (i.e., decreased cortical activity). Simply stated, the novice performer requires greater conscious processing (i.e., verbal analytic processing) of the task demands resulting in greater left hemisphere activation (Hatfield et al., 1984). Conversely, the expert

performer operates with greater automaticity and sustained visual-spatial processing as indicated by a decrease in the ratio of cortical activation between left and right hemispheres as the time to execution nears.

In the first attempt to directly relate the QE period to cortical modulations, Janelle, Hillman, and Hatfield, (2000) assessed the psychomotor performance of marksmen. Elite level performance was characterized by significantly longer QE periods and pronounced hemispheric asymmetry, providing the first empirical account of a relationship between the QE period and cerebral efficiency. According to Vickers' (1996a) conceptual account of Posner and Raichle's (1991) three-component network, the QE period may facilitate such cortical differences.

A limitation of EEG spectral activity, however, is the restricted inference from the spontaneous rhythmic oscillations in voltage (Fabiani, Gratton, & Coles, 2000) to a specific brain function or psychological process. Furthermore, the spectral technique decomposes the continuous EEG signal into specific frequency bands (i.e., Alpha, 8-12 and Beta, 13-36) to assess the cortical activity associated with a behavioral state, thereby ameliorating its temporal characteristics. As a result of the associated filtering, cortical excitation and/or inhibition occurring at subsequent frequency ranges may be attenuated. Although Event Related Desynchronization (ERD) procedures permit the precision and inference of time-locked analyses, signal processing of this nature is restricted to the desynchronization of specific frequency bands (e.g., Alpha, 8-13Hz). Moreover, the electro-cortical investigations of movement preparation and volition require a broad frequency range (DC – 40Hz), exceeding that of ERD studies.

A number of psychophysiological investigations have addressed athletes' attentional and preparatory states preceding task execution (e.g., Crews & Landers, 1993; Konttinen &

Lyytinen, 1992) by evaluating the electro-cortical modalities of event-related potentials (ERP) that occur across a range of frequency bands. According to Fabiani, Gratton, and Coles (2000), ERPs offer additional insight into the cortical manifestations that precede or follow a discrete event. The ERP is derived from the average of multiple responses and represents the temporal relationship of cortical activation to a specific event, thereby providing a time-locked index of the psychological correlates of performance. The bereitschaftspotential (BP), or readiness potential (RP) first described by Kornhuber and Deecke (1965), is one class of ERP that lends itself well to the study of the preparatory period preceding task execution. The BP is a negative potential that is characterized by a distinct cortical signature that precedes an actual, intended, or imagined event by 1 to 1.5 seconds and indexes anticipatory attention and movement preparation (Jahanshahi & Hallett, 2003).

The BP is a visually distinct waveform comprised of three components, each of which are temporally and cortically diverse (Deecke, Scheid, & Kornhuber, 1969). The early slow rising negativity (BP_{early}) reflects the activation of the supplementary motor area (SMA) and begins approximately 1500 ms prior to movement onset. The early activation of the BP_{early} has a widespread scalp distribution with maximal potentials recorded at the vertex (Deecke, 1987). According to Roland (1984; Roland, Larsen, Lassen, & Skinhoj, 1980), the SMA serves to retrieve and/or augment the requisite motor commands from memory. Accordingly, the more elaborate the motor sequence, the more precise the corresponding movement should be, as indexed by an increase in SMA activation (i.e., increased negativity). The second component, known as the BP_{late}, is characterized by a change in the steepness of the waveform's slope, which occurs approximately 400-500 ms prior to movement onset, and is known to reflect activation of the primary motor cortex (MI; Deecke, 1987; Shibasaki et al., 1980). Changes in BP_{late} have been

shown to reflect skill differences, such that a decrease in negativity is evident in the hemisphere ipsilateral to the active limb (Taylor, 1978); however the amplitude contralateral to the active limb increases during skilled performance (Chiarenza, Vasile, & Villa, 1990; Papakostopoulos, 1978). Finally, BP_{peak}, which reflects the coordinated activation of the SMA and MI, is most pronounced over the hemisphere contralateral to the responding hand and occurs approximately 50-60 ms prior to movement onset. As Brunia and van Boxtel (2000) state, the components of the readiness potential collectively index the initiation of voluntary, self-paced, motor acts.

Preparatory activity in the general context of sensorimotor transformations implicates an integrated neural path linking perception to action (Toni & Passingham, 2003). As such, the BP reflects activation of subcortical and cortical generators (cortico-basal ganglia-thalamo-cortical circuitry) necessary not only in motor execution but also in its preparation (Rektor, 2003). The BP has therefore been speculated to play a role in the detection and pairing of task relevant environmental features with the requisite elements of response execution (Brunia & van Boxtel, 2000). Accordingly, throughout the preparation and movement phases of skill execution, the visual attention centers (i.e., occipital and parietal cortex) disseminate requisite commands to motor regions of the cortex (i.e., motor cortex, premotor cortex, supplementary motor area, basal ganglia, and cerebellum; Vickers, 1996a, 1996b), all of which are reflected in the BP.

Previous research has revealed that the components of the BP are susceptible to modulation under a variety of environmental and task constraints. For example, the mean amplitude of the BP_{late} has been shown to increase with enhanced motivation (Andreassi, 1980) and reported to nearly double in amplitude with the addition of a monetary incentive (McAdam & Seales, 1969). Perhaps most relevant here, however, is a pronounced BP_{late} with increased response accuracy (Becker, Iwase, Jurgens, & Korhuber, 1976; McAdam & Rubin, 1971) in

visuo-motor tasks. More recently, sport researchers have applied the slow negative ERP paradigm to research with golfers (Crews & Landers, 1993), archers (Landers et al., 1994) and marksmen (Konttinen & Lyytinen, 1992; Konttinen, Lyytinen, & Era, 1999) revealing that elite performance is characterized by an increase in cortical negativity in the period immediately preceding task performance (BP_{peak}), a pattern indicative of the requisite motor program among experts.

Conceptually, the QE period is thought to represent the time needed to organize both the neural networks and visual parameters responsible for the orienting and control of visual attention (Vickers, 1996a, 1996b). Similarly, cortical activation levels are believed to reflect the cerebral efficiency by which the visuo-spatial parameters needed for effective performance are organized. According to Nunez (1995), the cortical efficiency noticed among experts may be the result of decreased cortico-cortical communication, suggesting the deactivation of irrelevant neural pathways and increased attention. Stabilization of gaze behaviors (i.e., increased QE) in experts coupled with an increase in cortical quieting may behaviorally represent a "pruning" (Hatfield & Hillman, 2001, p.378) of irrelevant resources, and the re-allocation of cognitive resources to task relevant components. Therefore, the cortical generators responsible for the BP, which have been shown to correspond with the preparation and execution of a motor task, may in turn benefit from the re-allocation of resources, allowing for the development of a more refined motor program.

Expertise, Visual Search and Emotion Regulation

In addition to its motor planning function, researchers have suggested that the QE period may also reflect a temporal window for the regulation of emotion (Janelle, Hillman, Apparies, Murray, Meili, Fallon, & Hatfield, 2000; Janelle, Hillman, & Hatfield, 2000; Vickers et al., 1999). Given the level of performance uncertainty that accompanies highly competitive and

challenging tasks, corresponding increases in stress, arousal, and anxiety are expected (Jones & Swain, 1992). According to the Processing Efficiency Theory (PET; Eysenck & Calvo, 1992), the interaction of individual state and trait levels of anxiety coupled with environmental constraints (e.g., performance pressure) directly impact the functional capacity of attention, rendering performance less efficient and potentially less effective. Cognitive anxiety, which is characterized by worry and an inability to concentrate, diverts thoughts and cognitions away from task relevant cues and preoccupies cognitions with outcome expectations and evaluation (Liebert & Morris, 1967). According to Baddeley (1986), elevated levels of cognitive anxiety reduce the cognitive resources (i.e., working memory) available and necessary to sustain task relevant processing.

Empirically, Murray and Janelle (2003) employed a dual-task auto racing simulation to demonstrate that the additional cognitive/attentional demands imparted by relative increases in anxiety result in increased search rate, rendering the performer less efficient. The notable reduction in processing efficiency may be in part due to a decreased ability to utilize or discriminate between relevant and irrelevant cues. That is, cue utilization becomes diminished under conditions of heightened anxiety and/or arousal, in which stimulus detection becomes less discriminable and information processing becomes less effective and efficient (Easterbrook, 1959). Though not a direct confirmation of this notion, Murray and Janelle (2006) reported ERP (P3) findings consistent with such an explanation.

Recent gaze behavior research in sport (Murray & Janelle, 2003; Williams & Elliot, 1999; Williams, Vickers, & Rodrigues, 2002) offers empirical support for the theoretical tenets put forth by Eysenck and Calvo (1992) and Easterbrook (1959). For example, Williams and Elliot (1999) examined the effects of cognitive anxiety and level of experience on anticipation and

visual search behavior in karate kumite. The viewing patterns of both groups' (Expert and Novice) were altered under the high anxiety condition as compared to the low anxiety condition, with a marked increase in attention to peripheral cues. Furthermore, search rate increased along with greater anxiety among novices. More specifically, experts in the high anxiety condition demonstrated an increase in the mean duration of their fixations while the mean fixation duration of the novice group decreased. The corresponding increase in search activity in the novice group can be explained by a comparative decrease in processing efficiency and ineffective cue utilization (Williams & Elliot, 1999).

In a related study, Janelle, Singer, and Williams (1999) examined changes in gaze behavior under varying levels of anxiety during a simulated racing task. Results indicated that as anxiety increased, processing efficiency and task performance decreased, while the corresponding gaze behaviors became more variable (i.e., more fixations of shorter duration). Janelle et al. (1999) concluded that anxiety increases attentional narrowing, resulting in the ineffective search and use of cues. Furthermore, Williams et al. (2002) assessed table-tennis performance under combinations of high and low working memory with corresponding changes in anxiety (high and low). As expected, results indicated increased effort, delayed reaction times, and increased search rates while performing under the high working memory and high anxiety condition as compared to the low working memory and low anxiety condition, a pattern indicative of less efficiency. As mentioned, Murray and Janelle (2003) used a dual-task paradigm to assess the effects of increased anxiety on a simulated driving task. Consistent with previous research (Janelle et al., 1999; Williams & Elliot, 1999; Williams et al., 2002), driving performance decreased as anxiety increased concomitantly with search rate, indicative of a decrease in processing efficiency.

Each of the aforementioned investigations lends support to the negative effects of anxiety on performance, processing efficiency and cue utilization. As mentioned, researchers have suggested that the QE period may reflect regulation of emotional states (Janelle et al., 2000; Vickers et al., 1999) so as to alleviate these detrimental effects. That is, the prolonged QE duration that is characteristic of experts may permit them to preclude processing of irrelevant stimuli, thereby circumventing the deleterious effects of anxiety and/or arousal by permitting the recruitment of task specific resources. For example, Vickers et al. (1999) examined the effects of cognitive stress and physiological arousal on the gaze behavior and shooting accuracy of elite biathletes. Although the QE was influenced by modulations in cognitive stress and physiological arousal, QE durations during elite performance were similar across levels of cognitive stress and physiological arousal. Furthermore, Williams, Singer, and Frehlich (2002) assessed the gaze behaviors of skilled and less skilled billiard players. They suggested that increased task complexity necessitates increased resources and preparation, and postulated that if the QE is related to cognitive processing a direct relationship between the two should be evident (Williams et al., 2002). Results demonstrated that as task complexity increased, so too did the corresponding QE period. Expert-novice differences were also evident. Specifically, experts continued to elicit longer QE periods as compared to their novice counterparts, and QE duration was proportionally longer on successful shots than on unsuccessful shots across skill levels, suggesting that the QE period may in fact aid in the circumvention of cognitive constraints (Janelle et al., 2000; Vickers et al., 1999).

Limitations

Although the seminal work of Vickers (1996a) sparked a number of studies corroborating the notion that an extended QE period characterizes experts, none of these investigations have assessed alternative theoretical postulates for the underlying psychological processes accounting

for such differences. As such, the primary motivation for the current investigation was to determine which of the competing accounts of the QE is the most viable for understanding the robust QE findings reported to date.

Notwithstanding the cortical processing advances originating from the early work of Hatfield et al. (1984) delineating levels of expertise, electroencephalographic measures of interest have been primarily spectral. Although the use of ERD and coherence analyses have provided additional insight into the expert advantage, these differences remain topographical, failing to provide theoretical accounts of the psychological processes under investigation (Lawton, Hung, Saarela, & Hatfield, 1998). Although Crews and Landers (1993) and Konttinen, Lyytinen, and Konttinen (1995) have examined the slow potential differences across levels of performance, the psychological variables contributing to cortical differences were primarily ignored in favor of motoric differences. However, according to Jahashahi and Hallett (2003) there are many psychological variables that can modulate the latency and amplitude of the BP. Therefore, one must consider the preparatory state of the individual (i.e., anxiety level) and the impending cortical adaptations (i.e,. changes in latency and amplitude of the BP) necessary to perform.

Finally with the exception of the work of Janelle, Hillman, and Hatfield (2000) and Janelle et al. (2000), the concurrent assessment of ocular and cortical indices has not occurred. Simultaneously recording the QE and the corresponding electro-cortical activity may shed light onto the visuo-motor processes differentiating skill levels. Although, cerebral efficiency has been linked with prolonged QE periods, these findings warrant replication and extension. Given the preparatory implications of the QE as well as the preparatory implications of the BP, a

concurrent investigation of these variables may provide greater insight into the underlying psychological processes of both phenomena.

In summary, researchers have provided evidence, although inferential, in support of the potential mechanisms of superior visuo-motor performance as evidenced by the QE. However, to date, researchers have failed to offer a concrete theoretical or mechanistic account of the QE. As such, the following investigation attempts to explicitly assess two mechanisms, motor programming and/or emotion regulation that may account for the robust relationship between QE duration and performance.

Statement of the Problem

Sport psychophysiologists interested in expertise have provided evidence for a unified theme of psychological efficiency, offering descriptions from the cortical and visual search domains (Hatfield, Hillman, Apparies, Janelle, & Vickers, 1999). The extant body of literature permits the conclusion that expert performance is characterized by regional cortical deactivation (i.e., increased alpha power) coupled with efficient cue utilization (i.e., fewer fixations of longer duration and prolonged QE). Although a relationship between the QE period and cerebral efficiency has been reported (Janelle, Hillman, Apparies, Murray, Meili, Fallon, & Hatfield, 2000), the extent to which such a relationship is evident is tenuous. Therefore, of primary interest in this investigation is the assessment of the underlying mechanisms of the QE period responsible for the psychomotor superiority of the expert (i.e., emotion regulation and/or motor planning).

The Current Study

To assess the extent to which the proposed mechanisms correspond with modulations of the QE period, the BP, which has been proposed as an electrophysiological index of cerebral efficiency during the premotor period (Papakostopoulos, 1978), was assessed under high and low

anxiety conditions. The preparatory set of the performer, which has been indexed by changes in QE duration, may be equally evident in cortical changes leading up to the point of movement execution.

Pursuant to this goal, expert (low handicap; LH) and near-expert (high handicap; HH) golfers were observed for putting accuracy under high and low anxiety conditions to assess the extent to which the QE period modulates the formulation of a motor-program and/or the attention consuming effects of anxiety. Several performance variables (i.e., putting accuracy, RE, MRE, and SRE) were examined to determine if the quiet-period changes under varying levels of anxiety and if so to what extent. Moreover, the extent to which these changes are reflected in the cortical measure of the BP were assessed.

Hypotheses

The following eight hypotheses were tested. The hypotheses address expected BP and QE differences between skill levels, as well as the predicted relationship between the BP and QE under normal conditions. Furthermore, several hypotheses were put forth to address the impact of the arousal-anxiety manipulation on performance, BP, and QE of HH and LH golfers.

1. The use of a monetary incentive, video camera, and written release would produce elevated cognitive and somatic anxiety levels in the high anxiety condition as compared to the low anxiety condition as measured by the Mental Readiness Form – Likert (MRF-L, Krane, 1994) and heart rate (BPM, BIOPAC Systems, Inc, Santa Barbara, CA). The use of such manipulations has been demonstrated to be a valid means for invoking an anxiety response across a variety of tasks (Hardy, Mullen, & Jones, 1996; Janelle, 1997, 2002; Murray & Janelle, 2003).

2. Across both the low and high anxiety conditions, the LH group would perform better (i.e., greater success/failure ratio, and reduced variability on missed putts) and exhibit a longer QE period than the HH group. Previous research has demonstrated consistent and robust QE differences between skill levels in both open and closed tasks (Harle & Vickers, 2001; Janelle, Hillman, Apparies, Murray, Meili, Fallon, & Hatfield, 2000; Mann et al., 2006; Vickers, 1992, 1996a, 1996b; Adolphe, Vickers, & Laplante, 1998; Vickers & Adolphe, 1997).

3. Variability in the duration of the QE would account for both inter and intra-group performance variability. More specifically, the LH group would not only exhibit a longer QE duration as compared to the HH group, but the QE duration of both LH and HH groups for successful putts would exceed the QE duration for missed putts. Research with golfers (Vickers, 1992), marksmen (Janelle et al, 2000), basketball players (Vickers, 1996b), biathletes (Vickers et al., 1999), and volleyball players (Vickers, 1997, 1998) indicates that experts not only demonstrate a longer QE when compared to less skilled performers, but within group performance differences are also notable.

4. Given that the BP is representative of the cortical mechanisms responsible for movement preparation and that increased negativity in the mean BP_{peak} and mean BP_{late} amplitude characterizes greater movement preparation and cerebral efficiency (Chiarenza, Vasile, & Villa, 1990; Papakostopoulos, 1978; Taylor, 1978), it was expected that the LH group would exhibit a greater BP_{late} amplitude coupled with a greater BP_{peak} amplitude compared to the HH group.

5. The mean amplitude of the BP_{late} and the mean amplitude of the BP_{peak} were predicted to discriminate between putts made and putts missed regardless of skill level. It has been suggested that the BP develops during the premotor period, a temporal period that corresponds with decreased heart rate and electromyographic activity that is both steady and tonic (Chiarenza et al., 1990). In accord with Lacey and Lacey's (1978) intake-rejection hypothesis, research assessing heart rate patterning and performance has reported that heart rate deceleration during the preparatory period facilitates sensorimotor efficiency, such that an orienting of attention to task relevant cues is permitted, thereby yielding performance increases (Boutcher & Zinsser, 1990; Crews, 1989; Hatfield & Hillman, 2001; Molander & Backman, 1989; Tremayne & Barry, 1990, 2001). Similar to the sensorimotor efficiency denoted by heart rate deceleration, the amplitude of the BP_{peak} is more pronounced with greater task involvement (McCallum, 1976) and is proportional to the preparatory set (Loveless & Sanford, 1974). Appropriately, an increase in mean BP_{early} amplitude and mean BP_{late} amplitude, coupled with an increase in BP_{peak} amplitude, would be evident for putts made as compared to putts missed.

6. According to Eysenck and Calvo (1992), an increase in anxiety is likely to result in a decrease in processing efficiency, stemming from the additional cognitive/attentional resources needed to perform a desired task. Furthermore, Eysenck (1982) postulates that, although anxiety may elicit a negative affective state, such increases in anxiety may also serve to increase motivation. As such, it is plausible that as environmental task constraints increase perceived anxiety, the corresponding appraisal of task difficulty may also increase. Therefore, I hypothesized that increased negativity for each component of the BP (i.e., BP_{early}, BP_{late}, and BP_{peak}) amplitude would be greater in the high anxiety condition as compared to the low anxiety condition due to a relative increase in the complexity of the task (Lang et al., 1989) and the increased mobilization of resources (i.e., motivation) to successfully complete the task.

7. The QE period is believed to index the time needed to organize the cognitive and visual components associated with the orienting of visual attention and execution of a self-paced task. Cortical and sub-cortical generators associated with the BP are also responsible for the

preparation and execution of a self-paced task. As such, a significant and positive correlation between BP and QE period was predicted. More specifically, I expected that as the duration of the QE period increases, relative increases in the amplitude of the BP_{peak} would be evident. Furthermore, as anxiety levels increase, a corresponding increase in both QE duration and $BP_{components}$ were expected across skill levels.

8. Increases in anxiety result in a corresponding increase in cognitive demand, as evidenced by attentional narrowing (Eysenck & Calvo, 1992) and the inefficient use of perceptual cues (Easterbrook, 1959). Therefore, I hypothesized that both the LH and HH groups would exhibit a longer QE period in the high anxiety condition as compared to the low anxiety condition. That is, an increase in the QE was hypothesized to circumvent the deleterious effects of anxiety, preventing a decrement in performance (Vickers et al., 1999). As such, a corresponding increase in QE duration would permit the allocation of attentional resources to the information processing of the visual cues previously attended to, while suppressing the processing of competing stimuli, thereby facilitating performance.

Although each of the eight aforementioned hypotheses were designed to address the covert psychophysiological differences between expert and near-expert performers, the ability to isolate the role of the QE duration during a self-paced task is principal to all others. Given the extent to which QE differences have been reported in the extant literature, expertise differences were expected. However, the degree to which the skill-based QE differences and BP changes are related offers both pragmatic and theoretical support for the role of pre-performance vision previously unaccounted for. Previous research supports the contention that changes in quiet-duration are directly related to inter- and intra-group variability, including under high stress conditions (Williams, et al., 2002), lending support to the arousal regulation hypothesis. However, the degree to which the QE period is believed to serve a motor programming function is speculative. Given that the BP is responsible for motor planning and pairing of environmental cues to response specifications (Brunia & van Boxtel, 2000), confirmation of a relationship between the QE period and the various BP components would lend empirical support to the motor programming function of the QE period.

Definition of Terms

Anxiety (State). State anxiety is defined as the subjective feelings of tension, apprehension, nervousness, and worry, coupled with the activation of the autonomic nervous system (Spielberger, 1983). Furthermore, anxiety is believed to be comprised of cognitive (i.e., thoughts and worries) and somatic (i.e., perception of physiological arousal such as increased heart rate) components (Liebert & Morris, 1967).

Bereitschaftspotential (BP). The BP, first described by Kornhuber and Deecke (1964), is a negative cortical potential that develops approximately 1-1.5 seconds prior to the onset of a self-paced task, suggesting that the BP has both motor preparation and attention components.

Closed Task. This is a skill that is performed in a stable or predictable environment in which the participant is in control of movement onset (Magill, 1998).

Cortical Generators. Cortical generators are known as the distinct regions of the cortex (e.g., Supplemental Motor Cortex, Motor Cortex) known to have topographical representation of the Bereitschaftspotential (e.g., Frontal, Parietal, Temporal).

Electroencephalography (EEG). The EEG is a process for recording the electrical potential at the scalp associated with the cortical activity of the underlying structures.

Event Related Potential (ERP). The ERP is a time-locked recording of cortical activation in accord with the International 10-20 system (Jasper, 1958). More specifically, the ERP is the result of an averaging of samples recorded from a continuous EEG that is time-locked to a specific event. As such, the averaging technique draws on the signal-to-noise ratio, such that the components of the waveform not deemed related to a specific event are assumed to randomly vary across samples, thereby rendering only a representation of systematic variation or components of the ERP (i.e., slope, amplitude; Fabiani et al., 2000).

Eye-Movement Registration. Eye-movement registration refers to the process of recording the visual search characteristics during a perceptual-cognitive, or perceptual-motor task. The most common procedure is the corneal-reflection method, which records the movement of the eye under the assumption that the central portion of the cornea corresponds with a point of visual interest (Duchowski, 2002; Williams, Davids, & Williams, 1999).

Fixations. Fixations are characterized by the tiny eye movements associated with tremors, drifts, and microsaccades (Duchowski, 2002) that are necessary to stabilize the fovea on a specific target, enabling comprehensive stimulus extraction and information-processing (Williams et al., 1999).

Gaze Behaviors. A gaze is the "absolute position of the eyes in space and depends on both the eye position in orbit and the head position in space" (Schmid & Zambarbieri, 1991, p.229). Therefore, a gaze behavior refers to a specific coordinated action of the eyes and head, which include a saccade, fixation, smooth-pursuit, vestibular ocular reflex, and the QE period.

Perceptual-Cognitive Skill. The ability to identify and acquire environmental information for integration with existing knowledge such that appropriate responses may be selected and executed (Marteniuk, 1976).

Quiet-Eye Period. The QE period, a component of the gaze behavior, is a measure defined as the elapsed time between the last visual fixation to a target and the initiation of the motor response (Vickers, 1996a).

Self-Paced Task. This is a skill that is performed free from external temporal constraints or prompts, while under the volition of the participant.

Spectral Analysis. Spectral analysis is the process of separating an EEG time series into its constituent frequencies (e.g., Alpha 8-12Hz, Beta 13-36Hz) by subjecting the raw EEG data to Fast Fourier Transform (FFT).

Spectral Power. The decomposition of the cortical levels expressed by means of a spectral analysis is inversely related to activation (Pfurstcheller, 1992). That is, spectral power refers to the decrease in activation otherwise known as the cortical quieting of the structures related to a perceptual-motor task. For example, an increase in left hemisphere Alpha power (8-13Hz), suggests a decrease in the amount of activation that is experienced.

Sub-Cortical Generators. Sub-cortical generators represent the deep structures of the brain (e.g., Basal Ganglia, Thalamus, Cerebellum) believed to significantly contribute to the development of the motor program and in turn the cortical structures known to have a topographical representation of the Bereitschaftspotential (e.g., Frontal, Parietal, Temporal).

Stimpmeter. The stimpmeter, designed by Edward S. Stimpson and revised and implemented by the USGA in 1978 (USGA, 2006), is a device used to quantify the speed of a putting surface. The stimpmeter is a V-shaped aluminum bar measuring 36in long and 1/2in wide that is designed to channel the golf ball and reduce unnecessary lateral movement as the ball is released. Positioned 6 inches from the top of the stimpmeter is a precisely milled ball-release notch designed to discharge a ball when the stimpmeter is raised approximately 20 degrees from the ground. The bottom of the stimpmeter is leveled to facilitate the desired angle of release. Three balls should be released independently from the same starting point and measured for the distance each ball travels from the end of the stimpmeter. The average distance traveled is referenced as the speed of the green. For example, if the average distance traveled of three golf balls released from the same position is 9.5ft then the speed of the green is a 9.5.

Visual Search. A two-stage process conducted to identify relevant cues in which a memory dependent systematic search (i.e., serial search) or a memory-less random search of the environment is coupled with a decision process confirming relevant stimulus identification.

Volition. Volition refers to the conscious will to act; a voluntary act that is endogenously driven and free of externally imposed restrictions (Libet, 2003).

Assumptions

The current investigation was conducted under the following assumptions:

1. The Mental Readiness Form – Likert (Krane, 1994) is an appropriate measure for assessing levels of cognitive and somatic anxiety prior to and during the course of the experimental session.

2. The use of a platform covered with a nylon NP 50 artificial putting surface (Synthetic Turf International, STI, Jupiter, FL) outfitted with a 4.25in regulation size golf hole adequately simulates an actual putting surface, thereby promoting ecological validity.

3. The putting task (i.e., 12 ft flat putt) and the corresponding dependent measure of putting accuracy (i.e., made vs. missed putts, bias, and consistency) are appropriate measures of performance.

4. Vertical and horizontal electro-oculogram measures used to derive QE duration are both appropriate and accurate.

5. The extensor carpi ulnaris (ECU) of the right arm is an appropriate muscle to demarcate the fiducial time point necessary for the off-line reduction and analysis of the Bereitschaftspotential and the corresponding cessation of the QE period.

Significance of the Study

The importance of understanding the complex integration of systems associated with expert performance is essential for the advancement of both theory and practice. To date, technological and methodological advances have permitted a rapid increase in research related to expert performance, which has lead to a greater conceptual understanding of the expert performer while executing self-paced, closed tasks. The work of Hatfield et al. (1984) precipitated an increase in theory driven research examining the information processing, cortical adaptations, and central nervous system differences of experts performing sensorimotor tasks. However, it was not until recently that researchers have begun to examine the various mechanisms of perceptual-cognitive expertise in an integrative manner (e.g., Hillman et al., 2000; Janelle, Hillman, & Hatfield., 2000). Of primary importance are theoretical and mechanistic developments stemming for the use of electroencephalographic and visual search technology within an expert-novice paradigm. For example, the use of continuous EEG and spectral analysis have reliably demonstrated the role of the alpha band, and to a lesser extent the

role of the beta I band in the preparatory period of marksmen, golfers, and archers, indicating the virtual automaticity or cerebral efficiency of the expert as denoted by a relative increase in alpha power in the left temporal region. Furthermore, the recent integration of eye movement registration techniques, including the QE period, has offered yet another piece of evidence in support of the expert advantage. However, the specific role that the quiet-period serves is still relatively unknown. That is, although performance has been demonstrated to vary in relation to the length of the QE period, with prolonged periods generally resulting in increased performance, uncertainty and speculation remain as to whether the QE period serves to facilitate the development and implementation of a requisite motor program or if the QE period serves to ameliorate the harmful performance effects of decreased efficiency.

As such, the significance of this investigation is founded on the theoretical implications and methodological innovations put forth. Specifically, my objective was to determine whether differences in cortical activity and QE characteristics could differentiate the expert and near-expert golfer, so as to clarify the role of the QE period in expert performance. I have proposed an innovative approach for the study of expert performance, incorporating a variety of variables that have individually and concomitantly differentiated the expert and novice performer. Moreover, the exploration of the relationship between the BP and the QE would further enable researchers to understand the integrative role of the perceptual-cognitive, motor, and emotional systems in the production of expert performance, while advancing the understanding of the utility of the BP in goal-directed and ecologically valid research. Lastly, the objective of this research was to extend the current state of the psychophysiological domain in sport by linking time-locked events during the preparatory period to distinct cortical signatures during a sensorimotor task.

CHAPTER 2
REVIEW OF LITERATURE

Capturing Expertise

The performance of experts across domains has intrigued scientists for centuries. More recently, scientific enquiry has attempted to put forth a theoretical framework from which the study of expertise can be undertaken in an attempt to deduce the mechanisms that set apart the expert from the novice. Since the principle work of Chase and Simon (1973), researchers have demonstrated that expertise is characterized by an extensive knowledge base that facilitates both stimulus recognition and subsequent procedural execution (Richman, Gobet, Stazewski, & Simon, 1996). To effectively capture the essence of the expert, the many traits comprising such individuals must be understood. As such, the systematic observation and manipulation of both the overt and covert psychological processes of expert and novice performers can provide detailed insight into those mechanisms separating the expert from the novice. To begin, a clear operational definition of what constitutes an expert is warranted.

Definition of Expertise

Sport expertise has been defined as the ability to consistently demonstrate superior athletic performance (Janelle & Hillman, 2003; Starkes, 1993). Although performance competency and mastery are requisite components of expertise, unquestionably other equally prominent components exist. Siedentop and Eldar (1989) concur that a primary requisite of expertise is the ability to demonstrate technical proficiency that is reliable and consistent. However, they also emphasize the importance of the athlete's aptitude to modify performance skills to meet varying contextual conditions. More precisely, experts possess an extensive procedural and declarative knowledge base (McPherson, 1993,1994, 1999, 2000; French, Spurgeon, & Nevett, 1995; French & Thomas, 1987) that enables them to extrapolate important information from relevant

performance cues in order to anticipate and predict future events (Ericcson, Krampe, & Tesch-Römer, 1993). Experts appear to maintain an uncanny ability to recall past performance information providing for accurate decisions of “what to do,” while demonstrating skill superiority (i.e., “how to do it”). However, although the expert may possess a rich knowledge base, processing during the task appears to operate automatically free from cognitive constraints (Anderson, 1982).

Moreover, other researchers have defined expertise as a superior task specific problem solving ability resulting from an extensive array of long-term memories that enhance pattern recognition (Holyoak, 1991). In comparison, Ennis (1994) suggests that experts possess and maintain a diverse repertoire of skills and strategies that can be employed within specific situations and contextual requirements. Elite level coaches have confirmed laboratory findings, stating that the discrimination of expert from novice athletes can be demonstrated along four dimensions, anticipation (i.e., attention to and interpretation of relative performance cues), declarative knowledge (i.e., knowledge of tactical and rule based information), self-knowledge (i.e., sense of own strengths and limitations), and greater cognitive latitude (i.e., quicker and more diverse problem solving) (Lyoka & Bressan, 1998).

Furthermore, technological and methodological advances permitting the assessment of the covert processes associated with performance have contributed to a more complete understanding of the expert advantage. For example, the measurement of electrocortical activity (i.e., EEG), heart rate (HR), and gaze behavior, have revealed pronounced hemispheric alpha asymmetry, cardiac deceleration, and longer QE periods respectively, each of which has been independently associated with superior performance (e.g., Hatfield, et al., 1984; Tremayne & Barry, 2001; Vickers, 1996a).

In sum, research examining the many underlying attributes of expertise, including perceptual, cognitive, and motor behavioral domains, has generally concluded that experts are more efficient, effective, and accurate in recognizing task specific patterns, are more proficient at making decisions, maintain superior procedural and declarative information, have a profound reservoir of contextual cues that are systematically retrievable, and possess an unparalleled ability to foreshadow events and outcomes (Holyoak, 1991; Starkes & Allard, 1993).

Expert Performance

Experts Are Faster and More Accurate at Recognizing Patterns

Skilled performers posses a superior ability to recognize and recall structured patterns during performance within a specific domain as compared to their less skilled counterparts as a result of their advanced knowledge structures that permit the chunking of small bits of information into much larger and more meaningful constituents. Simply, the ability to recognize and recall sport-specific cues is fundamental to memory structures in which previously presented information is encoded into short-term memory and stored in a retrievable form in long-term memory (Woo Sohn & Doane, 2003). It is known that experts acquire knowledge and skills to rapidly program information in long-term memory to facilitate the retrieval of performance information with efficiently processed contextual cues via long-term working memory (Ericsson & Delaney, 1999).

The seminal work of deGroot (1978) with chess masters demonstrated the ability of expert performers to rapidly perceive and store domain specific patterns into memory. Specifically, chess players were exposed to a board configuration for brief intervals. Following exposure they were requested to recite the location of each piece from memory. de Groot (1978) found that chess masters were near flawless in their recall, however players of lesser caliber were significantly less effective. Chase and Simon (1973) extended the work of de Groot (1978) by

implementing a new condition. In addition to being tested on the recall of a typical game board, participants were exposed to a game board with pieces unsystematically arranged. Although Chase and Simon (1973) replicated the initial findings of de Groot, they also found that the pattern recognition abilities of the expert group were context specific. To elaborate, when the chess pieces were arranged in a fashion comparable to an actual chess match, experts recalled the pieces with amazing accuracy. However, when the pieces were randomly placed, performance of the experts declined dramatically, resembling the recall accuracy of the lesser skilled group.

Similarly in sport, researchers have made use of recall paradigms, in which participants are exposed to domain specific slides depicting the strategic positioning of players in offensive or defensive formations. For example, Allard, Graham, and Paarsalu (1980) assessed the speed and accuracy of pattern recognition in basketball players and non-players. Participants were exposed to a series of slides that included structured (i.e., offensive formation) and unstructured (i.e., rebound) game situations for brief intervals of four seconds. Following exposure, participants demonstrated recall ability by identifying player locations on a reduced scale magnetic board. Allard et al. (1980) confirmed the findings of de Groot (1978) and Chase and Simon (1973), revealing that experts were more adept at recalling structured game knowledge compared to the non-player group, recognizing critical strategic patterns that formulate during competition.

Modifying and extending the work of Allard et al. (1980), Starkes (1987) assessed the expert knowledge structures and pattern recognition abilities of elite, skilled, and novice field hockey players. Similar to the Allard et al. (1980) study, participants viewed structured and unstructured slides depicting offensive attacks and turnovers. However, to accommodate the complexity of the field hockey pitch (11-on-11), viewing time was increased from four seconds to eight. Once again, response accuracy and recall ability was measured by identifying player

location on a reduced scale magnetic board. The results demonstrated the superior recall abilities of experts, extending the claim that experts possess domain specific pattern recognition and recall abilities to the sport context. More recently, research with snooker players and soccer players has corroborated these findings (Abernethy, Neal & Koning, 1994; Williams, Davids, Burwitz, & Williams, 1993; Williams & Davids, 1995). The notion that long-term working memory is a requisite skill to meet the particular information-processing demands of domain specific expertise (Ericsson & Delaney, 1999) supports these empirical findings while offering a theoretical account for the expert pattern recognition advantage.

Experts Have Superior Procedural, Declarative, and Strategic Knowledge

Declarative knowledge is "composed of factual information regarding concepts and their interrelationships"(Ennis, 1994, p. 167) including rules and definitions (Thomas, 1994). In comparison, procedural knowledge is "knowledge about how to perform or use the information [necessary to perform]" (Ennis, pg. 167). Consider that the link between a situation and the appropriate action is known as a procedure. Therefore, procedural knowledge can be further clarified by matching the appropriate movement given that a specific situation is coupled with the correct motor execution. As such, response selection and motor execution are matched to the stimulus (Thomas, 1994).

Researchers interested in determining the extent to which declarative knowledge is responsible for distinguishing expert athletes from lesser skilled performers began by adopting a cognitive research paradigm (see Chi, Feltovich, & Glaser, 1981) that required participants to categorize and sort pictures of domain specific stimuli into relevant categories. For example, Allard and Burnett (1985) assessed female basketball players from the Canadian National Team and novice players for their ability to make associations among the contextual cues provided within each picture. Participants were assessed on the extent (i.e., complex vs. simple) to which

basketball relevant categories were clustered (i.e., strategic formations vs. jump shots) and the time taken to form the clusters. The expert athletes systematically divided the pictures into divergent clusters for shots, offensive formations, rebounds, and defensive formations. In contrast, the novice participants were less structured in the organization of the pictures, identifying only two groups: one-on-one and all other formations combined. Allard and Bennett (1985) concluded that experts established higher order knowledge structures that translated into distinct groups based on basketball principles, contrary to the superficial structures portrayed by the novice group.

Although it has been argued that novices, in addition to experts, maintain a substantial declarative knowledge base, research has demonstrated unequivocal differences in declarative knowledge between experts and novices (French & Thomas, 1987; Thomas, Thomas, & Gallagher, 1993). Research with basketball players further corroborates expert-novice knowledge differences. French and Thomas (1987) studied the influence of knowledge, both procedural and declarative, on decision-making ability of high and low skill level. Results revealed that the high skill group not only performed the skills at a higher level, but they also possessed advanced basketball knowledge structures.

As another example, Williams and Davids (1995) tested soccer players of varying ability (i.e., high-skill, low-skill, and physically disabled) on a soccer recall, recognition, and anticipation ability task. The findings revealed that the highly-skilled players demonstrated superior anticipation, recall, and recognition as compared to the low-skill and physically disabled groups, supporting the notion that high level performers maintain a larger and more elaborate declarative knowledge base. Although declarative knowledge alone cannot account for performance differences in a domain that requires the physical execution of a task, it is believed

to be a fundamental component of skill rather than a consequence of experience (Williams & Davids, 1995).

Conversely, procedural knowledge, which is more pronounced in expert performers (French & Thomas, 1987; McPherson, 1993), may better be able to discriminate expert from novice performers. Research with high and low handicap golfers, revealed that the high handicap golfers demonstrated less knowledge about how to perform their skills as compared to the low handicap golfers (Thomas & Lee, 1991). This finding suggests that the low handicap golfers not only knew what to do, but they knew how to do it. The coupling of declarative and procedural knowledge arguably translates into decreased reaction times and subsequently increased decision-making speed and accuracy (Abernethy, Thomas, & Thomas, 1993).

Experts Are Superior at Anticipating Opponent's Actions

The use of advance visual cues has been demonstrated to facilitate sport performance by means of anticipating opponent's actions and decreasing overall response time. More specifically, elite performers have been shown to consistently use advance cues otherwise overlooked by less skilled performers (Williams & Davids, 1998; Williams et al., 1999). Contemporary research in sport has examined skill-based differences in a diverse array of sporting contexts (e.g., badminton, tennis, soccer, etc) using a variety of empirical paradigms to confirm the use of advance cues by highly skilled athletes translating into decreased response time. From an information-processing perspective, Buckolz, Prapavesis, and Fairs (1998) put forth a conceptual framework depicting the advantages of advance cue use in sport (Figure 2-1). Specifically, Buckolz et al. (1998) contend that the effective use of advance perceptual cues serves to alleviate performance restrictions imposed by temporal constraints. That is, a priori information (Figure 2-1, A) derived from either contextual cues (e.g., opponent's strength and weaknesses, environmental conditions, and current match context) and/or body language cues

from of ones opponent (e.g., stance, racket position, speed, body position etc…) can provide critical information necessary to foretell future actions. As a result, outcome expectancies are developed such that the performer engages in either selective preparation (Figure 2-1, J) or anticipatory mobilization (Figure 2-1, H). Therefore, anticipatory mobilization, a product of seeking and using information from advance perceptual cues can result in the elimination of reaction time and the subsequent reduction of movement time by simply permitting the commencement of a response sequence prior to the completion of an opponent's action sequence. Alternatively, selective preparation can reduce reaction time by matching a stimulus cue with a desirable response. For example, preparing to return a flat serve hit down the center line that plays out as anticipated; resulting in a pairing of the stimulus and the response. The ability of expert performers to extract perceptual cues can alleviate the temporal constraints imposed by reaction time. Extensive declarative knowledge can be used to formulate a priori scan paths to facilitate anticipation permitting extended movement times otherwise restricted.

Extensive empirical work has repeatedly demonstrated quicker response times favoring this notion of advance cue use. For example, Helsen and Pauwels (1992) presented penalty kicks, 2-on-2, and 3-on-3 video clips to experienced and inexperienced soccer athletes. Participants were required to physically respond to the scenarios presented on the film by executing a shot on goal or a pass to a teammate. The findings demonstrated that the experienced players were quicker and more accurate in their responses.

In an attempt to extend the work of Helsen and Pauwels (1992), Williams, Davids, Burwitz, and Williams (1994) investigated skill-based differences in anticipation using experienced and inexperienced soccer players in 11-on-11 soccer situations. Participants in this investigation responded verbally as quickly as possible to the final pass destination. Consistent

with previous research, the experienced players demonstrated superior anticipatory skills. Furthermore, Williams and Davids (1998) examined differences in anticipation and visual search strategies in 3-on-3 and 1-on-1 soccer situations. Twelve experienced and 12 inexperienced soccer players were presented with 20 offensive soccer sequences and asked to anticipate final pass location. The results demonstrated that the experienced players were more adept at anticipating final pass destination and did so more quickly as compared to the less skilled participants. Additionally, when aspects of the visual environment were occluded the performance of the advanced group was significantly hindered while the less skilled participants performance remained unaffected, further suggesting that advanced visual cues are requisite components of experienced performers swift and accurate decision-making.

Recent studies in baseball perceptual decision-making have supported expert novice differences. Radlo, Janelle, Barba, and Frehlich (2001) compared groups of baseball players (i.e., varsity players and college students) on a baseball pitch discrimination task that required the participants to identify the type of pitch seen (fastball or curveball) as quickly as possible by pressing one of two buttons. The findings demonstrated that elite performers were quicker and more accurate at identifying the type of pitch, supporting the notion that advanced cues, in addition to extensive knowledge structures facilitate accurate and expeditious decision-making.

Similarly, Abernethy and Russell (1987a, 1987b) demonstrated enhanced anticipatory behaviors of expert performers in badminton. Twenty expert and 35 novice badminton players were required to predict the landing position of a badminton shuttle-cock in response to varying levels of temporal occlusion (see later section on Occlusion Paradigms). Systematic expert-novice differences were apparent with the expert performers demonstrating a prolific ability to use cues presented earlier in the action sequence to predict stroke outcome. The novice

performers were constrained in their ability and required more elaborate schemas to draw definitive and accurate conclusions. In a similar vein, Abernethy (1990b) replicated the findings of Abernethy and Russell (1987a; 1987b) using squash players. The consistent findings of researchers across a variety of sporting contexts employing a diverse array of research paradigms, has repeatedly confirmed the enhanced abilities of experts to pick-up and process advanced cues that facilitate anticipation and response accuracy.

Experts Maintain Superior Perception of Relevant Kinematic Information

The use of advance cues by experts to facilitate anticipation speed and accuracy has proven robust, however the nature and extent of the cues necessary for enhanced decision-making in sport was relatively obscure until the advent of the occlusion paradigm. The seminal work of Jones and Miles (1978) assessed 32 professional lawn tennis coaches and 60 novice undergraduates on their ability to predict the landing location of a tennis serve. Participants viewed 24 serves that were equally distributed and randomly presented down the centerline, to the middle of the service area, or to the extreme right side of the service area. Temporal occlusion varied across three conditions of ball/kinematic exposure including eight frames (336 ms) post ball/racquet contact, 3 frames (126 ms) post ball/racquet contact, and one frame (42 ms) prior to ball/racquet contact. The use of advance cues was evident across conditions and expertise. Response accuracy remained consistent across the two post-contact occlusion conditions, yet were significantly impaired during the pre-contact condition. However, expertise differences were evident during the 126 ms post and 42 ms pre-contact conditions, with the expert level coaches demonstrating significantly better response accuracy, suggesting that experience and skill level can influence advance cue usage proficiency. Specifically, kinematic information was readily available during both post-contact occlusion conditions in which prediction accuracy was relatively stable. However, during the pre-contact occlusion condition,

only kinematic information was available proving to be the contributing factor in the expert-novice difference, with the experts using advance kinematic cues to predict the ball's landing position. Although somewhat of an abstract inference, subsequent research has directly validated this point.

Abernethy and Russell (1987a) implemented a spatial occlusion task, in which specific and relevant display features were masked from the participants. Consistent with the notion that kinematic cues may discriminate expert and novice performers, Abernethy & Russell (1987a) hypothesized that expert-novice differences would arise as the result of the expert performer's ability to pick up on task relevant cues earlier in the movement sequence, cues unattended to by less skilled performers. The spatial characteristics of the relevant advance kinematic cues used by expert (n=20) and novice (n=35) badminton players were assessed while predicting the landing position of a badminton shuttle. Selected areas of the display were occluded, removing task relevant kinematic cues including the opponent's racquet and arm, racquet only, head and face, lower body, and irrelevant background features. Results revealed that skill level influenced the reliance on advance cues, namely relevant kinematic cues. Specifically, expert performance significantly improved from racquet and arm occlusion to racquet only occlusion, whereas as the novice performers showed no additional performance change from one condition to the next. It can be concluded that the expert performers derived task pertinent information from both the racquet and the arm as compared to the novice group that appeared to benefit only from information provided by the racquet. Expert-novice differences in the ability to use spatial cues supports the notion that experts are more adept and in tune with the movement strategies of their opponents, ultimately improving decision-making under tight time constraints.

More recently, Shim and Carlton (1999) examined the influence of visual display on the anticipation of movement outcome on expert (*n*=13) and novice (*n*=12) tennis players. Participants observed an expert tennis player execute four shot combinations (i.e., groundstroke and lob either down the line or crosscourt) under three display conditions (i.e., live, 2-dimensional, or point-light display), at which time they were required to perform the appropriate stroke in response. Consistent with previous findings, the results indicated that the expert players were more accurate and faster compared to the novice players across the three conditions. However, when comparisons were made within groups, the expert players performed significantly better during the live condition as compared to the 2-dimensional and point-light display conditions, whereas no differences were noted across conditions for the novice performers.

In a similar study, Ward, Williams, and Bennett (2002) examined the effects of perceptual display manipulation in tennis. Experienced (*n*=8) and inexperienced (*n*=8) tennis players physically responded (i.e., moved one step toward the direction of the ball) to a series of filmed tennis strokes under normal and point-light display conditions. As expected, the findings showed that the experienced group performed better than the inexperienced group under both conditions. However, both groups under the point-light display condition experienced notable performance decrements. Specifically, the experienced group's response accuracy decreased nearly 10 percent, while the inexperienced group's performance remained constant, suggesting that although relevant joint movements were available, critical advance cues under normal conditions are essential to the performance of skilled players and potentially overlooked by less skilled performers.

Experts Maintain More Efficient and Effective Visual Search Patterns

The visual search literature has systematically illustrated expert-novice differences for fixation location and duration characteristics that are postulated to be indicative of the perceptual strategy used to extract task-relevant information from the environment. Skilled performers apply their advanced knowledge structures as a conceptual framework for adopting more efficient and effective search strategies characterized by fewer fixations of longer duration, while fixating on the more information dense areas of the display. From an information-processing perspective, the eye-movement behaviors of experts is theoretically more efficient and effective because information can be effectively chunked, allowing for advanced associations and inferences, submitting fewer fixations of longer duration.

Furthermore, Vickers (1996a) has proposed a unique gaze behavior appropriately labeled the quiet-eye (QE) period. Simply stated, the QE is a measure of the temporal period between the final fixation to a target and the initiation of a motor response; a period believed to facilitate the coordination of the processing of task relevant environmental cues and the formulation of the requisite motor plan for the successful completion of an upcoming task (Vickers, 1996a). Expertise research has routinely demonstrated that experts exhibit longer quiet eye periods ($\bar{r}_{pb}$ = 0.62) when compared to less skilled performers (Janelle et al., 2000; Mann et al., 2006; Vickers, 1992, 1996a, 1996b). Quiet-eye research has also revealed intra-group differences, suggesting that longer quiet eye periods correspond with increased accuracy (Harle & Vickers, 2001; Janelle, Hillman, & Hatfield, 2000; Vickers, 1996a, 1996b; Vickers & Adolphe, 1997).

Experts Demonstrate Physiological Patterns Indicative of Sensorimotor Efficiency

The information-processing style of the expert-performer has been reliably characterized as more effective, efficient, and less effortful than that of the less skilled. As such, it was postulated that as skill level progressively increases, so too does the automaticity of performance,

suggesting less cognitive involvement and effort among expert performers as compared to less skilled performers (Fitts & Posner, 1967). However, knowledge of the extent to which the expert exerts less effort or is otherwise more efficient has primarily been the product of deductive reasoning stemming from decision-making, visual-search, and response time and accuracy paradigms. Accordingly, the implementation of electrocortical modalities such as electroencephalography (EEG) have served to identify the covert cognitive processing activity and the corresponding momentary changes in cortical activity patterns across tasks and skill levels with excellent temporal resolution supporting the cerebral efficiency hypothesis.

EEG and spectral analysis techniques investigating cortical activation and hemispheric specialization during the preparatory period of self-paced closed motor skills such as golf putting (Crews & Landers, 1993), archery (Salazar, Landers, Petruzzello, & Han, 1990), and shooting (Deeny, Hillman, Janelle, & Hatfield, 2003; Hatfield, Landers, & Ray, 1984, 1987; Hillman, et al., 2000; Janelle, Hillman, & Hatfield, 2000) have reported a progressive increase in alpha power in the left hemisphere and a relative stability in alpha power in the right hemisphere of elite performers as compared to less skilled performers. Given that increased alpha power is inversely related to cortical activation, the information processing style of the expert is deemed more efficient than that of the less skilled performer.

In addition to the continuous EEG and spectral techniques, the use of event-related cortical potentials (ERP) has been a useful tool for determining the time-locked cortical processes associated with a specific event. For example, the Bereitschaftspotential (BP; Kornhuber & Deecke, 1964) which occurs in the preparatory period (i.e., 1-1.5s) immediately preceding a voluntary motor action is believed to represent the requisite preparation for the execution of a motor act (i.e., the motor program) (Brunia & van Boxtel, 2000). Research with marksmen

(Konttinen & Lyytinen, 1993) and golfers (Crews & Landers, 1993) suggests that an increase in BP negativity corresponds with an increased readiness to perform and performance excellence. As such, psychophysiological research has validated a cerebral efficiency hypothesis and further indicates that the expert maintains a well-developed sensorimotor program necessary for performance.

The early work of cognitive psychologists and the relentless inquiry into human information processing have yielded much of the information from which the above conclusions have been inferred. As such, the following section will proceed with a cursory review of the pivotal developments leading up to and significantly contributing to the current understanding of information-processing and cortical changes as applied to sport. Furthermore, an attempt to isolate the gaps in the current understanding with respect to the role of the QE period in motor preparation and/or emotion regulation for successful sport performance will be included.

Visual Perception in Sport

Expert performance is mediated by a number of factors including cognitive and perceptual motor skills, as well as task specific anatomical and physiological adaptations (Ericsson & Lehmann, 1996). Moreover, Janelle and Hillman (2003) postulate that in order "to obtain expert status, athletes must excel in no less than four domains: physiological, technical, cognitive (tactical/strategic; perceptual/ decision-making), and emotional (regulation/coping; psychological)" (p.21). It is commonly understood that expert performance is a product of the delicate balance between innate talents and the amount of practice/training (Ericsson, Krampe, & Tesch-Römer, 1993). Of particular importance is the latter, in which the athletes' declarative and procedural knowledge base develops and becomes both extensive and accessible. The extent of this knowledge can be inferred from indirect perception/action coupling and more specifically by means of the visual search behaviors and advance cue utilization abilities of exceptional

performers as compared to less skilled performers. The following review is an attempt to summarize a dense literature base encompassing the expert-novice paradigm and the varied research methodologies used to partition the perceptual differences noted across skilled and less skilled performers.

Occlusion Paradigms

In an attempt to reveal the most pertinent advance cues present in the environment, or at least those most frequently used by expert athletes, laboratory researchers have made extensive use of the occlusion paradigm. The use of the occlusion approach for the study of sport includes temporal and spatial techniques. In the case of the temporal paradigm, researchers have identified pivotal points during the flight of a ball, shuttle, or movement of an opponent at which time further visual information becomes inaccessible (e.g., a blank screen appears). Typical sport occlusion paradigms often include experimental conditions similar to the following adapted from Abernethy and Russell's (1987a) investigation of racquet sport athletes to assess advance cue usage:

t1: Occlusion of the display 4 frames (≅ 167msec) prior to racquet-shuttle contact;
t2: Occlusion of the display 2 frames (≅ 83 msec) prior to racquet-shuttle contact;
t3: Occlusion of the display at the point of racquet-shuttle contact;
t4: Occlusion of the display 2 frames (≅83 msec) subsequent to racquet-shuttle contact:
t5: No occlusion of the display until all outward flight of the shuttle was completed.

Recognizing the inherent limitations of temporal constraints (e.g., incomplete viewing of task), researchers have adapted the paradigm to occlude spatial or event cues. The advent of spatial occlusion techniques allotted the researcher more experimental control over what features of the display the participant could and could not see. Of primary importance, spatial occlusion permitted a continuous stream of information to be provided to the participant with the exception of the critical cues in question, allowing the researcher to isolate and infer the perceptual

strategies of an athlete. Adapted from Abernethy and Russell (1987b) the following sequence depicts a typical approach to the implementation of a spatial occlusion paradigm and its experimental conditions.

e1: The player's racquet and arm holding the racquet were occluded;
e2: The player's racquet (but not the arm holding it) was occluded;
e3: The player's face and head were occluded;
e4: The player's lower body was occluded;
e5: Irrelevant background features were occluded.

Occlusion Research

In a seminal study, Jones and Miles (1978) adopted the temporal occlusion paradigm in their investigation of advance cue use in lawn tennis. In support of the superior ability hypothesis of experts to extract relevant information from advance cues, Jones and Miles concluded that perceptual information germane to decision accuracy is readily available to athletes throughout the flight path of a tennis serve, regardless of performance level. However, as pertinent cues were occluded, level of expertise accounted for significant differences in prediction accuracy. Specifically, when the serve was occluded shortly (126 ms) after impact, performance differences were notable. Additionally, when occluded just (42 ms) prior to ball-racquet contact, performance differences were pronounced in favor of the top-level performers, signifying the ability of skilled tennis players to effectively make use of advance perceptual information in the performance environment typically provided by the opposing player.

In a similar study, Isaacs and Finch (1983) assessed the anticipatory timing of beginning (n= 34) and intermediate (n= 16) tennis players. Four temporal occlusion conditions (i.e., 10 msec before contact; 0 msec at contact; 15 msec post-contact; and 30 msec post-contact) were implemented to examine differences between tennis proficiency level and the participant's ability to accurately predict the placement of a tennis serve. Immediately following each viewing condition participants indicated the anticipated landing position of the serve on a specially

designed score sheet which replicated the divisions placed on the deuce service court during the filming of the serve. Based on the recommendations of Jones and Miles (1978), Isaacs and Finch assessed not only the percentage of correct responses for exact ball location, but also the degree of accuracy for latitude (direction) and longitudinal (depth) predictions. The results of this investigation mirrored those of Jones and Miles (1978). That is, players of greater ability were more accurate in their predictions of landing area across occlusion conditions, with more pronounced differences evident in the 10 ms prior to the ball-racquet contact occlusion condition, the condition with the least amount of advance perceptual information requiring the greatest amount of inference. Moreover, the intermediate players also demonstrated superior latitudinal prediction precision across temporal conditions, while longitudinal differences were less distinct. Additionally, a significant time effect was evident, as was a significant interaction of ability by time. The authors concluded that in the latter condition players of intermediate and novice ability did not posses the requisite skills to identify slight racquet angle variations during the serve, cues that are subtle and sufficient enough to influence the perception of service depth.

However, the very nature of stimulus presentation methods used in occlusion paradigms presents an inherent limitation of this type of research. In accord with the commentary provided by Isaac and Finch (1983), the inability for the intermediate performers to accurately predict longitudinal placement may not be at all related to ineffective cue use, but rather the result of using a two dimensional representation of a three dimensional space. Simply, the angle at which the film was recorded may have indirectly occluded the information necessary to acquire depth perception cues. Nevertheless, skill proficiency has again accounted for differences in the ability to predict the landing position of a tennis serve across temporal occlusions conditions.

In an attempt to extend the previous research, Abernethy and Russell (1987a) conducted two experiments to independently establish and compare the temporal and spatial characteristics of the advance cues used by expert and novice sport performers. In Experiment 1 five temporal occlusion conditions were used (i.e., 167 msec prior to racquet-shuttle contact; 83 msec prior to racquet-shuttle contact; occlusion at the point of racquet-shuttle contact; 83 msec subsequent to racquet-shuttle contact; and no occlusion). Participants were 20 expert and 35 novice badminton players who were required to predict the probable landing position of a badminton shuttle. Immediately following each trial, all responses were recorded on a scaled representation of the receiver's court. The findings were consistent with previous results, in that differences in prediction accuracy were notable between expert and novice performers across occlusion conditions. That is, from 83 msec prior to racquet-shuttle contact through the no-occlusion condition, expert and novice players differed in their performance accuracy. The authors also concluded that the cues essential for successful directional perception are present during the interval between 83 msec prior to racquet-shuttle contact and 83 msec post racquet-shuttle contact, while depth perception cues are present in the final 83 msec prior to racquet-shuttle contact. The collective findings suggest advance cues are apparently critical for depth perception whereas a greater window of opportunity presides for directional detection (Abernethy & Russell, 1987a).

In an effort to isolate expert's attention to the most salient of perceptual cues, Abernethy and Russell (1987a) adopted a spatial occlusion paradigm in Experiment 2, allowing for the constant temporal display of perceptual information while controlling the occlusion of explicit cues. The same population of badminton player's participated in this study as in study one. In a similar fashion, 32 different badminton strokes were included and subject to occlusion. The

following features of the display were systematically removed: (e1) the player's racquet and arm holding the racquet; (e2) the player's racquet; (e3) the player's face and head; (e4) the player's lower body; and (e5) an irrelevant background feature. The results of experiment two were again consistent with previous occlusion studies. The expert group demonstrated superior prediction accuracy (i.e., lower radial error, lateral error, and depth error) across occlusions conditions, with the exception of occlusion condition (e1), in which expert-novice performance was indistinguishable.

It should be noted however, that although within group comparisons revealed significant performance improvements from condition (e1) to (e2) for the experts, the novice performers' accuracy did not change. These results signify the fundamental differences between experts and novices for predicting the landing position of the badminton shuttle. First, experts were able to glean useful information from the opposing players arm compared to the novice player's who were only able to extract useful information from the opposition's racquet. Second, the time in which principle information was removed from a distal (e.g., racquet) to a more proximal (e.g., dominant arm) region signifies the advance use of kinematic information that precedes the motion of the more distal racquet to encode subsequent racquet movement and ball flight information. The two stage experimental approach used by Abernethy and Russell (1987a) not only provides additional empirical support for the findings of previous researchers (i.e., Jones & Miles, 1978; Isaac & Finch, 1983) employing temporal occlusion techniques, but Abernethy and Russell (1987a) were able to further isolate the importance of specific perceptual cues (i.e., opposing player's arm) necessary for the accurate estimation of the badminton shuttles' landing position.

In a follow-up study, Abernethy and Russell (1987b) replicated the temporal and spatial occlusion technique as reported earlier (Abernethy & Russell, 1987a). However, in attempt to extrapolate to the expert advantage of superior anticipatory cue use, eye movement registration equipment was implemented to assess the search strategies of expert and novice badminton players (for a discussion of the visual search findings, please see the section entitled *Visual Search)*. Results from this study echo those of earlier work. Expert players maintained a significantly lower prediction error rate across all temporal occlusions conditions except (t1), 167 msec prior to racquet-shuttle contact, and across all spatial occlusion conditions except (e1), the occlusion of racquet and arm**.** In the current context, the authors concluded that only the experts possessed the necessary knowledge structures to systematically construct perceptual connections from the information provided in the environment to that which was necessary for successful performance.

Despite the robust expert-novice differences across a variety of racquet sports, Abernethy (1988) set out to understand the developmental characteristics of perceptual skill and selective attention contributing to such differences using both temporal and spatial occlusion techniques. Matched groups of relative expert and novice badminton players from four distinct age groups (i.e., 12yrs, 15yrs, 18yrs, adult) were assessed using the same occlusion task previously employed by Abernethy (1987b). It was hypothesized that the expert group would systematically use advance cues more proficiently than novices and that this distinction would become more apparent across groups as the participants became older. Consistent with previous findings in sport (Abernethy & Russell, 1987a, 1987b; Isaac & Finch, 1983) it was further predicted that selective attention would vary as a function of skill level. Analysis of the radial error in the temporal occlusion condition revealed significant performance differences among

age, expertise, and occlusion conditions. These results signify the developmental changes associated with skill proficiency. That is, high skill combined with maturation appears to positively influence perceptual skill but maturation has little to no effect when performance ability is low. Figure 2-2 depicts this relationship between age effects and expertise on anticipatory cue use as a function of the occlusion condition.

The implementation of the temporal occlusion condition identified critical age and expertise differences during the most significant viewing times for attaining advance perceptual cues. However, the extent to which selective attention influences prediction accuracy as a function of age and skill could not to be determined. Therefore, in an attempt to bridge this gap Abernethy & Russell (1987a) conducted a spatial occlusion analysis and upheld the previous findings reported earlier. Results indicated that experts, regardless of their age, are more adept at extracting perceptual information from both the opponent's racquet and arm whereas novice badminton players were inept at using the kinematic cues provided by the opposing player's arm, relying on the racquet only for advance perceptual information.

Abernethy and Russell (1987b) examined the perceptual differences of two groups distinct in performance ability (i.e., international level and novice undergraduate students), identifying ostensible expert-novice differences. The comparison of such variable performers lends itself to large effects. However, Abernethy (1989) probed further in an effort to determine the sensitivity of these differences and whether or not the perceptual advantage was merely a product of expertise. Using a temporal and spatial occlusion task (see Abernethy & Russell, 1987a) intermediate (n=12, skilled but not elite) and novice (n=15, undergraduate students) badminton players were assessed on their ability to predict, from the film presented, the probable direction of their opponent's stroke. The results of the temporal condition show intermediate-novice

differences beginning as early as 167 ms prior to racquet-shuttle contact with the largest differences evident 83 ms prior to contact, confirming Abernethy and Russell's (1987a) previous findings with expert and novice players. The results of the spatial occlusion task also illustrate intermediate-novice differences in the prediction of stroke direction. Most notably, the error rate for occlusion conditions e1 (arm and racquet) and e2 (racquet only) differed significantly for both groups as compared to all other occlusions conditions. However, inconsistent with previous findings (Abernethy & Russell, 1987a), the intermediate group did not "statistically" perform better than the novice group during condition e1, yet it should be noted that performance trends were similar to the expert-novice differences of Abernethy and Russell (1987a). These results signify that perceptual advantages are evident with elevated levels of performance, even though performance may not be elite (Isaac & Finch, 1983).

In another study of tennis players, Buckolz, Prapavesis, and Fairs (1988) attempted to delineate the specific advance perceptual cues used by advanced (n=21) and intermediate (n=23) tennis players during passing shots. A series of tennis strokes (i.e., down-the-line, cross-court, and lob passing shots, for both forehand and backhand) were filmed at two different speeds (i.e., 24 frames/second and 48 frames/second) allowing for greater experimental control over the duration of cue exposure. A temporal occlusion paradigm was used to facilitate the identification of the cues used by and those that discriminated between the advanced and intermediate players. The authors unconventionally ordered the sequence of film clips, beginning with the most occluded condition (168 ms at 24frames/second and 84 ms at 48frames/second prior to ball contact) for a given stroke through to the least occluded condition (168 ms at 24frames/second and 84 ms at 48frames/second post ball contact) for that stroke. Once each occlusion condition had been delivered for a specific stroke, the next stroke was introduced. To further clarify, each

participant viewed each stroke under all occlusion conditions and at both film speeds prior to viewing the next stroke in the same sequence under the same conditions.

The results of Buckolz et al. (1988) are consistent with those previously reviewed; experts maintained an advantage over novice performers when advance perceptual cues were available. With the exception of down-the-line passing shots, significant differences were evident during the 168 ms prior to ball-racquet contact and at the moment of ball-racquet contact. In addition to providing further empirical support in favor of expert's ability to use advance cues, a significant contribution was garnered. Specifically, regardless of the duration of temporal viewing period and the amount of early ball-flight information, it was more difficult for participants to accurately anticipate the backhand shot as compared to the forehand. Even though experts are adept at attending to specific kinematic cues that often aid in the prediction of stroke outcome, experts are unable to anticipate much better than chance in the event of a backhand.

The previous research, although significantly contributing to the empirical understanding of expert-novice perceptual differences, neglected the potential role of peripheral vision in cue acquisition and utilization. In a modified occlusion paradigm, Davids, Rex Pe Palmer, and Savelsbergh (1989) examined the anticipatory ability of elite, club, and recreational tennis players using a forehand volley. Although an occlusion paradigm was used, the nature of the paradigm and the experimental task differed from those previously discussed. Participants wore a helmet that included Perspex sheets (i.e., opaque, clear, and no-screen), and acted as a visual occlusion device, reducing the visual field by 70° and thus occluding perception of the participant's own arm and racquet for the final 100-150 ms of ball flight. Although researchers typically view perceptual skills as those relative to the flight and landing location of a projectile or the movements of an opponent, perceptual skills in this case related to hand-eye-coordination

and the interception of a projectile in flight. In essence, this investigation assessed the role of the visual system and information processing during perception-action coupling. Participants were rated on placement accuracy and stroke quality while volleying a tennis ball at two separate speeds (i.e., 29.06 m/s and 20.12m/s). The tennis court was divided into distinct scoring zones to tally points for accuracy while quality was determined by a direct hit versus a miss-hit. Results indicated that performance was superior in the slower ball speed condition across skill levels, while there were no reported differences across screen conditions or levels of expertise.

Davids et al. (1989) speculated that to execute a tennis volley, one does not rely on visual feedback of effectors (i.e., one's own arm and racquet) due to the large surface area of the racquet, which is responsible for the interception of the projectile. However, the lack of skill-based differences may be a product of the task. Specifically, a ball machine was used to deliver the ball to be volleyed. With the exception of the variable ball speed, the machine operated with relative positional consistency and accuracy. Therefore, in a matter of a few trials it is suspect that even the most novice performer could anticipate with relative accuracy the end-point of the incoming ball relative to one's body position. Although an attempt was made to implement an ecologically valid task, a more dynamic approach (e.g., including backhand shots) is warranted. Additionally, the fact that the effectors were occluded for only the final 100-150 ms suggests that relative body positioning may be occurring relatively earlier in the perceptual-motor process rendering the final temporal period obsolete.

Returning to the typical temporal occlusion paradigms of earlier researchers, Goulet, Bard, and Fleury (1989) assessed expert (n=10) and novice (n=10) tennis players on their ability to correctly identify the type of serve presented (i.e., flat, top-spin, slice) under five occlusion conditions (i.e., (1) Preparatory Phase (875 ms), (2) Preparatory Phase until elbow reached

maximal height (1125 ms), (3) Preparatory Phase until ball/racquet contact (1208 ms), (4) Ritual Phase until ball/racquet contact (4710 ms), (5) entire serve without occlusion(5048 ms)). Bard and colleagues present results are consistent with previous occlusion research in that expert tennis players are better able to extrapolate and interpolate perceptual information to facilitate prediction accuracy. Additionally, experts not only use the information they extract differently they require less information all together (Goulet, Bard, & Fleury, 1989). Unique to this investigation however, the authors also assessed decision time and concluded that experts were not only more accurate but they arrived at their decisions much quicker than novices. Perhaps this distinction is the result of requiring less information to reach their conclusion while benefiting from the information that appears earlier in the display as compared to the novice players who depend on information presented much later in the event sequence.

To identify the specific visual cues used during squash performance as well as any systematic differences that may arise in cue use between expert and novice performers, Abernethy (1990a) applied the same paradigm to the study of expert and novice squash players (for the occlusion conditions applied, please refer to Abernethy and Russell, 1987a discussed earlier). Participants (expert, *n*=16; novice, *n*=20) viewed a sequence of film depicting variations of squash stroke and were required to verbally respond to the force and direction of their "opponent's" shot (i.e., down or cross for direction and long or short for force) with the intention of predicting the terminal point of the stroke. Unique to this investigation, participants were interviewed following the experiment and asked to reflect upon their experience and the "naturalness"(p.23) of the task as compared to that of an actual squash experience. Additionally, participants were probed as to the importance of each of the seven perceptual cues made available during the testing session (i.e., opposition's racquet, head, lower body, torso, dominant

arm, non-dominant arm, and court position). Results from the temporal occlusion condition for lateral error again supported previous findings, indicating that experts extracted information earlier in the visual display (i.e., 160-80 ms prior to ball/racquet contact) and more information (i.e., kinematic cues) than novice players, enhancing the prediction accuracy for stroke outcome. Additionally, experts were better able to predict stroke force (depth) as compared to novice squash players across occlusions conditions. Surprisingly, both the expert and novice groups continually improved prediction accuracy from (t1) through (t5). Previous findings have noted that novice performers typically do not improve performance until much later in the display (t3), however this does not appear to be the case here. According to Abernethy (1990a), squash players may have a tendency to reveal more accessible information about stroke depth earlier in their preparation than badminton players, implying that the existing occlusion condition failed to suppress a sufficient amount of advance information.

Results from the spatial occlusion condition for lateral error mirrored those of the temporal condition, in that the experts were more accurate in their predictions across conditions. However, contrary to previous investigations (i.e., Abernethy, 1988; Abernethy & Russell, 1987a) that have reported differences under occlusion condition (e1)-(e2) for experts and as early as (e2)-(e3) for novice performers, no within group performance differences were noted across occlusion conditions. Again, expertise differences were noted for depth error, with the skilled players predicting more accurately across all occlusion conditions. In accord with previous findings, both experts and novices demonstrated performance decrements when both the racquet and arm were occluded. Yet, unique to squash, the opponent’s head was also a significant source of advance information as illustrated by systematic performance decrements in prediction accuracy across groups while the head was occluded.

Previous researchers (e.g., Jones & Miles, 1978) have questioned the ecological validity of laboratory-based investigations. Therefore, in response to such skepticism, Abernethy (1990a) employed a subjective self-report index assessing the 'naturalness' (i.e., ability to replicate and provide a life-like simulation) of the visual display characteristics and temporal stress associated with squash performance. Results revealed no differences between experts and novices with a mean group rating of 4.53 out of 7 for display characteristics and 3.47 out of 7 for temporal stress. This finding suggests that participants were relatively engaged by the film task but thought the trial-to-trial period was too great, failing to capture the tempo of competition.

Abernethy (1990a) also collected subjective data to isolate the importance of specific perceptual cues that may account for the robust expert-novice differences. Both the expert and novice groups identified the racquet and the arm holding the racquet as the most important cue, a finding consistent with Abernethy and Russell (1987a). Empirically, novice performers appear unable to utilize advance kinematic information in a manner similar to the experts, yet no subjective differences identifying the most pertinent sources of information were noted. As such, experts apparently not only know where to look but they also maintain a wealth of declarative information, information that is seemingly unavailable to the novice performer.

The laboratory basis of the previous occlusion studies, although sound methodologically, have been questioned for their ecological validity. For example, Jones and Miles (1978) discuss the inherent sterility of the laboratory and the inability of a laboratory setting/task to accurately elicit comparable performance states. Such limitations may confound the empirical estimates of perceived expert-novice differences. Additionally, Abernethy and Russell (1987b) questioned the validity of the film presentation used in previous research and suggested that the use of film may neutralize any notable expert-novice differences.

With direct consideration given to the potential confounds of the laboratory, Abernethy (1990b) implemented a two experiment design. Experiment 1 was conducted inside the laboratory and Experiment 2 on a squash court using a temporal occlusion technique supplemented with the collection of eye movement data. The overall visual search findings of Experiment 1 will be discussed in a later section.

In the first experiment Abernethy (1990b), squash players were required to predict the stroke outcome from a filmed representation of an opposing player. Experimental conditions included the same temporal conditions as reported in Abernethy and Russell (1987b). Analyses of prediction accuracy for both stroke depth and direction across occlusion conditions revealed significant expert-novice differences, confirming the utility of advance cues for skilled players. In light this robust finding, improved prediction performance was found for stroke depth as compared to stroke direction across skill levels. This finding was contrary to previous research (i.e., Isaacs & Finch, 1983) that had reported increased difficulty for players to detect slight racquet variations and kinematic cues responsible for changes in depth. Overall, the findings support the rapid abilities of expert athletes to make use of more cues germane to prediction accuracy (Abernethy & Russell, 1987a, 1987b; Jones & Miles, 1978; Isaac & Finch, 1983). However, despite this finding, only slight visual search characteristics were evident, with the expert allocating more fixations to their opponent's arm and head coupled with fewer fixations to the contact zone as compared to the novice performer. Moreover, across the entire visual search sequence no skill-based differences for fixation duration were evident.

In the second experiment, in which a field-based assessment was conducted, the same basic conclusions were derived. Simply, although the experts outperformed the novice comparison group, the visual search behaviors of the experts were virtually indistinguishable

from the search behaviors of the novice group. Abernethy further concluded the perceptual advantage of the expert, although evident, is not the result of access to specific visual information, but rather the "capability to extract and utilize information from key fixation points" (Abernethy, 1990b, p. 75).

Analyses of individual, interceptive, racquet-sports have been the dominant choice for the bulk of research on advance visual cue use in sport. Although a wealth of information has been obtained from such work, little has been done to identify the critical cues for successful anticipation in team sports that are arguably inundated with more complex visual environments. Often in team sports, the anticipation of and reaction to the development of offensive plays results in their successful prevention. In-line with this logic, Wright, Pleasants, and Gomez-Meza (1990) examined the perceptual strategies of experienced (n=12) and novice (n=12) volleyball players' ability to identify the 'spiker' (i.e., left, right, or center net position) to whom the 'setter' intended to pass. A temporal occlusion paradigm was used to systematically alter the amount of visual information pre and post setter contact. The five conditions were as follows: C1: 167 ms (5 frames) prior to initial setter contact; C2: at initial setter contact; C3: 167 ms (5 frames) after initial setter contact; C4: 333 ms (10 frames) after initial setter contact; C5: 499 ms (15 frames) after initial setter contact. All decisions were recorded and analyzed for response accuracy and subjective reports were collected in an attempt to identify the most salient cues. Results indicated that the experienced group demonstrated superior response accuracy across occlusion conditions (i.e., C1-C3) with the most pronounced differences occurring at initial 'setter' contact (C2). No differences were noted for conditions C4-C5; both groups performed with 100 percent accuracy. Furthermore, the information garnered from the self-reports for assessing the perceptual strategies of these participants was distinct. The experienced group reported focusing on the

setter's body, followed by hands and ball flight. Conversely, the novice group identified the overwhelming importance of ball flight, followed by the 'spikers' move, and setter's body as the most pertinent cues. These variations in perceived locus of attention are exclusive to this investigation, as the study by Abernethy (1990b) found no differences in self-reported direction of attention between experts and novice squash players. Based on the unique characteristics of each sport one can only speculate as to the root of these differences. Regardless, the work of Wright et al. (1990) extended beyond racquet sport research to volleyball signifying the importance and effective use of advance visual cues by experienced athletes across multiple sports.

Houlston and Lowes (1993) further addressed the depth and direction prediction while assessing the cue-utilization processes of expert (*n*=6) and non-expert (*n*=6) wicketkeepers. A film occlusion technique with four distinct temporal conditions including; (t1), ball release; (t2), 156 msec post release; (t3), 234, sec post release; (t4), 390 msec post release) was used. Wicketkeepers were required to view a series of distinct deliveries and anticipate the landing position of the ball. A target mat was positioned in front of the batting wicket that was used to assist in the scoring of pitches. All predictions were recorded on a scaled version of the target mat and were evaluated for radial error as well as depth and lateral error. The results of this investigation were atypical to those previously noted. That is no differences between group prediction accuracy were noted across occlusion conditions. However, significant prediction differences were evident for lateral versus depth error; both the expert and novice groups predicted lateral error more accurately across occlusion conditions as compared to depth predictions with a significant improvement in depth perception occurring under (t4). The results suggest that lateral estimations can reliably occur early in the perceptual process, while depth

estimations require more time and more detail to be extracted in order to approach a level of accuracy resembling lateral estimations (see Figure 2-3).

Up to this point in the review, the majority of the investigations of advance visual information in sport have relied on the use of laboratory based film occlusion techniques, with one notable exception (Davids, Re Pe Palmer, & Savelsbergh, 1989).In an attempt to extend the findings from the laboratory to the real world, Starkes, Edwards, Dissanayake, and Dunn (1995) examined the role of experience and skill in the use of advance visual cues in volleyball. Skilled (*n*=8) and novice (*n*=8) volleyball players were assessed on their ability to predict the landing position of a volleyball serve while standing in the center of the service reception side of a regulation volleyball court. Participants were fitted with liquid crystal visual occlusion spectacles, which were used to occlude the volleyball serve at three distinct stages (i.e., (e1) pre-contact (ball reached highest point in toss), (e2) contact (hand struck the ball), and (e3) post-contact (prior to the ball crossing the net)). Participants observed the serves under the various occlusion conditions and then placed numbered markers on the floor indicting the anticipated landing position. Results from this investigation confirmed differences in expert-novice perceptual abilities; with the experts performing significantly better across all occlusion conditions. A significant effect for occlusion conditions was also noted, signifying that pre-contact occlusion proved most challenging to both skill levels. No differences were noted between the contact and post-contact occlusion conditions. It can therefore be concluded from this field study of advance perceptual cue use that experts extract more pertinent cues allowing for more accurate responses.

In a re-examination of the differences in anticipatory decision-making in tennis among expert, intermediate, and novice level players, Tenenbaum, Levy-Kolker, Sade, Liebermann, and

Lidor (1996) used a temporal occlusion paradigm. Eight different tennis strokes were video taped (1. Cross-court slice, 2. Forehand down the line, 3. Backhand down the line, 4. Backhand (winner) down the line, 5. Forehand volley (winner) near the net, 6. Serve, 7. Backhand drop volley cross-court, 8. Forehand cross-court) and were presented in the laboratory using the following six occlusion conditions:

1. 12 frames (-480 msec) prior to ball-racquet contact.
2. 8 frames (-320 msec) prior to ball-racquet contact.
3. 4 frames (-160 msec) prior to ball-racquet contact.
4. At the point of ball-racquet contact.
5. 4 frames (+160 msec) subsequent to ball-racquet contact.
6. 8 frames (+320 msec) subsequent to ball-racquet contact.

After viewing each occluded stroke participants responded as quickly as possible to the landing position of the ball. A response sheet with a scaled replica of the tennis court was used to record the predicted landing locations. Radial error for response accuracy was assessed across occlusion conditions.

The results of this investigation mirrored those of previous research, with the expert and intermediate groups outperforming the novice group in the advance occlusion conditions (i.e., -480, -320, and –160 msec prior to ball-racquet contact). No differences were noted between the expert and intermediate groups across occlusion conditions, suggesting that the benefits of advance perceptual skill may reach an asymptotic point when a level of performance competency has been attained. In conclusion, early temporal cues (i.e., cues up to the point of ball-racquet contact) appear to be detected and relied upon by skilled players, while remaining unprocessed by less skilled performers.

Interceptive sports such as the racquet sports discussed here (i.e., tennis, badminton, and squash) are predominant across sport science research on cue utilization. One of the few exceptions to this rule is the work of Paul and Glencross (1997) with expert (n=15) and novice

(*n*=15) baseball players, which examined the use of visual information throughout the duration of a baseball pitch using a typical temporal occlusion paradigm, including: (t1) 80 ms prior to the moment of ball release (MOR); (t2) at MOR; (t3) 80 ms after MOR; (t4) 160 ms after MOR; and (t5) 240 ms after MOR. Batters were required to predict, as quickly as possible, the location of the pitch as it passed through a grid imposed over the strike zone. Unlike previous findings (e.g., Abernethy & Russell, 1987a; Goulet et al., 1989; Jones & Miles, 1978) experts and novices did not differ in their ability to predict the landing position of the projectile. Even more peculiar was the direction of the trend (Figure 2-4). Systematic differences have been demonstrated indicating the ability of high skilled players to make better use of advance cues with differences in performance ability marginalized later in the temporal conditions. However, the opposite trend was depicted here; as more time was allotted to view the flight of the ball (i.e., ≅ 10 m) the larger was the difference in mean error scores between the expert and novice groups. Finally, when viewing pitches it appears that the first 80 ms (t3) after the pitch has been released is the most crucial to pitch detection, as the most notable performance differences between skill levels occurred at this point in time. In addition to group differences, (t3) is a critical time frame for pitch recognition, that is, distinguishing the type of pitch (e.g., curveballs vs. fastballs).

Experts' ability to extract advance cues for pitch recognition and prediction accuracy is questionable in the study of expert and novice baseball players. However, consistent with previous research, the temporal relationship between perceptual cue use and prediction accuracy still holds in favor of the expert performers, albeit occurring later in the cue extraction process. Perhaps one explanation is the required time necessary to visually acquire the spin of the ball for the corresponding pitch, a cue essential for recognition and response accuracy. In comparison to racket sports, pitchers in baseball are trained to mask the delivery of the ball until the absolute

latest point in the delivery, this process may confound early prediction accuracy in this investigation as compared to the robust early expert-novice differences as seen elsewhere (Abernethy & Russell, 1987a, 1987b).

Previous research has reported equivocal findings as to the proficiency for anticipation of lateral and depth positioning among expert and novice athletes, with depth positioning being more difficult to predict with relative accuracy. Such difficulties may prove troubling to sports (i.e., cricket, baseball, and tennis) that require acute depth perception while anticipating lateral direction. For example, a bowler in cricket will bounce the ball in front of the batter and depending on the spin, trajectory, and speed, the ball will react differently with the ground, forcing the batter to anticipate and react accordingly. The batters task in cricket is not unlike that of baseball, requiring the use of advance perceptual cues including kinematic cues provided by the bowler. Ball speed and rotation must also be processed effectively for the batter to make contact.

Renshaw and Fairweather (2000) assessed the perceptual discrimination ability of national (n=6), regional (n=6), and club (n=6) cricket batters exposed to 5 different types of bowling deliveries (legspinner, toward batters feet; topspinner, drops short followed by high a bounce; googly, away from batter; flipper, close to feet with low bounce; backspinner, similar to flipper with lower bounce) from two temporal occlusion conditions. The first condition contained the bowler's run-up and ball flight up to and including ground contact, while the second condition included the bowler's run-up and the first 80 ms of ball flight. Immediately following each trial the batter verbally reported the delivery type. The results revealed that overall the experts were more accurate than the regional and club level players for delivery discrimination. Consistent with previous findings, skill level was indicative of advance cue use (condition 1), however,

unlike previous findings, the cricket batters did not benefit from addition ball flight information, suggesting that kinematic cues provided by the bowlers run-up is critical to successful pitch detection. It should be noted that perceptual information after ground contact was not provided and may have proved useful for pitch detection and performance. Specifically, the nature of certain deliveries (i.e., legspinner and googly) will result in the ball changing direction after ground contact. This information may play a significant role in batting success over and above that of perceptual discrimination.

Summary

Researchers for nearly three decades have investigated the relationship between advance cue use and anticipation in sport with the intention of unveiling the core differences between expert and novice athletes. The ability to foreshadow events was believed to result from experts' extensive knowledge base and their ability to apply that knowledge in a manner that facilitates advance visual perception. The use of occlusion paradigms, introduced to sport researchers by Jones and Miles (1978), was swiftly espoused as the paradigm of choice to probe the perceptual behaviors of athletes. The use of both temporal and spatial occlusion techniques across a variety of sports including, tennis, badminton, squash, cricket, baseball, and volleyball, systematically demonstrated expert-novice disparities in the use of information presented early in the visual display. A summary of these experiments suggests that: (1) experts are better able to use kinematic cues (such as the dominant arm of a tennis player) that maintain subtle clues as to the direction and force of a tennis stroke. (2) experts are more adept at using early flight cues of the badminton shuttle to predict stroke location, cues not utilized by novice performers until much later in the flight, and (3) during volleyball offensive attack formations, advanced players were able to use early ball flight and kinematic cues to predict striking location opposed to the novice players who relied on ball flight information to base their tactical decisions. The findings

reported here have been relatively consistent, signifying the attunement of expert level performers to advance cues, otherwise neglected by novice performers.

The utility of the occlusion paradigm has been clearly confirmed, but the inherent limitations of this approach should not be left unstated. First, occlusion paradigms, both temporal and spatial, lack ecological validity. That is, the cues and decisions apparent in the laboratory cannot be inferred with confidence to reflect the cues and decisions influenced by the modulation of competition arousal, motivation and attention (Miles & Jones, 1978). Second, the use of temporal occlusion techniques prohibits the sequential connections of perceptual information that promote the use of altered cognitive processes. Rarely in sport is the athlete unable to view the opposition in his/her entirety, yet the occlusion paradigms inherently restrict the presentation of information. From an information-processing approach this may yoke very different connections between perceptual stimuli and declarative knowledge necessary to reach an accurate problem-solution. Third, the use of film and slide presentations reduce a three-dimensional world into a two-dimensional space, altering the perceptual and sensory experience. For example, Isaacs and Finch (1983) reported greater difficulty and decreased response accuracy for depth as opposed to lateral predictions that could largely be a product of the artificial display. Fourth, static slide presentation, although amenable for eye movement registration, fails to capture the dynamic nature of the visual environment within most sporting domains (Abernethy, Burgess-Limerick, & Parks, 1994). Finally, self-report indices of perceptual cues used for anticipation in sport have been equivocal, signifying the inability to rely on such information to confirm the nature and importance of the perceptual cues actually used in the decision-making process.

Regardless of these limitations many advances in the understanding of advance cue use in sport have emerged from the use of occlusion paradigms. However, the need to validate the

many assumptions put forth is warranted. In an attempt to resolve the many limitations of earlier research, eye-movement registration techniques were adopted. The following section will review the expert-novice differences in visual search strategies across sports.

Visual Search

The ability for expert athletes to extract advanced perceptual information has been linked to highly developed knowledge structures that are responsible for the appropriate allocation of visual attention and enhanced performance. Visual exploration of the typically dense array of perceptual cues is known as visual search, a process by which the eyes move about the visual environment (i.e., through saccades and smooth-pursuit) in an effort to locate and attend (i.e., fixate) to the most information rich areas.

From an information-processing perspective, it is argued that experts derive more task relevant information from each fixation, as opposed to lesser skilled performers who require more saccadic movements to gather equivalent information. Saccadic alterations of foveal location are deemed latent periods of information processing, from which minimal environmental information is extracted. Thus, the more saccades produced the more evidence there is of inefficient and ineffective search strategies (Williams, Davids, Burwitz, & Williams, 1993). As such, experts search with a high degree of visual acuity and efficiency. Without sufficient time to process task relevant cues, oversights and incorrect decisions are inevitable.

In addition to typical fixations, the QE period is believed to be a period of time when task relevant environmental cues are processed and motor plans are coordinated for the successful completion of an upcoming task (Vickers, 1996a). The following section will review from an expert-novice paradigm the progression of the visual search literature, including a description of the common methodology. Finally, a review of the QE literature will be provided, further exemplifying expert-novice differences in gaze behavior.

Eye Movement Registration

Knowing where and when to look is a crucial aspect of successful sport performance and, as noted above, the visual display is often vast and saturated with information, both relevant and irrelevant to the task at hand. It is therefore imperative that athletes are able to recognize the central and most information rich areas of the display and direct their attention appropriately (Williams et al., 1999). The awareness that skilled performers possess enhanced perceptual skills relative to information extraction and cue utilization has been reliably demonstrated across sporting and non-sporting domains and has led to further inquiry into the role perceptual skill acquisition has on the development of expertise.

One popular means of assessing perceptual skill and subsequent allocation of visual attention is through the use of eye tracking systems such as the Applied Science Laboratories 5000 series (ASL) eye movement measurement systems (Williams et al, 1999). These devices are specifically designed to measure fixations and other eye movements by gathering data generated from a light reflected off the cornea, as well as from a video image of the eye (Williams et al., 1999). The location of a visual gaze is typically assumed to index the focus of attention (Duchowski, 2002). When a visual fixation occurs, it is believed that a specific area of the environment is being attended to and that the most detailed, task relevant information is being obtained, while retrieving relatively less detailed information from surrounding peripheral areas. In addition to visual fixation locations, scan-paths lend themselves to the subsequent analysis and inference of the efficiency by which information is extracted for task completion (Williams, 2000). Efficient and successful performance is often characterized by visual search patterns that involve fewer fixations of longer duration, a pattern indicative of the expert performer maximizing the utility of the display and the time available to formulate a response (Williams, 2000;Williams, Davids, & Williams, 1999).

Eye Movement Research

The seminal years: 1976-1989

One of the first attempts to determine the visual search behaviors of basketball players and the first in sport to empirically validate the purported expert-novice visual search differences when solving strategic problems was conducted by Bard and Fleury (1976) using a NAC eye movement recorder. Expert (*n*=5,) and novice (*n*=5) basketball players were presented with 84 slides depicting one of 28 different typical offensive basketball schematics. At the onset of the stimulus, each participant was required to identify the type of solution required by the presented offensive strategy, selecting one of seven possible answer choices (i.e., shoot, dribble, four passing options, and stay). Two dependent variables were assessed, decision-time and number of visual fixations. Experts demonstrated fewer visual fixations per trial (3.3 vs. 4.9) than novice players. No differences between groups were noted for decision time, suggesting that the visual search patterns of experts were more efficient (i.e., fewer fixations of longer duration) than novice players. Moreover, distinct cognitive strategies were apparent, with experts concentrating fixations around the pairings of offensive-to-defensive players, while the novice players maintained more frequent fixations to teammates, neglecting the opposition. However, the efficacy of this difference is unknown, since no attempt was made to evaluate performance outcome.

As a follow-up to the previous basketball study (i.e., Bard & Fleury, 1976), a series of experiments with basketball and ice-hockey players (Bard & Fleury, 1987) was conducted using a NAC eye movement recorder to assess the number of fixations and fixation durations across tasks of varying complexity. As in the earlier study, basketball players were presented a series of schematics; this time contextual complexity was varied. The results demonstrated that experts

across the three complexity conditions reported fewer fixations of longer duration, while reaching conclusions more quickly. However, no attempt was made to assess response accuracy.

The second experiment (Bard & Fleury, 1987) was conducted with ice-hockey goalkeepers. In an on-ice investigation, goalkeepers fitted with an eye-tracking device (i.e., NAC eye movement recorder) were exposed to a wrist-shot or slap-shot from an experienced ice-hockey player and required to move in the appropriate direction in an attempt to 'block' the shot. Results showed that the expert goalkeepers evoked a quicker reaction (i.e., time from shot initiation to first overt movement to block the shot) but did not differ from novices on the number of fixations. However, further analysis revealed that although both the experts and novices emitted one fixation per trial per shot, fixation locations differed across skill level and shot type. Specifically, during the wrist-shot, the novice group fixated on the stick significantly more than the expert players, who spent more time fixating on the puck. During the slap-shot, a more complex task, the experts spent significantly more time fixating on the stick and less time on the puck as compared to the novices.

In the third experiment by Bard and Fleury (1987), ice-hockey goalkeepers viewed wrist-shots only. However, in an effort to create temporal uncertainty, the offensive player was only permitted to initiate the shot after skating with the puck for one, two, or four seconds. Goalkeepers were again assessed on reaction time and number of fixations. Consistent with the earlier findings, the expert players reacted significantly quicker across conditions, with notable performance decrements (i.e., slower reaction time) corresponding with increased temporal uncertainty (i.e., one second vs. four seconds). All goalkeepers established attentional preference for the stick and puck, with the expert players demonstrating a significant preference for the stick over the puck.

Although the results of these three investigations support the prediction of expert efficiency (i.e., fewer fixations of longer durations) they must be taken with caution. First, none of the investigations maintained an outcome measure, thus failing to identify the efficacy of the search strategy differences. Second, the temporal brevity of the shooting experiments does not lend itself to directly testing the efficiency hypothesis (i.e., temporal constraints only permitted one fixation), although clear differences were noted for fixation location.

Satisfying the limitations of the previous studies, Shank and Haywood (1987) assessed the abilities of varsity collegiate (n=9) and novice (n=9) baseball batters to predict pitch type (i.e., fastball or curveball), while recording the visual search patterns during the preparatory phase (i.e., wind-up and delivery) of a baseball pitch. Participants viewed a video of a pitcher on a regulation mound delivering fastballs and curveballs from either the wind-up or the stretch position from a right-hand batter's perspective. Eye movements were recorded with an Applied Science Laboratory (ASL) Model 210 Eye-Trac. Results from this investigation support the general findings from the occlusion research. The expert players were more adept at extracting pertinent advance cues compared to the novice players, respectively, as signified by the percentage of correctly identified pitches (i.e., 84.4% vs. 64.3%). Eye movement reaction time was assessed and defined as the moment from the point of ball release to the next eye movement. Results revealed a comparable latency period across groups, suggesting that ball tracking is not occurring and that such "quiet time" may be optimized by experts to process and formulate a motor plan (see Quiet-Eye), while novice players maybe dedicating this time to searching for a stimulus response, suggesting that the extraction of advance perceptual cues almost certainly occurs during the wind-up and the initial stage of the delivery.

Moreover, significant differences in visual search patterns were also noted (Shank & Haywood, 1987). Expert players spent more time fixating (63%) and blinking (26%) and less time searching the visual display (11%) than novices (i.e., 53%, 12%, and 35%, respectively). Of further interest are the specific areas of the display most frequently fixated on. Experts attended to the pitcher's release point whereas the novice players alternated fixations between the release point of the ball and the head of the pitcher. In sum, the work of Shank and Haywood (1987) provided definitive outcome evidence to support visual search differences between experts and novices in both the number of fixations and fixation durations. Although both groups experience post pitch release latencies of approximately 150 ms (i.e., no difference in reaction time) experts appear to have a cognitive advantage, as demonstrated by the effective use of advance kinematic cues for the accurate perception of the baseball pitch.

Abernethy and Russell (1987a, 1987b) made extensive use of the occlusion paradigms as noted above, but questioned the validity of the conclusions drawn from them, citing a lack of objective certainty as to what and where an athlete was attending. Using a temporal and spatial occlusion paradigm, Abernethy and Russell (1987b) collected visual search information with the Polymetric Mobile V0165 eye movement recorder while assessing the stroke prediction of expert and novice badminton players. Analysis of the visual search patterns used by the two groups included visual correction time, dwell time, mean fixation duration, search rate, and location (note; a fixation was defined as "any state in which the eye remained stationary for a period equal to, or in excess of 120 ms" p. 289). To isolate cue preferences, fixation locations were divided into five distinct regions (i.e., the opponent's arm and racquet, the shuttle during out flight, the opponent's trunk and body center, the opponent's head and face, the opponent's legs and feet).

Abernethy and Russell (1987b) demonstrated that both the expert and novice players exhibited early fixations to similar areas of interest including the opponent's racquet, head, trunk, and to a lesser extent the lower body. However, the frequency of fixations to a given location was proportionately different across regions, with the experts spending more time fixating on the racquet/arm complex (46.27%). In contrast, the novice group preferred the head (28.98%), the trunk (28.74%) and the racquet/arm complex (24.47%). Subsequent analyses revealed that regardless of the point of previous interest in the visual search sequence, experts and novices did not differ on subsequent fixation locations, suggesting that following early fixation preferences, expert and novice badminton players are not dissimilar in their visual search patterns. To clarify, the visual search analysis could not attribute perceptual skill differences to more effective or efficient search patterns. Simply, the two skill groups allocated their visual fixations to specific display regions similarly, were comparable in the order in which the cues were fixated on, and were indistinguishable in their corresponding search rate.

The lack of significant findings obtained by Abernethy and Russell (1987b) may not be the result of the small mean visual search differences between skill levels, but rather the large within group variability. For example, the expert performers may not have been a truly homogenous sample, suggesting that the members of the expert group may not have all been performing at the same level. However, assuming this is not the case, the findings of Abernethy and Russell (1987b) suggest that perceptual expertise is not the result of what one sees but rather how one uses the information seen.

In a multi-study experiment, Goulet, Bard, and Fleury (1989) assessed the search patterns of expert and novice tennis players preparing to return a tennis serve using eye movement registration techniques (i.e., NAC eye movement recorder, Model V) in Experiment 1 and an

occlusion paradigm in Experiment 2 that was discussed in a previous section. Participants viewed 27 randomly presented tennis serves and identified, as quickly as possible, the type of serve (i.e., flat, slice, or top-spin) delivered. The number of correct responses, number of fixations, scan-paths, and favored exchanges (i.e., direction of one fixation to the next) were assessed and scored according to 11 distinct regions isolated and coded for analysis. The serve itself was further divided into three distinct segments, the ritual (i.e., precedes serve and includes ball bounce and footwork), preparatory (i.e., initiation of the ball toss concluding with its apex), and execution (i.e., begins with knee extension and concluding with ball-racquet contact) phases in attempt to isolate the nature of the advance cues used. For response accuracy, experts (M = 69.9) correctly identified more serves than did the novice group (M = 52.2). For search rate, experts displayed more fixations than did novices during the ritual phase and specifically attended to the head and shoulder/trunk complex. Search patterns were similar across groups during the preparatory phase, with both groups favoring the server's head and the anticipated ball location. However, differences emerged again during the execution phase, with the experts terminating their fixations on the racquet much quicker than the novices, while the novice players proceeded to track the ball after ball-racquet contact. Expert players were apparently more attuned to the kinematic cues presented during the ritual phase, thereby aiding the decision-making process. Moreover, the perception of advance cues corresponded with the decreased decision time inferred from the temporal brevity of the terminal fixation on the racquet as compared to the novice players who sought further information in order to confirm their decision by tracking the flight-path of the ball.

Empirical and methodological advancements: 1990-1998

The limited and equivocal findings presented in the visual search literature were questioned by Abernethy (1990) who ascribed the lack of skill-based differences in his own

research (e.g., Abernethy & Russell, 1987b) to the insufficiently sensitive eye movement registration equipment used and the potential confound of laboratory based research. In an effort to overcome these limitations Abernethy (1990) employed the more sensitive NAC EMR-V Eyemark recorder in two experiments. Experiment 1, was a laboratory investigation of 15 expert and 17 novice squash players who viewed 160 trials of four different squash strokes. Each stroke was temporally occluded at one of five time frames (see the Occlusion section above for a more detailed description of the procedure). Most relevant to this discussion however, are the nine separate areas of interest used when comparing fixation location, duration, and sequence of fixations while anticipating stroke force and direction. A fixation was operationally defined as any case when the eye-mark remained stationary for at least 120 ms. In comparison, Experiment 2 was designed to assess visual search patterns using a more ecologically valid task while replicating Experiment 1. In this case while positioned on the midpoint of the service line of a squash court four expert and four novice squash players viewed 40 squash strokes of varied locations.

The findings from Experiment 1 revealed expert-novice performance differences both in terms of stroke force and direction (Abernethy, 1990). Anticipation accuracy was not measured during Experiment 2. The findings from the assessment of the visual search parameters in Experiment 1 revealed expert-novice differences for cue location. Specifically, experts spent more time fixating on the arm and head of the opponent and less time fixating on ball-racquet contact as compared to the novices. This result indicates the novice player's reliance on ball flight cues and the superior ability of experts to use advance cues. These results confirm the spatial and temporal occlusion findings reported above (Abernethy & Russell, 1987a, 1987b; Isaacs & Finch, 1983; Jones & Miles, 1978). Moreover, no differences were noted for fixation

duration or number of fixations across skill levels. The results of Experiment 2, as in previous work by Abernethy and Russell (1987b), failed to identify skill-based visual search differences. That is, the search patterns associated with fixation distribution, order, and duration remained stable across skill levels. Abernethy concluded that the notable performance differences exemplified in Experiment 1 were not the result of more efficient search strategies but rather the ability to make strategic inference from the information extracted. Again, the experts were better able to make use of the advance cues, while the novice players relied more on the ball-racquet contact zone and subsequent ball flight information.

The majority of research reviewed has relied on interceptive racquet sports and advance cue use for the prediction of stroke type and location. Extending the literature beyond racquet sports Helsen and Pauwels (1990) examined the behaviors of soccer players. Fifteen expert and 15 novice soccer players were presented with 90 slides of typical offensive soccer situations. The participants were required to view the slide and as quickly as possible verbalize the most correct decision (i.e., shoot, dribble, or pass). Visual search behavior was recorded using a NAC-V Eyemark recorder. The findings from this investigation indicate that experts were faster and more accurate in finding tactical solutions to offensive soccer situations. In accord with previous findings (e.g., Abernethy 1990a; Abernethy & Russell, 1987a), there was little difference amid the locations of fixations between skill groups. However, in contrast to previous work (e.g., Abernethy 1990a; Abernethy & Russell, 1987a), analysis of the visual search data for number of fixations revealed expert-novice differences. Experts displayed fewer fixations than novices. These results are a sign of the improved ability of experts to make use of the information they possess, while novices continue to seek out validation. As endorsed by Helsen and Pauwels (1990), fewer fixations allow for faster information-processing time and result in shorter

response time, equating to better performance. Essentially, fewer fixations place less demand on long-term working memory and experts can retrieve an appropriate response to the problem-space more proficiently with the use of their extensive knowledge base.

Returning to racquet sports, Cauraugh, Singer, and Chen (1993) investigated the visual search patterns and anticipation strategies used to predict an opponent's tennis stroke. Expert (*n*=30) and novice (*n*=30) tennis players viewed two different types of tennis serves (i.e., spin or flat) and had to identify its direction (i.e., left, right, or center court) as quickly and accurately as possible. An Eye-Trac, Model 210 was used for recording eye fixations. A fixation was operationally defined as a stationary eye for a minimum of 133 ms. The visual search data revealed significant expert-novice differences. Specifically, of the nine predetermined areas for fixations, the novice players demonstrated a preference for the head and left shoulder, with no other notable differences with experts present. Additionally, experts dedicated more time per location, that is, their fixations were of longer duration than the novice players. When considering the visual search patterns across the three phases of the serve (i.e., preparation, execution, and follow-through), the novice players fixated more frequently on the head during the preparation phase. Similarly, skill-based differences were evident for ground strokes with the novice players fixating more frequently on their opponent's hips. No other visual search differences between groups were found. However, consistent with previous findings, the experts were both quicker and more accurate in predicting the type and location of their opponent's shots.

Despite the promising results of these studies in terms of identifying expert-novice visual search differences, with the exception of Helsen and Pauwels (1990), research reviewed to this point has involved interceptive racquet sports and the correct identification of stroke force,

location, or type. The nature of the scan-paths and the extent of the expert-novice differences cannot be generalized to closed-tasks or those that require precise aiming at a far target. Vickers (1992), interested in the systematic changes in visual search as aiming accuracy improved, assessed low handicap (i.e., 0-8) and higher handicap (i.e., 10-16) tournament caliber golfers. To determine eye movements and gaze behaviors, participants were fitted with a mobile ASL 3001H Eye View recorder, while executing consecutive putts from a distance of 3m. Participants were required to continuously putt in sets of twelve until ten successful (i.e., hit) and ten unsuccessful (i.e., misses) putts were recorded. For coding and analysis of the putt, three distinct stroke segments (i.e., preparation, backswing/foreswing, and contact phase) and six gaze locations (i.e., feet, ball, club head, cup, and putting surface) were analyzed for fixation duration (stabilized gaze for a minimum of 99.99 ms), saccades (eye movement from one location to another with a duration of 133.2 ms), express saccades (rapid shifts lasting 66.6-99.9 ms) and smooth pursuit (tracked object for 99.9 ms or more) movements. The results of this investigation revealed that the low handicap (LH) golfers used significantly fewer fixations (14.2) per putt than the higher handicap (HH) golfers (19.4), while total putt time was indistinguishable. In-line with this finding, LH golfers maintained fewer fixations of longer duration during the preparation and backswing/foreswing phases. Furthermore these results revealed that better golfers employ variable gaze behaviors, including more express saccades between fixation locations and fixations of longer duration to the ball and target, while minimizing gaze behaviors to the club head and putting surface. Conversely, the HH golfers dedicated significantly more gaze behaviors (fixations, saccades, etc.) to the putting surface and feet and were more consistent in their gaze behaviors across stroke phase and fixation location.

The work of Vickers (1992) provides direct evidence to support the importance of visual gaze behaviors in an aiming task. Specifically, although advance visual information is imperative for the successful anticipation of an opponent's stroke, information gathered during the preparation and backswing/foreswing phase of a golf putt is equally important. Vickers (1992) postulates that fewer fixations of longer duration allows for the coordination of the eyes and hands, synchronizing the visual information with a distinct motor plan.

The paucity of visual search research in open-tasks coupled with many conceptual and methodological limitations (e.g., use of static slides, scaled image presentation, brief film clips, and small sample size) has necessitated the need for the further exploration of skill-based visual search differences in open-skill sports (Williams et al., 1994). Williams et al. (1994) conducted an examination of perception and decision-making in sport, assessing skill-based differences in visual search strategies, and the corresponding response time and response accuracy while viewing 11-on-11 soccer situations. An ASL 4000 SU eye movement registration system was used to record visual search strategies across 13 distinct soccer scenarios from a defensive perspective. Filmed scenarios were displayed on 3m x 3m projection screen. A reference grid was imposed on the field to facilitate scoring and to provide a point of distinction for verbal responses indicating the location of the final pass destination. Results indicated skill-based differences for response time, fixation location, number of fixations, and fixation duration (Note: a fixation was defined as a condition in which the eye remained stationary for a period equal to or in excess of 120 ms). Specifically, although no differences were evident for response accuracy, expert players responded much more quickly, confirming the use of advance perceptual information. Williams et al. (1992) derived a response time latency of 200 ms, indicating that the skilled players were able to anticipate final pass destination prior to foot

strike, and consistent with the occlusion research, the novice players relied on ball-flight information. Furthermore, contrary to the notion that experts exhibit a more efficient search strategy, it was demonstrated that the experts performed a more elaborate search of the display, frequently shifting gaze from a central location to other information areas and back (e.g., more fixations of shorter duration). Although appearing less efficient, Williams et al. (1992) suggested that the broad scope with numerous important elements (i.e., 11-on-11), required such an elaborate search process. To compare, the novice players spent more time watching the ball while the experienced players spent more time gathering information away from the ball, facilitating pattern recognition and decision-making proficiency, behaviors indicative of highly skilled players. It can therefore be concluded that the task itself may be equally as important, if not more influential on the search strategies employed, as compared to the level of expertise and skill proficiency alone.

The potential for task type and complexity to inversely influence skill-based visual search differences was examined by Ripoll, Kerlirzin, Stein, and Reine (1995). Expert (n=6), intermediate (n=6), and novice (n=6) kick-boxers viewed video-recorded images of an opponent portraying different tactical maneuvers (i.e., attacks, openings, or feints) that required a quick and accurate response to block or counter successfully. The participants used a joystick to react to their opponent's maneuvers, while simultaneously recording response time and accuracy. Two experiments were conducted. The first experiment assessed response time and response accuracy only, while the second experiment explored skill-based differences in visual search behaviors using a NAC-V Eyemark recorder. To further clarify, for Experiment 1, three levels of task complexity (i.e., simple A, simple B, and complex) were introduced. During condition simple A, the participants were explicitly instructed to respond to attacks (i.e., punch or kick) and to ignore

other maneuvers. In simple condition B, participants were to respond to openings while ignoring the other two possibilities when present. The complex condition required the participants to react to both attacks and openings and ignore feints. In Experiment 1, the simple conditions A and B failed to reveal skill-based differences in response accuracy and response time. It was concluded that expertise does not discriminate between skill levels during a simple task. However, when the participants had to respond to attacks and openings (complex task), experts were more efficient (i.e., time and accuracy) in their responses as compared to both the intermediate and novice groups. Surprisingly, the novice group outperformed the intermediate group.

The findings of Ripoll et al. (1995) suggest that the expert boxers were able to recognize the type of movement initiated by the opponent, signifying the potential for a more successful counter. Unfortunately, this finding was not maintained in a comparison of the lesser skilled groups. In conjunction with the efficiency differences between the experts and less skilled boxers, skill-based differences for the accuracy of response were revealed. Again there were no differences between the intermediate and novice boxers. It was postulated that the lack of performance differences was due to the homogeneity of the intermediate and novice groups. Although the novice group did not have any formal combat experience, their practice experiences may have been equivalent to that of the intermediate group (Ripoll et al., 1995). Nevertheless, these findings are suspect. Following Experiment 1 Ripoll et al. (1995) concluded that expertise appears only in the presence of a complex problem space.

In an extension of the previous study, Experiment 2 explicitly assessed skill-based visual search differences in complex conditions (Ripoll et al., 1995). For the purpose of off-line analysis, the visual display was divided into six distinct regions, including: the (a) head, (b) trunk, (c) arm/fist, (d) pelvis, (e) legs, and (f) other unidentified fixations. The results of

Experiment 2 revealed skill-based visual search differences for number of fixations, fixation location, and fixation duration. Specifically, experts (43.3) completed fewer fixations as compared to both the intermediate (105.8) and novice (122.67) groups. Moreover, consistent with Williams et al. (1994), task complexity evoked a more systematic search of the display as evidenced by the expert's use of a "visual pivot". That is, the experts spent the most time fixating and used the head as a point of reference from which subsequent eye movements originated from and returned to. In contrast, the less skilled boxers favored the arm/fist complex and the trunk (see Figure 2-5). However, unlike soccer players who showed more fixations of shorter duration as a function of task complexity and expertise (Williams et al., 1994), the work of Ripoll et al. (1995) is consistent with the notion of visual search efficiency, in that the experts maintained fewer fixations of longer duration, a finding that may be attributable to the less complex visual display. Furthermore, efficiency may have resulted from the rich knowledge base of the experts that facilitates the matching of a stimulus to a response process. A second, alternative explanation attends to the imminent threat imposed by the sport of French boxing, in which the defender cannot afford to miss a perceptual cue and thus relies more heavily on the peripheral system as opposed to the rapid shifting of visual attention around the display.

Returning to racquet sports, Singer, Cauraugh, Chen, Steinberg, and Frehlich (1996) advanced the work of Goulet et al. (1989) using a simulated tennis experiment to investigate the visual search, anticipatory behaviors, reaction time, and decision accuracy of highly-skilled (n=30) and beginner (n=30) tennis players. An ASL Model 210 Eye-Trac monitoring system was used to record the visual search tendencies of participants while viewing a video presentation of serves and ground strokes. Participants were instructed to respond as quickly and accurately as possible to the type of serve (i.e., flat or spin) and location (i.e., left, right, or center) of ball

placement for each stroke. Anticipation time for each serve was measured using a monitoring system that was activated when the video model initiated the ball toss sequence. Similarly, anticipation time was measured for ground strokes, beginning when the ball bounced on the opponent's side of the court initiating the ground stroke. Decision speed for serve type was determined with the participant pressing one of two switches with either their index finger (flat) or middle finger (spin). Participants used a joystick to manipulate with their dominant hand the anticipated direction of both serves and ground strokes.

The results of Singer et al. (1996) confirmed expert-novice visual search differences, with the novice players fixating longer on the head during the serve compared to the expert players. No significant skill-based differences were present for ground strokes. Finally, anticipation measures (i.e., speed and accuracy) for the serve and ground strokes revealed that experts were faster and more accurate in their responses than novices.

In addition to the quantitative analysis, Singer et al. (1996) conducted a qualitative analysis of the visual search patterns of the two best expert players and two randomly selected novice players. The results of the qualitative analysis revealed that during the serve, the expert players tracked the ball as it was tossed until the point of contact, at which point they refocused visual attention on the racquet and arm region of their opponent, and subsequently tracked the flight of the ball. The novice players were less systematic in their search behaviors until ball-racquet contact was made, at which point the ball was tracked. During ground strokes, the experts focused on the hip region, followed by the racquet, racquet-ball contact, and subsequent tracking of the ball's flight path. Again, the novice players were random and unsystematic with a common interest in tracking the ball post-contact. These findings are consistent with the majority of the spatial occlusion research suggesting that experts make better use of advance and distal

cues as compared to the novice players. Unique to this qualitative analysis however, was the experts' frequent use of the hips as a primary source of information during the ground stroke. It can be speculated that such a difference emerges during ground strokes as result of the close proximity of the arm-racquet complex to the hip region. Furthermore, during the ground stroke the hips may be a better indication of stroke direction; however, further research is warranted to explore this possibility.

Williams and Davids (1997) conducted two investigations to examine the relationship between visual search behavior and concurrent verbal reports in a test of advance cue use and decision-making in soccer. Experiment 1 was a replication of the 11-on-11 anticipation test used in the previous work of Williams et al. (1994). However, in this investigation, participants verbalized the location of their attention throughout each viewing sequence. An ASL 4000 SU eye movement registration system was used to record visual search patterns of experienced (n=10) and less experienced (n=10) soccer players across a total of 26 soccer action sequences presented on a 3.5m x 3m projection screen. A reference grid was imposed on the field to facilitate scoring and to provide a point of distinction for the verbal responses indicating the location of the final pass destination. Results indicated that no expert-novice differences were evident for reaction time or response error. Consistent with the previous findings (e.g., Abernethy & Russell 1987b; Goulet et al., 1989), no skill-based differences for search rate were revealed, yet search order differences were noted. Specifically, the expert players displayed a systematic search strategy, maintaining a visual pivot (i.e., from the box to other areas and back to the box); however no differences were noted for the verbal reports of attention direction. Although the expert athletes fixated more frequently to the box, the novice players sustained

their attention within the box for longer periods, signifying their inability to differentiate the relevant from the extraneous.

Experiment 2 (Williams & Davids, 1997) was a modified version of the 11-on-11 protocol used in Experiment 1, examining the relationship between concurrent verbal reports and visual search during a less complex 3-on-3 soccer task. Twelve experienced and 12 less experienced soccer players viewed 20 offensive soccer sequences. Participants were required to anticipate the pass destination as quickly and accurately as possible and were again required to verbalize the location of their attention throughout each viewing sequence. The results from Experiment 2 contrasted those from Experiment 1; although both groups were equally successful in predicting the final outcome, the experienced players responded quicker. No differences were noted for search order in either the eye movement condition or the verbal report condition. Skill-based differences for fixation location were revealed, mirroring the results of the 11-on-11 conditions. Specifically, the novice performers spent more time fixating within the box, while the experienced players used the box as reference point, frequently directing their attention to the left and right sides of the display. Williams and Davids (1997) concluded that the inexperienced players were “ball-watchers,” again identifying the inability of novice players to differentiate relevant from extraneous cues.

The work of Williams and Davids (1997) suggests that task complexity may not be a significant mediating variable in the search strategy of experienced and inexperienced soccer player as indexed by the similar findings in 11-on-11 and 3-on-3 soccer situations. However, the nature of the sport may influence such behavior. In three experiments (i.e., Williams & Davids, 1997, Experiment 1 and 2; Williams et al., 1994) of perceptual decision-making, experts employed more fixations as compared to the less-skilled players. Additionally, experts adopted a

systematic search with a common area of interest, a pattern neglected by the more variable approach of the inexperienced players. This pattern of results contradicts the findings of Goulet et al. (1989), Helsen and Pauwels, (1993), and Ripoll et al. (1995) who found that experts maintained fewer fixations of longer duration. It further appears that novice athletes have the knowledge of what they should be doing, but are unable to extract the relevant information necessary to enhance performance as indicated by the verbal protocols used here by Williams and Davids, (1997).

Williams and Davids (1998) conducted an extension of their previous work on complex (11-on-11) and less complex (3-on-3) decision-making in soccer with an examination of visual search, anticipation, and expertise using three complimentary methodological approaches. Experiment 1 examined skill-based visual search and anticipation differences during 3-on-3 and 1-on-1 offensive situations. Experiment 2 used a similar protocol with the addition of a spatial occlusion condition. Experiment 3, compared the scan-paths and the concurrent collection of verbal reports of participants across 3 levels of task complexity (i.e., 11-on-11, 3-on-3, and 1-on-1). An ASL 4000SU eye movement registration system was use to record visual search behavior.

Experiment 1. Williams and Davids (1998) compared 12 experienced and 12 less experienced soccer players who viewed 20 offensive soccer sequences in which they acted as a defender, responding as quickly and as accurately as possible by stepping onto a response pad (i.e., left, right, front, or back) indicating the anticipated direction and final destination of the ball. The results demonstrated the expert's superior ability to anticipate and respond quicker than the less-skilled players during both the 3-on-3 and 1-on-1 conditions. However, the highly-skilled players were only more accurate in their predictions during the 1-on-1 task. Moreover, the results of the visual search data revealed no skill-based differences in the allocation of fixations

to regions of the display, search order, or search rate during the 3-on-3 conditions. Conversely, visual search differences in the 1-on-1 conditions were evident. Specifically, the experts had a tendency to pivot (i.e., more fixations of shorter duration) their visual attention between the ball and their opponent's hip region compared to the less-skilled players. Although no statistical differences were reported for fixation location, the experts spent more time fixating on the area between their opponent's knees and chest. Williams and Davids (1998) reported an effect size of 1.08 signifying the practical significance of a mean difference of this magnitude for soccer players in a 1-on-1 confrontation.

Experiment 2. Williams and Davids (1998) used the same procedure and participants as those reported in Experiment 1 with the exception of 2 additional spatial occlusion conditions for the 3-on-3 task, and four spatial occlusion conditions for the 1-on-1 task. Specifically, for the 3-on-3 anticipation test the spatial occlusion conditions consisted of (e1) the removal of all irrelevant perimeter information by cropping the visual display to include only the positions and movements of the players and (e2) a reduction of the visual display to include only the ball or the ball passer. For the 1-on-1 anticipation test, the spatial occlusion conditions consisted of the removal of (e1) the opponent's head and shoulders; (e2) the hips; (e3) the lower leg; and (e4) an irrelevant area of the display. The results from the 3-on-3 conditions showed significant performance decrements across occlusion conditions for the skilled group (i.e., from (e1) to (e2)) and stable performance across conditions for the less-skilled players. Nevertheless, the highly-skilled players maintained their advantage over the novices performing quicker and more accurately under both occlusion conditions. The results of the1-on-1 occlusion condition revealed a similar performance advantage for experts across occlusion conditions; however, no statistical significance was reported.

Experiment 3. Williams and Davids (1998) used the same participants and test procedures as in Experiment 1 with the addition of obtaining concurrent verbal reports. Consistent with the findings of Experiment 1, the highly-skilled players had quicker response times but were equaled in response accuracy by the less-skilled players. Furthermore, both groups reported similar patterns of attention allocation to the left and right sides of the box, yet the less-skilled players spent significantly more time fixating within the box (i.e., ball and or ball carrier) than the highly-skilled players. No further differences were apparent to search order, yet the experienced players' fixations were more equally distributed across the different viewing areas (i.e., left, right, and box), with the less skilled players spending more time within the box.

It can be concluded from the work of Williams and Davids (1998) that skilled players are able to make sufficient use of advance performance cues, reducing the time necessary to derive a conclusion and respond. More importantly, skilled players apparently rely less on information provided by the ball and more on the information presented throughout the visual display as evident by the frequency of fixations directed at the opposing player's hip region during the 1-on-1 conditions. Additionally, the discrepancy between verbal reports of frequent alternation of attention allocation and visual fixations of equal distribution during the 3-on-3 conditions suggests that skilled players rely more on non-ball specific information gathered through the peripheral system.

Contemporary investigations: 1999-2002

Task type and complexity have both been points of contention for eye movement researchers (e.g., Ripoll et al., 1995; Williams & Davids, 1997). However, the extent to which performance related anxiety mediates the visual search process has been neglected. Attending to this gap in the literature, Williams and Elliot (1999) examined the effects of cognitive anxiety and level of experience on anticipation and visual search behavior in karate kumite. In accord

with the Processing Efficiency Theory (PET; Eysenck & Calvo, 1992), Williams and Elliot (1999) postulated a positive relationship between anxiety, number of visual fixations, and fixation location. Simply, the major tenet of the PET states that as arousal, and more specifically anxiety increases, the breadth of the attention system narrows, rendering information in the peripheral environment neglected or when searched, searched in a more deliberate and inefficient process. Therefore, Williams and Elliot (1999) predicted that as anxiety increased, so too would the number of fixations to the periphery of the visual display as a result of attentional narrowing. Experienced (*n*=8) and inexperienced (*n*=8) martial artists viewed a series of film sequences depicting both fist and foot strikes and were required to physically respond as quickly and as accurately as possible as if acting to avoid the impending strike. Three trained judges were used to assess the accuracy of the participant's responses under low-anxiety (neutral statements) and high-anxiety conditions (competition incentive). Visual search behaviors were examined with an ASL 4000SU eye movement recorder, with particular attention given to search rate and fixation location (i.e., head, chest, shoulders, pelvis, arm/fist, leg/foot, and unclassified).

For the dependent measures of response accuracy and viewing time, the experts were shown to be more accurate in their response to the impending strikes, but did not differ from the novice group in the amount of time they spent viewing the display before responding (Williams & Elliot, 1999). The results of the visual search data failed to demonstrate group differences in fixation location. In spite of the lack of statistical significance, a trend was present indicating that the experts spent proportionately more time fixating on the head (45.2% vs. 34.8%) and pelvis (12.9% vs. 4.6%) and less time fixating on the chest (24.3% vs. 34.9%) and arm/fist (7.0% vs. 17.5%) locations as compared to the inexperienced performers. In response to the alterations of cognitive anxiety, both groups deviated from their typical viewing patterns under the high

anxiety condition as compared to the low anxiety condition, with an increase in fixations to both the shoulder and arm/fist regions, suggesting that the experienced performers were no more resilient to the effects of anxiety than were the inexperienced performers. Search rate was also altered by modulations in anxiety across skill levels. Specifically, in the high anxiety condition the experienced group showed an increase in the mean duration of their fixations (236.53 ms vs. 219.61 ms) while the inexperienced group's fixation duration decreased (250.58 ms vs. 284.44 ms) in comparison to the low anxiety condition. Additionally, both groups exhibited more fixations and more fixation locations under the high anxiety condition as compared to the low anxiety condition, suggesting that as anxiety levels increase the visual search profiles of experienced and inexperienced performers become more similar.

The ecological validity of laboratory studies was questioned earlier in the review with respect to occlusion-based research. A primary concern was the inability of static slides to capture the essential display features of real world tasks. In response, a methodological shift to the use of film and action sequences occurred; however, the concurrent use of both mediums within the same experiment with the same sample had not occurred. In an effort to assess the relative importance of the perimetric and optimetric parameters and visual search in perceptual decision-making in soccer, Helsen and Starkes (1999) conducted a multi-method investigation of skill-based differences. A three-study approach was used to examine the mediating variables of skilled perception. Experiment 1 assessed visual acuity and other hardware issues of perception and will not be discussed further. Experiment 2, using a static slide presentation, assessed the skill-based visual search and anticipation differences of expert and intermediate soccer players during 11-on-11 open soccer play. In Experiment 3, film rather than static slides were presented

to participants while maintaining the same protocol as in Experiment 2. A NAC-V eye movement registration system was use to record visual search behavior.

Experiment 2 (Helsen & Starkes, 1999). Expert (*n*=14) and intermediate (*n*=14) soccer players viewed 30 slides depicting a typical offensive soccer situation from the perspective of the ball carrier. Upon slide presentation, the participant was to respond verbally as quickly and accurately as possible, identifying the most appropriate move (i.e., shoot, dribble, pass). The results of Experiment 2 indicated that the expert group performed better than the intermediate group for trials in which dribbling and passing were the appropriate responses for both response time and accuracy. No skill-based differences were revealed for shooting scenarios. The results of the visual search data demonstrated that experts maintained fewer fixations than the intermediate players but did not differ in the duration of fixations. Analysis of the scan-paths during *correct* decisions did not reveal any group differences. However, skill-based differences were illustrated when considering the scan-paths during *incorrect* decisions. Specifically, the expert group spent more time viewing the ball carrier, reducing the amount of time spent in searching other areas, while the intermediate group spent less time fixating on the goal. The truncated search pattern of the experts during incorrect decisions reflects the behavior more characteristic of novice players who allocate their attention to a limited focal point, which is often the ball rather than using a more systematic proportional distribution of fixations across the visual display.

Experiment 3 (Helsen & Starkes, 1999). The procedure and participants were the same as those reported in Experiment 2, with two modifications. First, the simulation consisted of 30 different tactical soccer situations that were projected life-size using a dynamic film approach. Second, the participants performed a tactical decision with the ball (i.e., shoot, dribble, or pass)

in response to the film, as quickly and as accurately as possible. The results of Experiment 2 revealed that experts were faster and more accurate in responding to the various tactical problems. Specifically, the experts demonstrated faster initiation time, ball/foot contact time, and total response time. Of the three areas in which the experts demonstrated superiority, initiation time offers an explanation for the ability of the expert group to make use of advance cues, whereas the differences in ball/foot contact and total response time may be accounted for by physical skill differences. The results of the visual search data mirrored that of Experiment 2. Specifically, experts maintained fewer fixations than the intermediate players, but they did not differ in the duration of fixations. Finally, during the dynamic task the expert players were more inclined to make use of the defenders, free back, and free space as compared to the intermediate performers, who fixated more on the ball and the goal.

The work of Helsen and Starkes (1999) supports the notion that experts process advance cues, thereby reducing response time in both film and static soccer presentations. Furthermore, visual search differences were evident by the fewer fixations performed by the experts, indicative of an efficient search process, and providing support for the differential cue accessibility and processing capabilities of expert performers.

Savelsbergh, Williams, Van Der Kamp, and Ward (2002) conducted a study examining the skill-based differences in anticipation and visual search during the penalty kick in soccer. An ASL 4000SU eye tracker and an Ascension Technologies magnetic head-tracker were used to record the visual search behaviors of expert (n=7) and novice (n=7) goalkeepers while viewing a presentation of 120 penalty-kick trials. The participants were situated behind a joystick that was used to indicate and record both response time and accuracy. Accuracy was determined by the placement of the joystick relative to the position of the incoming soccer ball. To further clarify, if

the position of the joystick intercepted the coordinates of the flight path of the soccer ball at the time it crossed the goal-line a ‘save’ was declared. Therefore, accuracy was determined by the (a) number of total saves; (b) correct side (i.e., correct lateral prediction, but incorrect vertical prediction); (c) correct height (i.e. incorrect lateral prediction, but correct vertical prediction); and (d) proportion of corrections (i.e., percentage of corrective movements). The visual search data were assessed for search rate, and percentage of viewing time distributed to the following fixation locations: head, trunk, shoulders, arms, hips, kicking leg, non-kicking leg, ball, and unclassified.

The anticipation tests revealed no significant skill-based differences for save percentage (Savelsbergh et al., 2002). However, it is possible that the secondary measures of accuracy may be more indicative of skill-based differences. Specifically, the expert goalkeepers predicted shot height and direction more accurately, committed fewer corrective movements, and began their responses closer to ball-foot contact than the novice goalkeepers. The nature of the contrived task may therefore, have contributed to the lack of significant accuracy differences. Simply, the novice performers committed more corrective movements throughout the sequence, suggesting that more information was required for these athletes to confirm their decision, a luxury unavailable in a real-world condition.

Secondly, experts were better able to anticipate the height and direction of shots more accurately and initiate their responses just prior (300 ms) to ball-foot contact, suggestive of the effective use of advance cues (Savelsbergh et al., 2002). In contrast, the novice group initiated their response 500 ms prior to ball-foot contact. Although such a brief differential existed between the expert and novice players, the early response time by the novice players may be more suited to a guess, whereas the expert players are able to match the advance cues with an

appropriate response in the brief time period. The results of the visual search data revealed that the expert goalkeepers performed a more efficient and less exhaustive search of the visual display. That is, they fixated on fewer areas of the display while using fewer fixations of longer duration. Moreover, the experts garnered more information from the kicking leg, non-kicking leg, ball, and head regions, as compared to the novice performers who spent more time fixating on the trunk, arm, and hip regions. Overall, these results demonstrate the importance of highly reactive participants to acquire perceptual information early in the display in order to process and formulate a correct motor response.

In a unique study of the advance cues used in a motor task, Byrnes (2002) examined the visual search behaviors of expert (*n*=5), intermediate (*n*=5), and novice (*n*=5) equestrian riders. An ASL 5000 eye tracking system was used to record visual search behaviors as the participants viewed a computer simulation of the fences located throughout an equestrian course. Participants were not constrained in any manner, therefore they were free to look at the course from a variety of angles and perspectives for as long as they desired. The visual search data were assessed for number of fixations, fixation duration, and location of fixations. The results from the investigation revealed that expert riders made more fixations across fences than both the intermediate and novice riders yet no differences were evident between the intermediate and novice groups. Furthermore, no skill-based differences were evident for fixation duration. Fixation locations were analyzed according to predetermined areas of interest. The expert riders directed significantly more fixations within the predetermined areas of interest as compared to both the intermediate and novice riders, yet no differences were found between the intermediate and novice riders. In conclusion, the work of Byrnes (2002) signifies the meticulous nature of

expert riders, as indicated by the exhaustive nature in which they search a display in preparing for competition.

The relationship between visual perception, anticipation, and visual search behaviors of experienced (*n*=8) and novice (*n*=8) tennis players was assessed by Ward, Williams, and Bennett (2002). Participants stood in front of a 3m x 3.5m "life-size" projection screen which depicted normal and point light displays of tennis ground strokes. From a theoretical perspective, Ward et al. (2002) postulated that experienced tennis players are more attune to perceptual cues than inexperienced performers. Therefore, when the perceptual display was modified to emit minimal detail (i.e., point light display), both response accuracy and visual search behavior of the novice performers was believed to suffer, yet the experienced players were expected to portray similar visual search behaviors while responding comparably across displays. Response accuracy was assessed by physically responding to the anticipated direction of the impending stroke. Two pressure sensitive mats were designated as the starting position, with four additional mats placed around the participant that were used to record the response direction. Visual search data were recorded using an ASL 5000 eye movement tracking system.

Anticipation data revealed skill-based differences for decision time, with the experts responding quicker (Ward et al., 2002). No skill-based differences were evident for response accuracy between groups in either condition. However, a performance decrement of 9.9% was noted under the point light display as compared to the normal display for the experienced group, whereas the inexperienced participants' response accuracy score remained stable. This result suggests that the lack of detail is more detrimental to experienced athletes. The visual search data revealed that regardless of the viewing condition, the experienced players spent more time fixating on the head-shoulder and trunk regions as compared to inexperienced players, who spent

more time attending to the racquet area. Search rate data revealed a decrease in the total number of fixation locations and total fixations whereas fixation duration increased for both groups while viewing the point light display. This result confirms the difficulty for both experienced and inexperienced individuals to extract perceptual cues from point light displays. Although no between group differences were noted, search order revealed that experienced players emitted successive fixations around the torso more than the inexperienced group. Moreover, the inexperienced group altered their fixation patterns when viewing the point light display, fixating more to the racquet, ball, and ball-racquet areas. Conversely the experienced players were more resilient, maintaining their preferred search order even when viewing the point light display.

The work of Ward et al. (2002) provides support for the notion that experienced players possess the ability to extract relevant performance cues even from the most sparse arrays. Although, response accuracy diminished marginally while viewing the point light display, decision time was stable across conditions (Ward et al., 2002).

Visual search summary and review

In the wake of previous methodological and inferential limitations (e.g., temporal and spatial occlusion) in the study of expert-novice perceptual differences, more recent technological advances, such as the advent of eye movement registration techniques were thought to provide greater insight into the cue utilization and decision making process of skilled and less-skilled performers. Visual search data were further used to draw conclusions about attention allocation and more specifically selective attention. It was commonplace that experts would require less perceptual information as a result of their extensive knowledge base permitting the detection of stimulus redundancy (Abernethy, 1988). Unfortunately, the equivocal findings across a variety of sport tasks and furthermore task complexity has generated more questions than initially answered. Specifically, temporal stress, whether inherent (i.e., increased response uncertainty) or

imposed (i.e., experimental control), appears to influence the relationship between fixation duration and the total number of fixations (Abernethy, 1988, 1990b).

However, the practical significance of the systematic findings that experts perform much quicker than novices is significant. Sport by nature requires dynamic thinking and split second decision-making. Clearly the use of advance perceptual information aids in this process. Although the visual search behaviors of expert athletes have been equivocal across tasks of varying type and complexity, the issue may not be at all be related to information sought via foveal fixations but rather a result of the information collected from the peripheral system (Abernethy, 1988; Williams et al., 1993; Williams et al., 1999). More direct research is warranted assessing the peripheral vision differences in expert and novice performers and their respective abilities to gather, process, and translate that information into enhanced performance.

Moreover, experts may engage in an advanced level of preattentive processing as suggested by Neisser (1967), therefore constructing *a priori* strategies to facilitate the decision-making process. To further clarify, a common finding throughout the visual search literature was comparable response accuracy between skill levels, however expertise was indicative of faster decision-times suggesting that certain cues would appear to “pop-out” to the expert while diligent pursuits were required by the less-skilled athletes.

Nevertheless, this narrative review has provided inclusive evidence as to the distinct visual search tendencies unique to athletes of varied skill level. Caution should be taken however, when attempting to infer even from the equivocal findings reported here. The very nature of the tasks assessed coupled with the inconsistent use of “experts” and “novices” sufficiently impedes the ability to decisively conclude skill-based visual search differences. In response to this limitation a quantitative analysis of this literature base is warranted.

Finally, it can be concluded that eye movement registration techniques cannot ensure an accurate understanding of the information *extracted* from the visual display despite the ability to index the location of the eye relative to the visual display. As Abernethy (1988) indicates the capacity for athletes to shift their attention without additional eye movements fosters the need for a distinction between "looking" and "seeing". To confound this problem further, little is known of the function peripheral vision assumes for information extraction during the visual search of a dynamic visual display.

In sum, eye movement registration techniques have furthered the understanding of the visual search strategies of athletes. Moreover, as technology continues to push the boundaries of applied research, more definitive ecologically valid conclusions may be drawn as to the performance differences present during actual competition.

Quiet Eye

Although traditional eye-tracking research has been limited to the measurement of the number, duration, and frequency of visual fixations, the location of fixations, visual pivots, and saccades, more recent trends have focused on a measure that is believed to be associated with the organization of visual attention and information processing, the QE period. Specifically, the "quiet-eye period" is a measure defined as the elapsed time between the last visual fixation to a target and the initiation of the motor response (Vickers, 1996a). For example, the QE period of a marksman is identified as the elapsed time from the last recorded visual fixation to the commencement of the trigger pull. Literature examining the QE period and whether or not the QE period can mechanistically account for notable expert-novice performance differences is the focus of this section of the review.

From a theoretical perspective, Vickers (1996a) proposed the location-suppression hypothesis to account for the requisite behaviors necessary for aiming. For example, consider

tasks such as baseball pitching, archery, dart throwing, pistol or rifle shooting, basketball free-throw shooting, and even billiards. These tasks require the identification of a target in the environment through visual search, followed by the successful merging of environmental coordinates and movement to accomplish the goal successfully. Vickers (1996a, 1996b) postulates that fixations of relatively longer duration are necessary during the preparatory stages of the task and are directly associated with increased accuracy. Simply, prolonged fixations are not associated with vigilance, but rather a result of the opportunity to process cues that have already been extracted from the environment more acutely. Once movement has been initiated new environmental cues are crucial to maintaining focus on the target, however, the execution phase of task completion requires astute focus. According to Vickers (1996a) it is during the execution when suppression occurs; the new visual information presented to the performer is significantly filtered, reducing the probability of distraction from task irrelevant cues.

Pre-performance routines in self-paced tasks are a common thread among applied sport psychologists and athletes looking for a performance advantage. Free throw shooting in basketball is the quintessential example of the importance of synchronizing the mind and body prior to motor execution through pre-performance routines. However, the link between gaze control and success is limited.

Vickers (1996b) studied 16 elite, female basketball players, who competed at the intercollegiate and national levels. However, Vickers dichotomized the group as experts and near-experts based on their free-throw shooting percentage during one full season, including playoffs. Those who achieved an accuracy rating exceeding 75% were deemed expert, whereas those who shot less than 65% successfully were classified as near-experts. Gaze behavior was recorded during the completion of 10 successful and 10 unsuccessful shots. Results indicated that

only the expert group located a target early in their search patterns and fixated on that target until the initiation of the shot. Again, this suggests expert performers exhibit distinct gaze behaviors. Furthermore, the QE period was able to consistently discriminate between skilled and lesser skilled athletes.

Complex tracking and aiming tasks such as hitting a baseball, returning a tennis serve, and receiving a volleyball serve are characterized by three distinct segments (Vickers & Adolphe, 1997), beginning with the detection phase (i.e., determining the flight path of the object), followed by the pursuit tracking phase (i.e., following the flight path), and concluding with the aiming phase (i.e., orienting the body to make contact with the projectile).

To address the role of gaze behavior across the three distinct segments associated with the reception of an object, Vickers and Adolphe (1997) tracked the gaze behaviors of 12 elite volleyball players as they received a serve and executed a passing shot to a designated target. Experts were classified as those who achieved a reception and pass rating of 64% or better. The near-expert comparison group were those who achieved a reception and pass rating of less than 50%. Results indicated that the expert group demonstrated unique gaze behaviors as compared to the near-experts. That is, the expert group demonstrated a pronounced QE period, meanwhile the near-expert group failed to establish a QE period at all, such that the purist tracking of the ball during flight was replaced with a higher incidence of corrective footwork. Unique to this investigation, the QE period was also evident in the reception of an object.

To this point QE researchers had neglected to account for the influence that emotions may have on gaze behavior. Traditional expertise research has suggested that elite performers have superior mental skills that provide more effective emotional regulation and coping strategies (Gould, Weil, & Weinberg, 1981). In an attempt to fill this gap Vickers, Williams, Hillis,

Rodrigues, & Coyne (1999) examined the effects of cognitive anxiety and physiological arousal on gaze behavior and shooting accuracy. Eleven elite biathletes fired 10 shots at a target 5m away while under high anxiety and low anxiety conditions. Quiet-eye was influenced by the modulations in cognitive anxiety and physiological arousal, as was performance. It is worth noting however, that regardless of the experimental condition, successful shots (i.e., hits) were associated with prolonged QE periods, while unsuccessful shots were characterized by reduced or non-existent QE periods.

It can be argued that as task complexity increases the fundamental rules necessary for successful completion will also change (Wulf & Shea, 2002). In the case of a billiards task of varying complexity Williams, Singer, and Frehlich (2002) assessed the gaze behaviors of skilled and less skilled participants. It was proposed that skilled players would generate longer QE periods during the preparation phase. Furthermore, as task complexity increased it was hypothesized that respective QE period would also increase. The increased complexity necessitates increased resources and preparation, therefore, if the QE is related to cognitive processing a direct relationship between the two should be evident (Williams et al., 2002). Results confirmed the hypothesis and provided further support for the location-suppression hypothesis and QE as a function of expertise. Moreover, it was demonstrated that as task complexity increased, so too did the corresponding QE period. Expert-novice differences maintained their relationship as experts continued to elicit longer QE periods, while successful shots and unsuccessful shots across skill levels could be differentiated by the QE gaze behavior.

Finally, Janelle et al. (2002) further extended the QE research paradigm to small-bore rifle shooters. Marksmen are renowned for their unmatched ability to regulate their physiology (Konttinen & Lyytinen, 1992) and focus their attention prior to each shot (Konttinen & Lyytinen,

1993; Lawton, Hung, Saarela, & Hatfield, 1998). Consistent with the notion that the QE period is associated with the coordination and production of the requisite resources to execute a task successfully while filtering out irrelevant environmental cues, it was postulated that expert shooters would engage in prolonged QE periods when compared to novice shooters. Confirming this hypothesis, Janelle and colleagues (2002) reported performance and QE differences between groups, with the expert group outperforming the novices and exhibiting relatively longer QE periods.

Quiet Eye Summary and Review

Advances in research technology, specifically advances in visual search equipment, have provided a unique opportunity for expertise researchers to probe previously unattainable questions from a mechanistic perspective. The resulting gaze behavior research in sport has provided valuable insight into the mechanisms that may differentiate expert from novice performers. In this case, the QE period, has indexed a mechanism that appears to be temporally linked with the organization of visual information and necessary for the coordination of the motor pathways required for successful execution of a desired task. To this point, research has reliably demonstrated relatively prolonged QE periods as an effective marker for differentiating skilled and lesser skilled athletes. Moreover, these findings have shown consistency across domains as diverse as a rifle shooting and billiards and across tasks that require aiming at a target (e.g., billiards and shooting) to those that require the individual to receive a projectile momentarily while aiming and releasing it to a designated target (e.g., volleyball).

Expertise, Visual Search and Emotion Regulation

The interaction between the visual and emotional systems has been robustly demonstrated across a variety of tasks (e.g., martial arts, driving, billiards, biathlon shooting), suggesting that as anxiety increases, a corresponding reduction in visual attention efficiency and psychomotor

performance is likely (Murray & Janelle, 2003; Williams & Elliott, 1999; Williams, Vickers, & Rodrigues, 2002; Williams, Singer, & Frehlich, 2002). It is a commonly held belief that anxiety leads to attentional narrowing, such that the breadth of attention is reduced and distractibility is increased (Easterbrook, 1959), often resulting in an increase in search rate (Janelle, Singer, & Williams, 1999; Murray & Janelle, 2003). Moreover, under periods of heightened anxiety, a mobilization of additional attentional resources is likely to occur in an effort to offset the deleterious effects of anxiety, ultimately rendering a less efficient performance (Eysenck & Calvo, 1992; Janelle, 2002).

When the outcome of an ensuing event is uncertain, participants typically experience elevated levels of stress, arousal, and anxiety (Jones & Swain, 1992). Consequently, the highly complex, competitive, and unpredictable nature of sport often prompts heightened arousal and anxiety. According to the Processing Efficiency Theory (PET; Eysenck & Calvo, 1992), the interaction of individual state and trait levels of anxiety coupled with environmental constraints (e.g., performance pressure and/or uncertainty) directly impact the functional capacity of attention. Specifically, the processing efficiency theory implicates the capacity and resilience of the short-term working memory system as an inherent limitation in human information processing. Short-term working memory is thus susceptible to the adverse effects of increased state anxiety, thereby comprising performance. That is, cognitive anxiety, which is characterized by worry and an inability to concentrate, may redirect attention toward a preoccupation with thoughts of evaluation and outcome expectations, and away from task relevant cues (Liebert & Morris, 1967). However, a major tenet of the processing efficiency theory states that as anxiety increases, performance decrements may be avoided via the recruitment and allocation of

additional cognitive resources, thereby preventing the decline in available working memory resources while sustaining performance.

Recent gaze behavior research in sport (e.g., Janelle, Singer, & Williams, 1999; Murray & Janelle, 2003; Williams & Elliot, 1999; Williams, Vickers, & Rodrigues, 2002) offers empirical support for the theoretical tenets put forth by Eysenck and Calvo (1992) and Easterbrook (1959), such that visual search efficiency declines with increases in stress and anxiety, while preserving performance. Furthermore, skill-based differences in sport have been reliably reported, with expert performers engaging in fewer fixations of longer duration as compared to less skilled participants (Mann, Williams, Ward, & Janelle, 2006; Williams, Davids, & Williams, 1999). Accordingly, such skill-based visual search differences may be the result of greater self-monitoring of performance processes among novice performers, leaving them with fewer cognitive resources available for task execution as compared to experts.

The seminal work of Janelle et al. (1999) in sport, examined changes in gaze behavior under varying levels of anxiety during a simulated auto-racing task. During the course of the driving task, participants were required to detect and discriminate between relevant and irrelevant cues randomly presented about the periphery of the visual display while being subjected to random manipulations in anxiety. Results indicated that as anxiety increased, processing efficiency and task performance decreased. Additionally, such changes were coupled with a marked increase in gaze behavior variability (i.e., more fixations of shorter duration). As such, Janelle et al. (1999) concluded that heightened anxiety can lead to increases in attentional narrowing, resulting in the ineffective search and use of perceptual cues.

In a related study, Murray and Janelle (2003) employed a dual-task auto-racing simulation to assess the relationship between visual search behaviors and modulations in anxiety. Murray

and Janelle reported that the additional cognitive and attentional demands associated with the relative increases in anxiety resulted in a significant decrease in processing efficiency. Specifically, as anxiety increased so did search rate, rendering the performer less efficient. The notable reduction in processing efficiency may be in part due to a decreased ability to utilize or discriminate between relevant and irrelevant cues. According to Easterbrook (1959) narrowing of attention is a natural by-product of the interaction between arousal and task demands, such that the breadth of attention becomes constrained. For example, under normal conditions and moderate arousal, the discrimination of task relevant cues from task irrelevant cues is a relatively effortless process. However, as arousal increases the scope of attention is reduced, restricting the number of cues, both task relevant and irrelevant, that can be simultaneously processed and distinguished, ultimately compromising the use of task relevant cues.

Furthermore, Williams et al. (2002) assessed table-tennis performance under combinations of high and low working memory with corresponding changes in anxiety (high and low). As expected, results indicated increased effort, delayed reaction times, and increased search rates while performing under the high working memory and high anxiety condition as compared to the low working memory and low anxiety condition, a pattern indicative of less efficiency.

In the first expert-novice comparison, Williams and Elliot (1999) examined the effects of cognitive anxiety and level of experience on anticipation and visual search behavior during simulated karate kumite combat situations. Expert and novice martial artists viewed a series of film sequences depicting both fist and foot strikes. Participants were required to physically counter each simulated strike as quickly and as accurately as possible under low anxiety and high anxiety conditions. Consistent with the Processing Efficiency Theory and Cue Utilization Hypothesis, Williams and Elliot (1999) predicted and found evidence to support the idea that as

anxiety increased, so too would the number of fixations to the periphery of the visual display. Specifically, they found that as cognitive anxiety increased, the viewing patterns of the expert and novice groups' changed variably, with a marked increase in attention to peripheral cues. Worth noting however, was a reported decrease in visual search efficiency in the novice group. That is, while the experts in the high anxiety condition demonstrated an increase in their respective mean fixation duration, the mean fixation duration of the novice group decreased. Consistent with previous findings, the corresponding increase in search rate among the novice group can be explained by a comparative decrease in processing efficiency and ineffective cue utilization (Williams & Elliot, 1999).

Collectively, the aforementioned investigations lend support to the negative effects of anxiety on performance, processing efficiency and cue utilization. Moreover, these findings can be viewed as illustrating the increase in the cognitive/attentional demands which accompany increases in anxiety and arousal. However, the increased fixation duration of the expert group in the Williams and Elliott study, may suggest that a decrease in visual search rate permits the allocation of additional cognitive resources to offset the attentional demands imposed by heightened anxiety. As such, the QE period may serve an anxiety regulation function during self-paced tasks.

The QE research has demonstrated a unique and robust relationship between performance and gaze stability during the temporal period immediately preceding task performance. Given the magnitude of this relationship, it is not out of the question to infer that the QE period serves a motor planning function. However, in light of the well-established relationship between anxiety, visual search, and performance across tasks of varying complexity, researchers have suggested that the QE period may also reflect a temporal window for the regulation of emotion (Janelle et

al., 2000; Vickers et al., 1999). That is, the prolonged QE duration that is characteristic of expert and superior performance may facilitate the prevention of the processing of irrelevant stimuli, a characteristic commonly associated with increases in anxiety and/or arousal. Central to Eysenck and Calvo's (1992) Processing Efficiency Theory is a self-regulatory system, a system in place to mediate the effects of anxiety on processing and performance (p. 415). The QE period may provide an indirect measure of this regulatory system.

In the first exploration of the relationship between QE duration, anxiety, and performance, Vickers et al. (1999) examined the effects of cognitive stress and physiological arousal on the gaze behavior and shooting accuracy of elite biathletes. Although the QE period was influenced by modulations in cognitive stress and physiological arousal, QE durations during 'best' performances were similar across levels of cognitive stress and physiological arousal. Specifically, during the high anxiety conditions, QE duration for hits continued to exceed the quiet duration for misses. As such, it is plausible to infer that a prolonged QE period may serve to alleviate the attention demanding effects of anxiety on performance.

Furthermore, Williams, Singer, and Frehlich (2002) assessed the gaze behaviors of skilled and less skilled billiard players. Although not a direct assessment of anxiety, Williams et al. (2002) imposed temporal constraints intended to increase task complexity. They suggested that increased task complexity necessitates increased resources and preparation, and postulated that if the QE is related to cognitive processing a direct relationship between the two should be evident (Williams et al., 2002). Results demonstrated that as task complexity increased, so too did the corresponding QE period. Expert-novice differences were also evident. Specifically, experts continued to elicit longer QE periods as compared to their novice counterparts, and QE duration was proportionally longer on successful shots than on unsuccessful shots across skill

levels, suggesting that the QE period may in fact aid in the circumvention of cognitive constraints (Janelle, Hillman, Apparies, Murray, Meili, Fallon, & Hatfield, 2000; Vickers et al., 1999).

Expertise, Visual Search and Emotion Regulation: Summary and Review

In conclusion, the effects of anxiety on information processing efficiency have been reported across a variety of tasks in which visual search efficiency declines with corresponding increases in anxiety and task difficulty. Most intriguing however, is the fact that the QE/performance relationship is not mediated by changes in task complexity (Williams et al., 2002), modulations in cognitive anxiety or physiological arousal (Vickers et al., 1999). Although, the duration of the QE period has been demonstrated to change as a function of task complexity and other constraints, the performance relationship remains robust, with increases in QE consistently being associated with increased performance and expertise. As such, as task complexity and or arousal and anxiety increase, the associated increase in QE duration may serve a regulatory function permitting the formulation of a precise motor program necessary for performance. The following section will demonstrate the cortical adaptations separating the expert from the novice performer. Of primary importance across the psychophysiological literature is the reported psychomotor efficiency of the expert, coupled with an increased readiness to perform. As such, the cortical signatures associated with such efficiency and readiness to perform may be the result of prolonged QE periods as reported here.

Cortical Activity and the Preparatory Period

The systematic observation of electro-cortical activity provides a noninvasive, objective index for deducing the concomitant psychological processes responsible for the information-processing and sensorimotor distinctions of expert and near-expert performers. Specifically, the use of continuous electroencephalographic (EEG) techniques (e.g., spectral analysis and event

related potentials) permits a concurrent, real-time look into the underlying cortical structures contributing to the psychological processes accounting for skill differences. Self-paced tasks demanding visuomotor coordination such as golf putting, archery, and marksmanship have been extensively used in the sport sciences. Each of the aforementioned tasks inherently requires the participant to remain relatively motionless during the preparatory period, reducing the potential confound of movement artifact in the EEG waveform. Moreover, each task places great demand on the psychomotor systems (i.e., attention, emotion, motor control and preparation) conducive to psychophysiological recording (Hatfield & Hillman, 2001).

To date, the majority of research in sport has relied on spectral analysis techniques to address issues of hemispheric asymmetry during the preparatory period to infer the covert psychological processes associated with superior performance. As such, research stemming from the spectral domain has consistently reported cerebral efficiency in favor of the expert. However, the use of event-related potentials (ERP) is far less prevalent, despite the advantage of the functional significance of the information processing transactions that are manifested in the components of the ERP as a function of context (Fabiani, Gratton, & Coles, 2000). Of interest here is the Bereitschaftspotential. Therefore, the purpose of this section is to provide a review of the electro-cortical literature in sport as it relates to both the spectral and ERP components during the preparatory period of a self-paced task.

Spectral Activity

Sport psychophysiologists (e.g., Crews & Landers, 1993; Hatfield, Landers, & Ray, 1984, 1987; Salazar, Landers, Petruzzello, & Han, 1990) investigating the covert cortical processes of skilled performers have made extensive use of the electroencephalographic (EEG) spectral analytic techniques, comparing and contrasting levels of hemispheric activation. Specifically, the decomposition of the EEG waveform, permits the analysis of a specific frequency band in the

spectrum ranging from DC to 44Hz. Sport research however, has placed a great deal of emphasis on the alpha (8-12HZ) band and to a much lesser extent, the beta band (13-36Hz) of the power spectrum. Alpha power, which is believed to result from thalamic input to the cortex (Lopes da Silva, 1991), has been used to infer the functional and mechanistic significance of various cortical structures across hemispheres. Because alpha activity is inversely related to cortical activation, the comparison of left and right hemispheres permits the inference of the specific cortical regions necessary for the execution of a given visuo-motor task.

The early work of Hatfield and colleagues (1982) was the first in a series of investigations (Hatfield, Landers, & Ray, 1984, 1987) examining the covert cognitive processes associated with skilled psychomotor performance of elite marksmen. In this seminal study, cortical activity was recorded during the preparatory period leading up to the point of trigger pull. As hypothesized, Hatfield and colleagues confirmed alpha power differences across hemispheres, with greater cortical quieting in the left as compared to the right hemisphere.

In a subsequent attempt to further isolate the cortical patterns of expert marksmen during the preparatory period, Hatfield, Landers, and Ray (1984) conducted a study in which the 7.5 second pre-shot period was subdivided into three 2.5 second epochs facilitating the analysis of cortical activity as the time to trigger pull neared. Furthermore, a more elaborate montage was employed including T3, T4, O1, and O2 reference sites. Cortical activation across the three 2.5 second epochs revealed a steady global decrease in cortical excitation. More telling however were the asymmetrical differences noted between the left and right temporal regions, while relative symmetry remained across the occipital sites. Together, these findings suggest that cortical specificity plays a significant role in the performance of skilled athletes. To elaborate, the decrease in left hemisphere activation may represent a reduction in verbal-analytic processing

as the time to trigger pull nears coupled with a relative increase in visual-spatial processing, permitting an ideal preparatory set for target shooting (Hatfield et al.,1984).

Given that athletes, coaches, and sports scientists place great importance on pre-performance routines for facilitating attentional focus the early psychophysiological work of Hatfield and colleagues sparked a surge of research into the covert attentional focus patterns associated with self-paced closed skill sports.

For example, Salazar et al. (1990) examined hemisphere-related temporal changes in EEG activity of 28 elite archers during the 3-second period preceding arrow release. Cortical activity was recorded from left (T3) and right (T4) temporal areas while performance was measured as the distance from the inside edge of the arrow to the center of the target. Their results revealed a steady cortical state in the right hemisphere coupled with a significant decrease in left temporal cortical activity (i.e., increase alpha power). Furthermore, the 1-second period immediately prior to arrow release for the four best and four worst shots for each participant was analyzed, indicating that pre-performance cognitive states are reflected in subsequent performance. More specifically, although right hemisphere activity was consistent across both best and worst shots, a significant increase in left hemisphere alpha power was evident for best shots, suggesting that optimal performance may be related to a reduction in verbal analytic processing, a finding consistent with the work of Hatfield and his colleagues (1984, 1987).

In another study (Crews & Landers, 1993), the electro-cortical activity and golf putting performance of highly skilled golfers (N = 34) was analyzed with emphasis placed on the primary motor (C3, C4) and temporal (T3, T4) cortices. Similar to previous research (e.g., Hatfield et al. 1984; Salazar et al. 1990), the pre-performance period was subdivided into three 1-second epochs prior to the initiation of the putting stroke. However, unique to this investigation

was the inclusion of a variety of EEG analysis techniques, including spectral power and the slow wave analysis of the Bereitschaftspotential. Corroborating previous findings, the spectral analysis revealed a significant increase in the left hemisphere alpha power while reporting relative stability in the right hemisphere. Again these results suggest a relationship between performance and a reduction in verbal analytic processing with active visual-spatial processing during the preparatory period of skilled performers.

To further explore the covert attentional strategies and preparation to respond, Crews and Landers (1993) extended their analysis to include the Bereitschaftspotential, an index of the psychomotor readiness to perform. Their results revealed a negative shift in the cortical potential over the left hemisphere from epoch 2 to epoch 1, indicating an enhanced preparatory set, coupled with relative stability over the right hemisphere. Consistent with BP research, the asymmetrical changes are consistent with limb dominance and performance execution (see section Bereitschaftspotential).

Lastly, Crews and Landers (1993) hypothesized that each of the EEG measures recorded would correlate with performance, with an increased probability for such a relationship occurring at epoch 1 (i.e., the final second before arrow release). Contrary to previous research, the results of the spectral analysis revealed a significant relationship between the alpha activity of the motor region of the right hemisphere and putting performance error, suggesting that tasks requiring precise movement contributions from both limbs may result in symmetrical cortical contributions. The Bereitschaftspotential was not related to performance.

In an effort to advance the conceptual understanding of the aforementioned cortical patterns, Hillman, Apparies, Janelle, and Hatfield (2000) compared the EEG spectral activity of skilled marksmen prior to the execution and withdrawal of shots. To clarify, during competition

marksmen are permitted to ‘reject’ or withdraw their rifle from the target prior to trigger pull, suggesting a state of mental or physical unrest. Accordingly, Hillman and colleagues hypothesized that the cortical signatures of the pre-performance period preceding rejected shots would reflect an inability to adaptively allocate visual-spatial processing, resulting in an increase in right hemispheric EEG alpha power relative to an executed shot. The results of the comparison between executed and rejected shots revealed a relative and progressive increase in alpha power for rejected shots as compared to executed shots, supporting the notion that the decision to withdraw from a shot is representative of incongruent cortical activation for the requisite task.

Collectively, the results of the early psychophysiological work provide empirical support for the relationship between pre-performance cortical activation and the quality of performance of highly skilled participants. The analysis of EEG spectral activity across hemispheres has revealed that the analytic left hemisphere (T3) shows marked increases in alpha power during the time period immediately prior to task execution, while the visual-spatial processing associated with right hemisphere (T4) activation remains relatively vigilant during the same period. Overall, as the time to task execution nears, cortical activity declines, and the relative shift in hemispheric dominance suggests cortical specificity among highly skilled performers.

Discrepant findings have been reported however with respect to role of the occipital EEG alpha power. For example, the seminal work of Hatfield et al. (1984) reported an increase in alpha power in the left occipital region (O1), but failed to replicate that finding in a later study (Hatfield, Landers, & Ray, 1987).

Given the apparent discrepancies of occipital EEG alpha power noted in the previous work of Hatfield et al. (1984), Hatfield, Landers, and Ray (1987), and Loze, Collins, and Holmes (2001) inferred that the processing of visuo-motor stimuli should either remain constant or

decrease in the preparatory period immediately preceding trigger pull. That is, when performing a well-learned skill, the continued acquisition and analysis of visual information immediately prior to performance may interfere with the formulation and execution of the requisite motor program. As such, cortical idling or quieting in the occipital lobe would suggest a reduction in visual attention. Therefore, Loze et al. (2001) examined the cortical activity of six expert air-pistol shooters across best and worst shots to determine the mediating role of occipital EEG alpha power on shooting performance.

Continuous electroencephalographic activity was collected from Oz, T3, and T4, and was referenced to linked mastoids. Post acquisition analysis consisted of the reduction of pre-shot data into three 2 sec EEG epochs for which spectral analysis was conducted, yielding absolute alpha (8-13Hz) power values of best and worst shots. Results indicated that occipital alpha power was greater in best shots, with the greatest difference in power noted in the third epoch (i.e., the final 2-second period immediately prior to trigger pull). Moreover, not only did alpha power increase during best shots, alpha power was found to decrease in the final epoch prior to worst shots. Corroborating previous EEG work (e.g., Hatfield et al., 1984; Hatfield and Landers, 1987), hemispheric asymmetry was also reported. That is, significantly greater alpha power was evident in the left temporal region (T3) as compared to the right temporal region (T4), a finding consistent with the notion of cerebral efficiency.

In-line with the dominant theory of motor expertise (Fits & Posner, 1967), the work of Loze et al. (2001) lends support to the notion that skilled performance is optimized when conscious processing during skill execution is minimized. In this case, visual information processing gives way to the formulation and execution of the necessary motor program, increasing the probability of optimal performance. Although, compelling, such conclusions are

tenuous, given that the cortical regions associated with the generation and execution of the motor pathways were not assessed. For example, the slow potentials known to have motor preparation and execution implications should be concurrently assessed to determine the actual effect of verbal-analytic and visual-spatial processing on the motor pathways, as opposed to relying on the inferential connections based solely on performance outcome.

The early investigations of cortical activity during rifle shooting, archery, and golf putting provided direct accounts of the relationship between covert psychological process and performance in highly skilled performers. Unfortunately, the lack of a control or comparison group (i.e., less skilled participants) in the aforementioned investigations renders it difficult to infer the extent to which these cortical profiles can account for skill development. That is, are the cortical patterns denoted above requisite for skilled performance? Or are such patterns consistent across all skill levels? The direct comparisons of expert and less skilled performers should provide insight into the cognitive processing differences as skill becomes more efficient, well learned, or automatic.

Expertise Differences in Cortical Activity

The development of sport-specific psychomotor abilities and cognitions has been argued to result in less effortful and more automatic performance, which in turn permits highly skilled performers to act with less cognitive stress compared to their less skilled counterparts. As such, expertise researchers have provided extensive empirical accounts that document the cortical differences of skilled and unskilled performers. Extending the aforementioned intra-subject designs, expertise researchers not only hypothesized a significant relationship between hemispheric activation and performance within groups, but further anticipated cortical differences across skill levels. That is, EEG spectral power was expected to reflect the heightened mental effort associated with unskilled performance.

Haufler, Spalding, Santa-Maria, and Hatfield (2000) conducted the first study investigating the covert psychomotor differences of skilled and unskilled performers. In their study EEG spectral activity of the left and right frontal, temporal, parietal, and occipital regions of competitive marksmen and novice shooters was recorded during the 6 second preparatory period of 40 self-paced trials, with the resulting data being partitioned into six 1 second epochs.

When compared with the marksmen group, the novice shooters were predicted to exert more cognitive effort as a result of their active engagement in verbal-analytic processing. Confirming their hypothesis, Haufler et al. (2000) reported that during the 6 second aiming period, the marksmen exhibited less cortical activity in the left hemisphere as compared to the novice shooters across reference sites with the greatest alpha power evident in the left temporal (T3) region. The notable cortical differences between the marksmen and novice shooters suggests that during the process of skill acquisition, cortical adaptation occurs in the order of cortical specialization. As such, it can be inferred that the cortical areas associated with the greatest expert-novice difference are those most relevant to task performance.

In a similar study, Janelle et al. (2000) examined expertise differences in cortical activation during rifle shooting. Unlike other expertise studies, the participants included were similar in years of shooting, differing only in their competitive experience, suggesting that any notable difference can be inferred to be the direct result of skill and not the result of exposure or familiarity with the task. Corroborating previous research (Crews & Landers, 1993; Hatfield et al., 1984, 1987), Janelle and colleagues reported a direct intra-subject relationship across skill levels between performance and hemispheric activation. To elaborate, successful performance was characterized by an increase in left hemisphere alpha power compared to that of the right hemisphere. Moreover, expected expertise differences were also reported. Specifically, although

both groups appeared to display similar cortical patterns, the experts consistently demonstrated greater hemispheric asymmetry as compared to the novice group, suggesting a pronounced level of cortical specificity.

Lending credence to the conclusions of cortical efficiency and specificity of experts is the developmental approach to the study of cerebral cortical activity in novice performers. The early stages of skill acquisition is often uncoordinated and accompanied by effortful cognitive analysis. However as skill progresses, coordinated movement requires less conscious regulation, and performance becomes autonomous, free from cognitive constraints (Anderson, 1982; Fitts & Posner, 1967). Therefore, in an effort to empirically evaluate the neurocognitive adaptations hypothesized to occur during skill acquisition and the development of expertise, Landers, Han, Salazar, Petruzzello, Kubitz, and Gannon (1994) conducted a longitudinal investigation of novice archers. As anticipated, as the skill of the novice archers developed over the course of the 14-week training program, so to did their corresponding cortical patterns. Specifically, EEG asymmetry was characterized by pronounced alpha power in the left hemisphere as compared to the right, with the most notable differences occurring 0.5 seconds prior to arrow release. Although lacking an expert comparison group, the cortical adaptations reported by Landers et al. (1994) are consistent with the notion of psychomotor efficiency put forth by Fitts and Posner (1967) and further suggest that the degree of psychomotor skill acquisition is reflected in EEG cortical asymmetry (Hatfield & Hillman, 2001).

In a more recent investigation, Kerick, Douglas, and Hatfield (2004) recorded EEG event-related alpha power (ERAP) in an effort to increase the temporal resolution of alpha power estimates over a 14-week training period in novice pistol shooters. Confirming previous research (i.e., Landers et al., 1994), as performance improved over the course of the 14-week training

period, ERAP asymmetry evolved with pronounced increases evident in the left temporal (T3) region as compared to the right.

Collectively, the expertise and developmental research has consistently revealed intra-subject and inter-subject hemispheric asymmetry characterized by relative cortical stability in the right hemisphere and increased alpha power in the left. These results are consistent with the notion of psychomotor efficiency characterized by a decrease in verbal-analytic processing associated with the left hemisphere and a lack of cortical quieting in the right due to the visuo-spatial processing associated with precision sports.

Coherence

The conscious processing of task relevant cues is often considered characteristic of the novice performer as indexed by decreased levels of hemispheric asymmetry and in general elevated levels of cortical activity in the anterior-temporal regions (i.e., T3 and T4; Hatfield et al., 1984; Hatfield, Landers, & Ray, 1987). Although the use of asymmetry metrics provide an index of the magnitude and direction of the differential levels of activation in specific cortical regions across hemispheres, the electroencephalographic technique of coherence analysis, permits the functional assessment between various regions of the cerebral cortex (Davidson, Jackson, & Larson, 2000). That is, coherence is a frequency band specific analysis that reflects the degree of linear relatedness of two cortical regions during the time course of a specific task. The greater the coherence, the greater is the correlation between the two points of reference, suggesting active communication between the sites. Conversely, low coherence is indicative of relative cortical autonomy. For example, elite level performers are believed to operate free from cognitive constraints, relying less on verbal cues (Anderson, 1982). Accordingly, low coherence is expected between the visuo-spatial, verbal-analytic, and motor programming regions of the cortex as skill proficiency increases (Deeny, Hillman, Janelle, & Hatfield, 2003).

Consequently, Deeny et al. (2003) employed coherence procedures to assess whether alpha (low 8-10Hz and High 10-13hz) and beta (13-22Hz) band coherence of left anterior-temporal region (T3) and the motor planning regions (pre-motor cortex; Fz) of the cortex are inversely related to skill level. Ten expert and 9 skilled marksmen performed 40 shots each using the Noptel Shooter Training System (ST-2000) during an 80 minute testing session. Cortico-cortical communication was assessed during four one-second epochs preceding trigger pull. Results indicated that compared to the skilled group, the expert marksmen demonstrated lower coherence between the anterior-temporal and motor regions of the cortex for low alpha and beta frequencies. Subsequent analyses further indicated lower coherence between motor regions and all left hemisphere reference sites for high-alpha activity and lower coherence for beta activity between the anterior-temporal site and midline locations (i.e., Cz, Pz) in the expert group.

The findings of Deeny et al. (2003) support the notion of decreased cortical communication between functionally diverse brain regions in the elite level performer. As previously mentioned, much of the psychophysiological research in sport has ascribed to the basic tenets of Fitts and Posner's (1967) notion of automaticity, such that elite level performance is governed by the automatic processing of the planning and execution of movement. Moreover, as skill develops, the cortical regions necessary for skill execution become more specialized, therefore relying more on the cortical mechanisms responsible motor programming and execution (i.e, supplementary motor cortex, primary motor cortex, and the corresponding sub-cortical generators) as confirmed by the psychological differences of expert and skilled marksmen.

Bereitschaftspotential

The Bereitschaftspotential (BP) (or Readiness Potential) first described by Korhuber and Deecke (1964) is a negative moving cortical slow potential that precedes the onset of self-paced

movements by approximately 1 to 1.5 second. The slow negative cortical waves, of which the BP is one, are believed to be associated with arousal, the recruitment and augmenting of responses, and the general facilitation of processes required for task completion (Deecke, 1973). That is, an increase in negativity consistent with the BP is representative of cortical activation or excitation. By deductive reasoning, Brunia (1993) reports that all functions, including perception, attention, and preparation are realized by complex patterns of facilitation and inhibition in specific neuronal circuits which must be depolarized in order to produce an action. Therefore, it becomes possible to study, through electroencephalography, the cortical activity of the pre-motor period given that the depolarization process characterized by an increase in negativity at the surface of the cortex must precipitate an action (Brunia, 1993). Accordingly, readiness to act is depicted by a cortical signature manifested in motor and attentional processes during the preparatory period (Brunia, 1993; Deecke, 1973).

The BP is a visually distinct waveform (see Figure 2-6), denoted by three critical components that are temporally and cortically distinct (Deecke, Scheid, & Kornhuber, 1969): the BP_{early}, BP_{late}, and BP_{peak}. The slow rising negativity of the BP_{early} starts approximately 1500 ms prior to movement onset and although demonstrated to have a wide spread scalp distribution with maximal potentials recorded at the vertex, the early onset and pronounced amplitude implicates the supplementary motor area (SMA). The relative increase in cortical activity associated with the mid-frontal (C_z) region is not altogether surprising given its role in working memory, inhibition, planning, and executive functioning, including the integration and regulation of emotion and its corollaries. Specifically, the SMA is reportedly central to the planning and initiation of voluntary movement (Parent, 1996). For example, the BP is absent in movements exogenously driven (i.e., reflexive or passive movements) but is further exaggerated in those

movements associated with a consequence for the accuracy of motor execution (Becker, Iwase, Jurgens, & Korhuber, 1976; McAdam & Rubin, 1971; McAdam & Seales, 1969; Reagan, 1989). As such, any modulation in affect may result in unsystematic variability in the motor pathways, resulting in alterations in the quality of performance (Hatfield & Hillman, 2001).

The second component, known as the BP_{late}, is characterized by a change in the steepness of the waveform's slope, which occurs approximately 400-500 ms prior to movement onset. The rapid increase in negativity has been linked to the function of the primary motor cortex (MI). That is, the serial activation of the SMA and MI (preceding movement onset) results in an amplified negativity toward the hemisphere contralateral to movement suggesting the formulation of a more elaborate motor program as indicated by in increased cortical activation (Cui & Deecke, 1999; Deecke & Kornhuber, 1978; Shibasaki et al., 1980; Deecke et al., 1985; Boschert & Deecke, 1986). Lastly, the BP_{peak} is most pronounced over the hemisphere contralateral to the responding hand and occurs approximately 50-60 ms prior to movement onset. As Brunia and van Boxtel (2000) suggest that the components of the readiness potential comprise a process responsible for the initiation of voluntary, self-paced, motor acts.

The components of the BP, particularly the BP_{early}, which has been associated with the pre-movement activation of the supplementary motor areas (SMA), and the BP_{late}, which is associated with the activation of the primary motor cortex (MI), implicate the BP as the only psychophysiological correlate of motivation, preparation, intention, and initiation of self-paced goal directed behaviors in man (Deecke & Kornhuber, 2003). As such, the BP has been considered a means to address the preparatory processes of voluntary, goal-directed actions while observing the concurrent interaction of attention and motivation (Licht & Homberg, 1990).

The classic BP paradigm first described by Kornhuber and Deecke (1964) emphasized single finger movements with physical and temporal constraints, in which self-paced movements were accompanied by an inter-trial interval of five seconds or more. Although the initial protocol proved innovative, the nature of such a design may have led to the automatic performance of successive trials, negating the effects associated with voluntary, self-paced actions. Fortunately, subsequent research implemented protocols with fewer temporal and movement constraints, more representative of the fast paced complex movements of the real world, lending credence to the investigation of object or goal directed movements (Jahanshahi & Hallet, 2003).

Although the sport science literature is replete with electro-cortical investigations of expertise, few studies have specifically examined the event-related cortical slow potentials preceding a movement, while even fewer have examined the specific temporal components of the BP in sport.

The early work of Konttinen and Lyytinen (1992) determined that the preparatory period of marksmen is functionally occupied by either the motor demands (i.e., stabilizing the gun) or the visuo-spatial components (i.e., sighting the target) of the task, each of which can be identified by a distinct cortical signature characterized by the direction of the waveforms deflection. During target shooting, as the marksman allocates attention to the features (visuo-spatial processing) of the target, slow potential negativity becomes pronounced, a pattern indicative of increased readiness. Conversely, if attention is directed toward the requisite mechanics (i.e., gun hold) of the task, slow potential positivity becomes pronounced, suggesting a decreased readiness to act. Although general pre-shot cortical trends were evident among skill levels, Konttinen and Lyytinen (1993) put forth the notion that inter-individual pre-shot cortical patterns should also emerge during the preparatory period distinguishing high and low scoring trials.

The slow wave activity of seven male and five female marksmen was obtained from frontal (Fz), central (Cz), and occipital (Oz) midline and centro-lateral (C3, C4) sites during the 7.5 second period preceding trigger pull and the 1.5 second period following trigger pull. The marksmen completed 300 shots from a standing position to a target positioned 18m away. The average amplitude for each of five 1.5-second epochs was calculated and used for subsequent analyses. The results of Konttinen and Lyytinen (1993) revealed that each marksman developed a unique cortical signature, supporting the concept of intra-individual styles of preparation. Furthermore, and perhaps more importantly, distinct cortical profiles were evident for high scoring and low scoring shots suggesting that the cortical activity during the preparatory period is representative of the psychological readiness to perform which directly impacts performance outcome.

Given the potential of the slow cortical wave for implicating an athlete's attentional set, arousal level, and overall readiness to perform, Crews and Landers (1993) assessed the motor and temporal cortical activation levels of high skilled golfers during the three-second period preceding the putting stroke. It was hypothesized that a greater cortical change would be evident in the left hemisphere (T3, C3) as compared to the right (T4, C4), supporting previous research indicating greater hemispheric changes in the hemisphere contralateral to the dominant limb (see Jahanshahi & Hallett, 2003). Although the results confirmed a greater left hemisphere shift from epoch 2 to epoch 1, performance remained consistent, failing to support the findings of Konttinen and Lyytinnen (1993) who reported a significant relationship between cortical changes and performance outcome.

Despite the lack of empirical support by Crews and Landers (1993), the work of Konttinen & Lyytinen (1993a, 1993b) suggest that inter and intra-individual variability can reflect superior

and failed performance (Konttinen, Lyytinen, & Konttinen, 1995). As such, Konttinen et al. (1995) continued to probe the relationship between preparatory set, cortical activity, and performance. Cortical slow potentials were recorded from the frontal mid-line (Fz), centro-lateral (C3, C4), and occipital mid-line (Oz) locations during the observation of 6 elite (internationally ranked) and 6 sub-elite (nationally ranked) marksmen while performing 180-200 shots from a distance of 18 meters. Unique to this investigation, the 7.5 second preparatory window was divided into five 1.5 second epochs for which positive, neutral, negative, and irregular wave types could be classified. The objective of the Konttinen et al. (1995) study was to establish a typology of slow potentials reflecting the association between cortical activity and performance. Their results revealed an optimal cortical relationship, denoted by frontal mid-line deactivation coupled with increased asymmetrical activation in the centro-lateral hemisphere. More specifically, Konttinen et al. (1995) concluded that the magnitude and topography of optimal performance may be described by an efficient motor program, as indicated by decreased frontal activation, paired with intense visuo-spatial processing as indicated by an increase in right hemisphere negativity. In essence, if a motor program is established and accessible, motor regulation will proceed effectively and efficiently without much cognitive effort, which is discernible by an increase in SP negativity. Conversely, however, if the requisite motor program is either primitive or unavailable, additional effort is necessary to perform the task resulting in an increase in slow positivity (Warren & Karrer, 1984 as cited in Konttinen et al., 1995). Therefore, the cortical profile of superior performance put forth by Konttinen et al. (1995) lends empirical support to the notion of automatic processing in experts (Fitts & Posner, 1967), while further implicating the need for an external focus of attention for well learned skills (i.e., to the target) in lieu of an internal/cognitive processing approach (Anderson, 1982). Overall, the findings of

Konttinen et al. (1995) not only support an optimal cortical profile, but they also lend support to the initial hypotheses put forth by Crews and Landers (1993); that is, slow potential changes can be representative of variability in performance.

The initial work of Konttinen and Lyytinen (1992) suggests that increased cortical negativity in the frontal, central, and occipital regions reflects a general activation corresponding with an increased preparedness to respond. However, later research has associated increases in cortical positivity with unrefined or poorly constructed motor programs, suggesting that a slow potential cortical profile may be more representative of the effort exuded to maintain motor control (i.e., rifle stability; Konttinen & Lyytinen, 1995), compared with the visuo-motor preparedness associated with increased negativity.

To further clarify the prevalence and role of the competing cortical deflections, Konttinen, Lyytinen, and Era (1999) conducted a follow-up study assessing psychomotor effort during shooting performance while concurrently measuring the amplitude, direction, and velocity of postural sway during the pre-shot period (i.e., 7.5 seconds preceding trigger pull). Given that previous research has consistently reported enhanced postural balance among expert marksmen as compared to lesser skilled performers (Aalto, Pyykko, Ilmarinen, Kahkonen, & Starck, 1990; Niinimaa & McAvoy, 1983), Konttinen and Lyytinen (1992, 1993), predicted that poor shooting performance would correspond with a heightened allocation of resources and psychomotor effort and a corresponding decrease in available resources and effectiveness for visuo-spatial processing. Accordingly, Konttinen et al. (1999) hypothesized that frontal midline cortical activity reflects the psychomotor effort required prior to trigger pull. Specifically, the additional psychomotor effort expended to stabilize the rifle during low scoring shots would be reflected in a positive cortical deflection and would override the slow potential negativity associated with

optimal visuo-spatial processing. Conversely, during successful or high scoring shots, minimal psychomotor effort was expected, resulting in a pronounced negative deflection indicative of arousal regulation and visuo-spatial processing. In accord with their hypotheses, Konttinen et al. (1999) reported that changes in postural sway were aptly reflected in the frontal regions, with increased postural sway related to increases in frontal positivity, while minimal postural sway was manifested in decreased frontal positivity. Although, such a relationship between postural sway and cortical activation levels was demonstrated, Konttinen et al. (1999) concluded that postural sway alone was not a significant predictor of performance. Rather, the psychomotor demands of the task are reflected in the changes in cortical activation during the preparatory period, which are better able to discriminate skill levels by observing the cognitive effort expended to regulate performance.

In line with Fitts and Posner (1967), Konttinen et al. (1999) suggest that experts spend less physical and psychological energy attending to subsidiary tasks (i.e., regulate postural sway). That is, the experts had already learned an effective strategy for regulating postural oscillations, whereas the less skilled marksmen had to consciously attend to the regulation of postural sway, thereby reducing the available cognitive resources for performance execution. Modulations in slow potential positivity and negativity have been shown to reflect effort and cognitive processing, both of which have been linked to performance outcome, with greater negativity corresponding with better performance.

More recently, Konttinen, Landers, & Lyttinen (2000) examined the aiming strategies of competitive marksmen, focusing on the final 1000 ms epoch prior to trigger pull. Specifically, it was hypothesized that the final 1000 ms of the aiming period could discriminate between elite and pre-elite marksmen. That is, the elite performers were expected to demonstrate a more

optimal aiming period characterized by a prolonged period of rifle stability as compared to the pre-elite performers. Furthermore, the cortical profile of the elite performers was expected to be more negative than that of the pre-elite performers, a profile indicative of less effortful, automatic processing.

Specifically, the BP of six elite and six pre-elite marksmen was recorded from the frontal (Fz), centro-lateral (C3,C4), and occipital midline (Oz) cortical regions. The results indicated that the elite performers exhibited more accurate and less variable performance than the pre-elite performers and were significantly more stable in their respective rifle hold while preparing to pull the trigger. However, contrary to the anticipated findings, the BP analyses revealed a greater positive cortical shift in the elite performers as compared to the pre-elite performers. According to Konttinen et al. (2000) the increased positivity is likely due to the sustained gross motor activation, which is not related to the central timing mechanism (p.175). As previously mentioned, the work of Karrer et al. (1978) indicates that a positive shift may be the result of an insufficient motor plan necessary to inhibit irrelevant body movements. As such, the positive deflection reported by Konttinnen and colleagues (2000) may be the result of an increased effort of elite marksmen to prevent extraneous movements and not at all an indication of the preparatory set. Alternatively, the physical stress imparted by the rifle hold may have in fact masked the BP negativity among the elite markmen (Konttinen et al., 2000).

Although Konttinen and colleagues (2000) failed to provide empirical evidence to support the BP as a measure for assessing psychomotor differences among expert and near-expert performers, the BP should not deemed inappropriate for the study of psychomotor performance differences. As previously mentioned the main preparatory function of the marksmen is the inhibition of extraneous motor activity during the stabilization of the rifle hold (Konttinen &

Lyytinen, 1993, 2000). Conversely, the execution of the golf putt requires the facilitation of a pre-planned motor act, a task that is more conducive to the use of the BP as means for investigating the motor program. As such, it is plausible that the level of physical involvement (i.e., prolonged and variable muscular activation prior to trigger pull) in the preparatory period leading up to the point of trigger pull in marksmen, may overshadow the slow potential nature recordings of the BP.

Cortical Activity and the Preparatory Period Summary and Review

The systematic observation of electro-cortical activity permits a real-time look into the underlying cortical structures contributing to the psychological processes accounting for psychomotor skill differences. Self-paced tasks demanding visuomotor coordination such as golf putting, archery, and marksmanship place great demand on the psychomotor systems (i.e., attention, emotion, motor control and preparation) conducive to psychophysiological recording (Hatfield & Hillman, 2001).

The early work of Hatfield and colleagues (1982) sparked a series of investigations (Hatfield, Landers, & Ray, 1984, 1987) which examined the covert cognitive processes associated with skilled psychomotor performance of elite marksmen and other self-paced activities. To date, the majority of research in sport has relied on spectral analysis techniques to address issues of hemispheric asymmetry consistently reporting skill automaticity and cerebral efficiency in favor of the expert, concluding that the reported decrease in left hemisphere activation with the concomitant increase right hemisphere activation may represent a reduction in verbal-analytic processing coupled with vigilant visual-spatial processing as the time to performance execution nears; arguably an optimal preparatory set for self-paced precision sports (Hatfield et al.,1984).

Furthermore, the results of the early psychophysiological work provide empirical support for the relationship between pre-performance cortical specificity and the quality of performance of highly skilled participants, with greater asymmetry corresponding with increased performance. As such, this work lends credence to Fitts & Posner's 1967 Theory of Skill Automaticity, such that skilled performance is optimized when conscious processing during skill execution is minimized.

The systematic observation of the slow wave, Bereitschaftspotential (BP) provides a window to assess cortical activity central to the planning and initiation of voluntary movement. During target shooting, research has revealed that marksmen tend to allocate attention to the features of the target and away from the conscious processing of the motor components of the task. Accordingly, the cortical signature of successful performance is depicted by an increase in slow potential negativity. Conversely, sub-optimal and novice performance is characterized by an attentional focus that is directed toward the requisite mechanics (i.e., gun hold) of the task in which the cortical signature during the pre-performance period is denoted by slow potential positivity, or an otherwise decreased readiness to act.

The systematic observation of expert and novice performers across domains has proven invaluable. Since the seminal work of Chase and Simon (1973), research has supported the notion that experts posses an extensive knowledge base that facilitates both stimulus recognition and procedural execution (Richman, Gobet, Stazewski, & Simon, 1996). Furthermore, the advent of eye-movement registration techniques coupled with various electro-cortical modalities have advanced the current understanding of the covert psychological behaviors distinguishing the expert from novice performer. Accordingly, the continued exploration into the role of the quiet

eye period may serve to better link the visual, emotional, and motor programming components of expert performance.

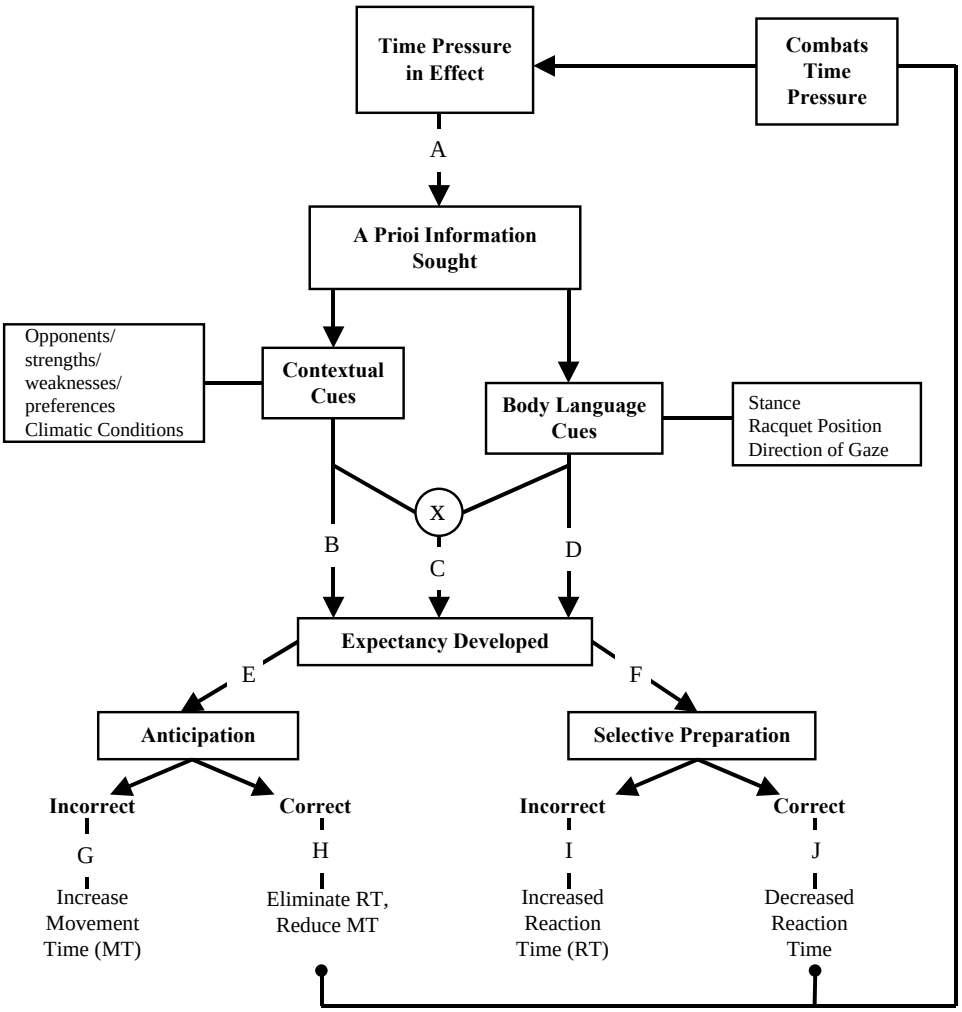

Figure 2-1 An information-processing account of the advantages of advance cue usage. (Adapted from E. Buckolz, H. Prapavesis, and J. Fairs (1988). Advance cues and their use in predicting tennis passing shots. *Canadian Journal of Sport Science, 13(1), 20-30*).

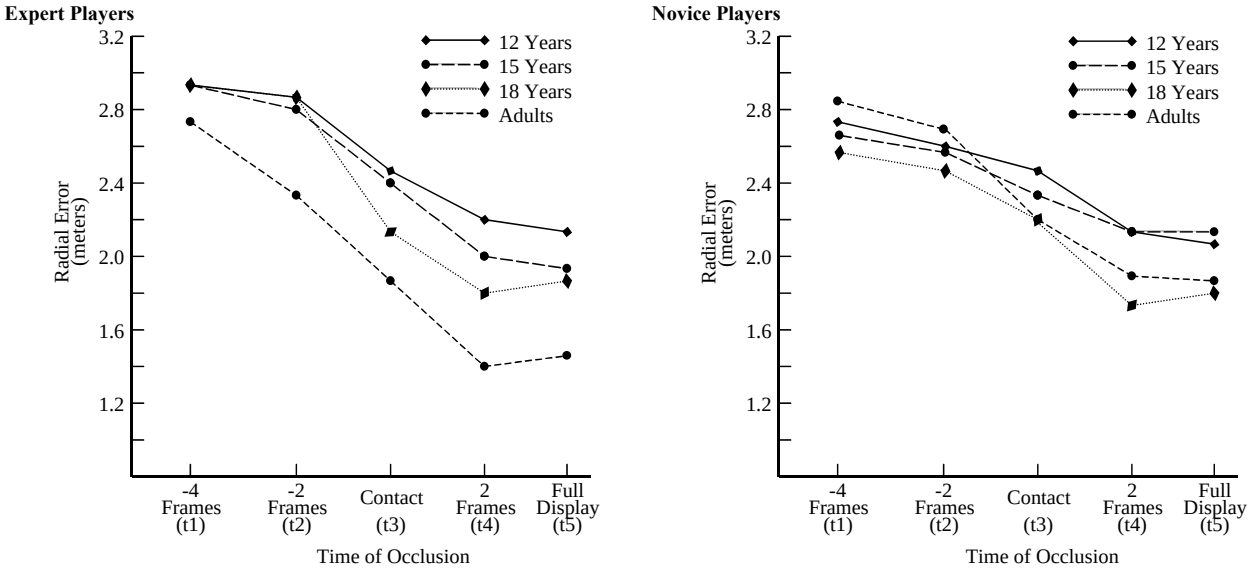

Figure 2-2 Radial error for expert and novice badminton players as a function of the degree of temporal occlusion. (Adapted from B. Abernethy (1988). The effects of age and expertise upon perceptual skill development in a racquet sport. *Research Quarterly for Exercise and Sport, 59(3),* 21-221).

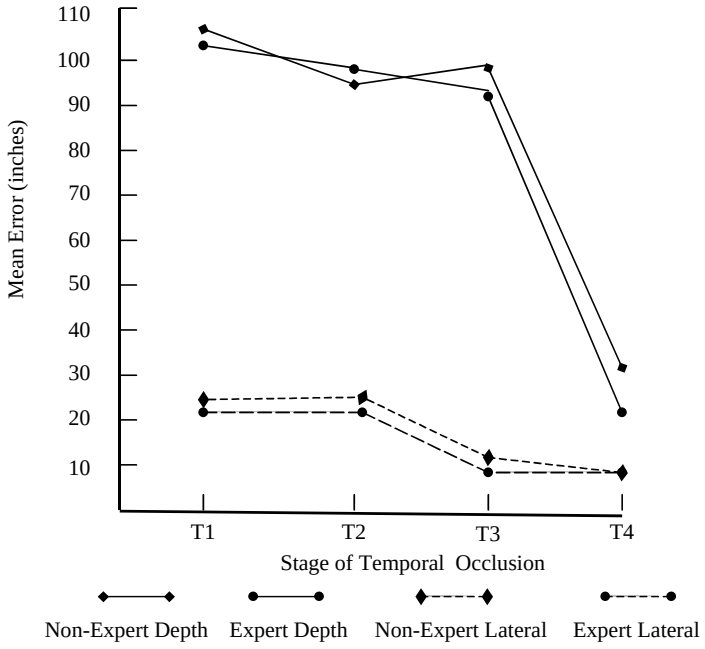

Figure 2-3 Lateral and depth error for expert and novice wicketkeepers as a function of the degree of temporal occlusion. (Adapted from D.R. Houlston & R. Lowes (1993). *Anticipatory cue-utilization processes amongst expert*).

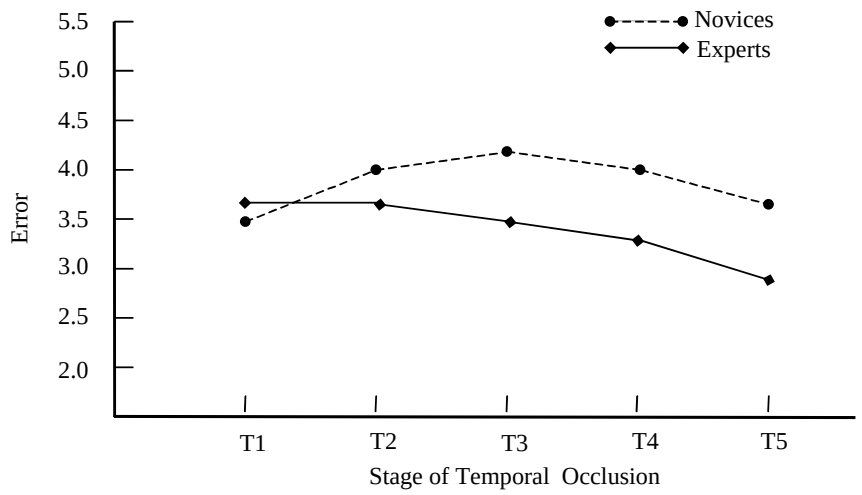

Figure 2-4 Error scores for experts and novices. A depiction of an atypical trend in anticipatory cue use when comparing expert with novice participants. (Adapted from G. Paul and D. Glencross (1997). Expert perception and decision making in baseball. *International Journal of Sport Psychology, 28,* 35-56).

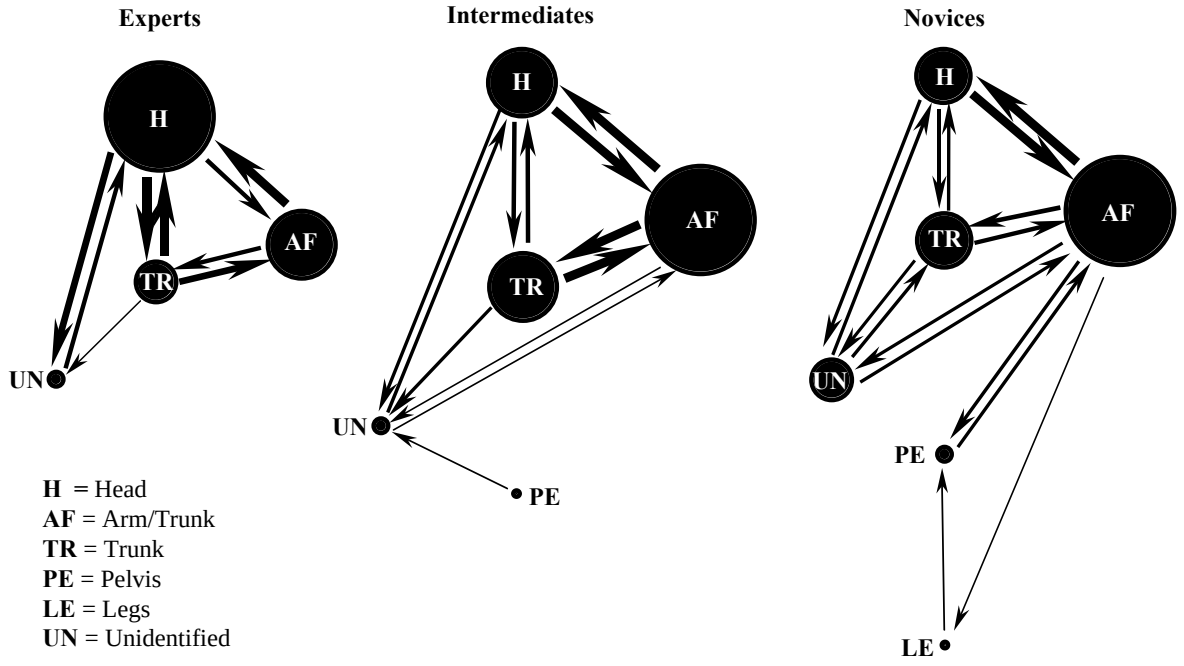

Figure 2-5 Scan-paths of expert, intermediate, and novice boxers. Arrows describe the direction of gaze movements between locations and the proportional associations between locations. The size of each circle is proportional to the percentage of fixation at each location. (Adapted from H. Ripoll, Y. Kerlirzin, J.F. Stein, and B. Reine (1995). Analysis of information processing, decision-making, and visual strategies in complex problem solving sport situations. *Human Movement Science, 14,* 325-349).

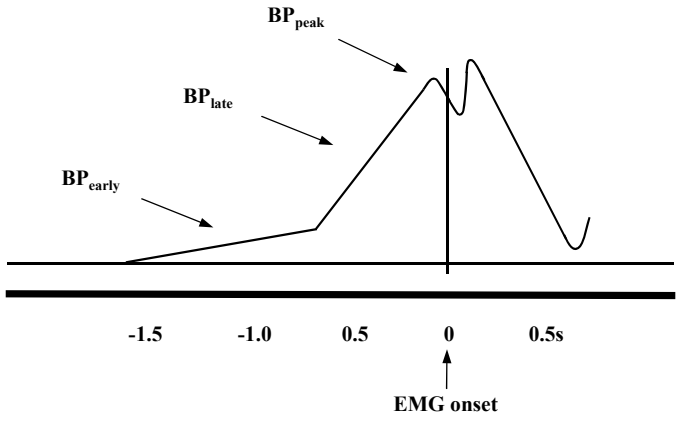

Figure 2-6 Temporal schematic of the Bereitschaftspotential (BP) prior to movement onset. Adapted from Jahanshahi, M., & Hallett, M. (2003). The Bereitschaftspotential: What does it measure and where does it come from. In M. Jahanshahi and M. Hallett (Eds.), *The Bereitschaftspotential*: *Movement Related Cortical Potentials* (1-17). New York, NY: Kluwer Academic/Plenum Publishers.

CHAPTER 3
METHODS

Participants

Twenty volunteers were randomly recruited from various golf clubs in the Southeastern United States and ranged in age from 18-35 (experts *M* = 26.0, *SD* = 6.85; near-experts *M* = 26.20, *SD* = 5.83). Participants were objectively classified according to the United States Golf Association (USGA) handicap system, with the experts (i.e., LH) ranging from a 0-2 (*M* = 1.20, *SD* = 1.23) handicap and the near-experts (i.e., HH) ranging from a 10-12 (*M* = 11.30, *SD* = 0.82) handicap. The LH group (*n* = 10) averaged 14.7 (*SD* = 5.95) years of playing experience, and completed an average of 56.50 (*SD* = 22.12) rounds of golf over the previous 12 months. In comparison, the HH group (*n* = 10) averaged 12.4 (*SD* = 4.94) years of playing experience, and completed an average of 24.30 (*SD* = 9.69) rounds of golf over the previous 12 months. All participants were right-handed and right-eye dominant.

Instrumentation

The following instruments were used to record the measurement of golf putting performance: QE duration, cortical activity, heart rate, and anxiety across conditions.

Putting Surface

Golf putting performance was assessed using a nylon NP 50 artificial putting surface (Synthetic Turf International, STI, Jupiter, FL) outfitted with a 4.25in. regulation size golf hole. A synthetic putting surface was used in lieu of an actual putting green because it permits laboratory control (e.g., temperature, lighting, speed of green, slope, etc.) with analogous ecological validity. The speed of the green was determined using a stimpmeter and in accord with STI rating, the putting surface measured 10.5 feet, an indication of a fast green. Furthermore, the turf was placed on a platform that was constructed to ensure a level and flat

putting surface. The testing area was designed to accommodate a 12ft. putt while leaving 25.75in. of space behind the hole and approximately 22in. on either side of the hole to allow for the measurement and analysis of accuracy, bias, and consistency. Figure 3-1 provides a graphical depiction, detailing the dimensions of the putting platform.

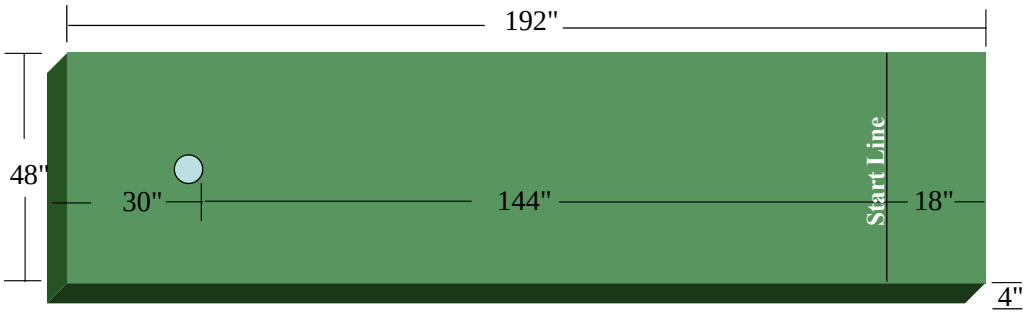

Figure 3-1 Putting green dimensions.

Putting Performance

The target (i.e., golf hole) was supplemented with an imposed grid used for assessing accuracy, bias, and consistency (Reeve, Fischman, Christina, & Cauraugh, 1994; Hancock, Butler, & Fischman, 1995). Specifically, a 30in x 40in matrix progressing in 1in. increments on both the vertical and horizontal axes was projected onto the putting surface with a Sharp Notevision LCD Projector (Model XG-NV2U, Tokyo, Japan). The coordinate (0,0) indicates the center of the golf hole. The image was projected after each stroke and removed prior to each subsequent stroke to avoid latent visual assessment of performance or impairment of performance potentially induced by the display of the grid.

Gaze Behavior

A BIOPAC electro-oculogram amplifier (EOG 100B; BIOPAC Systems, Inc., Santa Barbara, CA), with a bandpass range from DC to 100Hz was used to record eye-movements; specifically, QE duration. Analog data were sampled at 1000Hz using an MP 150 analog/digital converter and recorded on-line with AcqKnowledge 7.0 (BIOPAC Systems, Inc., Santa Barbara,

CA) software installed on a Dell XPS computer (Dell Inc., Austin, TX). The EOG 100B amplifier is a biopotential amplifier designed to record changes in the corneal-retinal potential as the eye navigates the visual environment relative to head position (BIOPAC, 2006; Duchowski, 2002). Simply stated, as the eye moves in the horizontal and vertical planes the corneal-retinal potential adjusts accordingly and is reflected in voltage changes in the range of 15-200μV with corresponding eye-movements measuring approximately 20μV/degrees of eye-movement (Duchowski, 2002).

Cortical Activity (Bereitshaftspotential)

Continuous EEG data were collected and amplified 5000 times using the BIOPAC EEG amplifier (EEG100B; BIOPAC Systems, Inc., Santa Barbara, CA), with a bandpass range from DC to 70 Hz. Analog data were sampled at 1000Hz using an MP 150 analog/digital converter and recorded on-line with AcqKnowledge 7.0 (BIOPAC Systems, Inc., Santa Barbara, CA) software. A digital marker was generated using LabVIEW 8.0 (National Instruments, Austin, TX) to facilitate the identification of the EMG fiducial time point on the EEG trace to indicate the onset of the putting stroke and corresponding BP waveform necessary for post acquisition analysis.

Electromyogram

To determine movement onset, electromyogram (EMG) activity was collected and amplified 5000 times using a BIOPAC EMG amplifier (EMG 100B; BIOPAC Systems, Inc., Santa Barbara, CA), with a bandpass range from DC to 70Hz. Analog data were sampled at 1000Hz using an MP 150 analog/digital converter and recorded on-line with AcqKnowledge 7.0 (BIOPAC Systems, Inc., Santa Barbara, CA) software. The EMG data were rectified and used to obtain the fiducial point for averaging the EEG and QE as described below.

Anxiety

To assess the modulation of anxiety levels across conditions, the Mental Readiness Form-Likert (MRF-L; Krane, 1994) was implemented prior to each putt. Developed with the intention of assessing anxiety levels preceding and during competition, the MRF-L is a convenient and practical alternative to the Competitive State Anxiety Inventory-2 (CSAI-2; Martens et al., 1990). The MRF-L is a three-item assessment, on an 11-point scale, of cognitive anxiety (worried – not worried), somatic anxiety (tense – not tense) and self-confidence (confident – not confident). Given that the CSAI-2 is considered the criterion measure of anxiety in sport, reported correlations of 0.76, 0.69, and 0.68 for cognitive anxiety, somatic anxiety, and self-confidence between the MRF-L and CSAI-2 dimensions respectively, confirm the MRF-L's utility in sport (Krane, 1994). For the purpose of this investigation only the dimensions of cognitive and somatic anxiety were assessed.

Heart Rate

To measure heart rate, ECG activity was collected using pre-gelled disposable snap electrodes located on the anterior portion of the left and right forearms. Analog data were sampled at 1000Hz using a BIOPAC EMG amplifier (ECG 100C; BIOPAC Systems, Inc., Santa Barbara, CA) and was recorded on-line with AcqKnowledge 7.0 (BIOPAC Systems, Inc., Santa Barbara, CA) software.

Procedure

Upon arriving for testing, participants were informed of the general purpose of the investigation and were provided with a brief tour of the testing equipment and apparatus. Following the tour, each participant was asked to read and complete a university approved informed consent document and a brief demographic questionnaire. Participants were also permitted to ask any questions regarding the experiment.

Upon providing consent, participants were prepared for electro-ocular (EOG), electromyographic (EMG), heart rate (ECG) and electroencephalographic (EEG) measurement in accord with the guidelines put forth by the Society for Psychophysiological Research (Pivik, Broughton, Coppola, Davidson, Fox, & Nuwer, 1993). Vertical (VEOG) and Horizontal (HEOG) bipolar electro-oculograhpic movements were collected to assess QE duration and to control for ocular artifact in the EEG waveform. Four 4mm Biopac silver/silver chloride (Ag/AgCl) electrodes (EL204) were positioned above and below the right eye, and lateral to each eye, adjacent to the left and right orbital fossi.

EMG activity was recorded using two 10mm silver/silver chloride (Ag/AgCl) electrodes placed 3 cm apart over the muscle belly of the extensor carpi ulnaris (ECU) of the right arm. EMG activity was sampled at 1000Hz and amplified (x 5000) using the Biopac EMG amplifier (EMG 100B).

ECG activity was recorded using two pre-gelled snap electrodes placed over the radial artery of the left and right forearm. ECG activity was sampled at 1000Hz and amplified (x 5000) using the Biopac ECG amplifier (ECG 100C).

The continuous EEG was recorded with an array of 6 silver/silver chloride (Ag/AgCl) electrodes in accord with the International 10–20 system (Jasper, 1958) using a lycra electrode cap manufactured by Electrode-Cap International, Inc. (ECI, Eaton, OH). A central cluster of electrodes was positioned over the left, mid-line, and right central (primary motor cortex: C3, Cz, C4) sites to concentrate on those cortical regions known to have implications in motor planning and execution, as well as source generators of the BP (Orgogozo et al. 1979; Roland et al. 1980; Ikeda et al. 1993; Rektor et al. 1994; Huckabee, et al. 2003). Furthermore, an additional cluster of electrodes was positioned over the parietal cortex (P3, P4), a region associated with visuo-

motor control and suspected to have implications in QE functioning (Brunia & van Boxtel, 2000). All sites were referenced to linked ears. The mid-frontal (FPz) site served as the ground with electrode impedance being kept below 5 k**Ω**.

After being outfitted with the requisite physiological attire, each participant was individually tested. The testing session consisted of 10 practice trials followed by 90 additional trials under two counter-balanced conditions (i.e., 45 putts per condition) designed to manipulate state levels of anxiety (i.e., low anxiety, high anxiety). The practice session served to acclimate the participant to the testing equipment and apparatus. Given that all participants were skilled golfers, a learning effect was not expected, thereby justifying the minimal number of practice putts.

In accord with previous research (e.g., Hardy et al., 1996, Masters, 1992; Murray & Janelle, 2003), the low anxiety condition consisted of simple, non-evaluative directives, in which participants were asked to perform to the best of their ability so that the researcher can better understand the characteristics and behaviors associated with the golf putt. Conversely, the high anxiety condition was comprised of the addition of a video camera and the completion of a written release permitting the use of the video footage for broadcast on a nationally televised news program. Last, participants were informed that their performance would be compared to all other participants and that they would be competing for a $100 cash prize. In accord with BP protocol, participants initiated each movement at their own volition, free from external cues or prompts. The testing session took approximately120 minutes, including time for set-up, familiarization, practice, testing, equipment removal, and debriefing.

Data Reduction

Putting Performance

Putting performance was quantified as the percentage of total putts made per condition and was used to stratify the QE and BP data into “hit” and “miss” categories for subsequent analysis. Furthermore, missed putts were recorded on an (x,y) coordinate system to further specify performance error, including the assessment of bias and consistency between levels of expertise (Reeve, Fischman, Christina, & Cauraugh, 1994; Hancock, Butler, & Fischman, 1995).

The use of the coordinate system permitted the quantification of radial error, (RE), group-centroid radial error (GRE), and bivariate variable error (BVE). Simply stated, each metric provided an index of accuracy, bias, and consistency with respect to the center of a target respectively (Hancock et al., 1995). RE is simply the non-direction single trial distance from the target. GRE indexes the overall magnitude and direction of bias. Finally, BVE, defined as the average deviation about the target, allowed for inference regarding the consistency or lack there of, of a given participant’s performance. As such, the BVE is an index of the intra-subject variability across trials.

Electromyogram

Given that the onset of EMG activity corresponding with the initiation of the putting stroke is critical to the subsequent data reduction and analysis of the dependent measures (i.e., BP and QE), a custom program written in LabVIEW 8.0 (National Instruments, Austin, TX) was used to coordinate EMG onset with the off-line reduction of eye-movement and BP data.

Heart Rate (BPM)

Using AcqKnowledge 7.0 (BIOPAC Systems, Inc., Santa Barbara, CA) software, the R-wave data were transformed to BPM in order to obtain the mean heart rate for the 5-second period prior to movement onset.

Gaze Behavior

Gaze behavior, indicated by recorded changes in the corneal-retinal potential as the eye navigates the visual display, was reduced off-line. As the eye moves in orbit, the corneal-retinal potential deviates approximately 20 μV/degree of eye-movement (Duchowski, 2002). Given that the eye is known to perturbate approximately 5 degrees to maintain a fixation and that movements greater than 5 degrees suggests a shift in visual gaze (i.e., saccade), a predetermined threshold corresponding with 5 degrees of movement was established. That is, eye-movements greater than 5 degrees or 100 μV was used to objectively measure gaze behavior.

The measurement and reduction of gaze behavior served two objectives: 1) to ensure an artifact free recording of the BP, and 2) to denote the onset of QE. Eye movements (e.g., blinks, saccades) exceeding the aforementioned threshold occurring within the 1500 ms preparatory period immediately prior to movement onset resulted in the rejection of that trial from further BP consideration and analysis. The QE was determined as the time between the last deviation in the corneal-retinal potential exceeding the predetermined threshold and the onset of the EMG burst recorded from the ECU of the right forearm.

Cortical Activity

Three common components of the BP (i.e., early, late, and peak BP) were evaluated. First, a digital trigger generated by LabVIEW 8.0 during the acquisition of cortical data were used to locate the EMG burst respective to movement onset. For each trial across each electrode site, a custom LabVIEW analysis program calibrated the aforementioned burst of EMG onset to establish a fiducial time point corresponding with the initiation of the putting stroke. Data were then statistically and visually inspected for eye-movement and muscular artifact. If rendered clean, the data were reduced to a 3500 ms epoch, in which 2500 ms of data pre-movement and

1000 ms of data post movement was retained for the subsequent analysis of the BP and its constituents. All retained data were baseline corrected (McAdam & Rubin, 1970). Baseline was operationally defined as the first 1000ms epoch preceding BP_{early} onset. The data were parsed according to group (i.e., HH and LH), for which four conditions (i.e., high-anxiety-hit, high-anxiety-miss, low-anxiety-hit, and low-anxiety-miss) per participant, free of muscular and eye-movement artifacts were derived, averaged, and measured.

Following the reduction and classification of data, a grand average BP was generated according to level of expertise, anxiety, and performance to facilitate subsequent analyses. For each average across each electrode site, a custom LabVIEW analysis program was used to detect and calculate the BP_{early}, BP_{late}, and BP_{peak} components, measured as follows. It has been routinely established that BP onset, if present, should appear approximately 1500 ms prior to EMG onset (Jahanshahi & Hallett, 2003), and was therefore declared as the point of demarcation for subsequent calculations. Specifically, the duration of the BP_{early} is the difference in time from the point of BP onset (i.e., 1500 ms) to the start of the BP_{late} component. The BP_{late} component becomes visually apparent 400-500 ms pre-movement and concludes with the BP_{peak} (Deecke et al., 1969; Shibasaki et al., 1980). The BP_{peak} was calculated as the average amplitude occurring 100 ms prior to movement onset (Slobounov, Tutwiler, Rearick, & Challis, 1999). The BP_{late} was calculated as the mean amplitude beginning 500 ms prior to movement onset, concluding 100 ms prior to EMG onset. Lastly, the BP_{early} was calculated as the average amplitude of the interval occurring 1500-500 ms prior to EMG onset.

Data Analysis

The following section outlines the data analytic procedures for each of the eight aforementioned hypotheses. The calculation of effect size estimates (i.e., Cohen's *d*) served to quantify skill-based differences across the variety of dependent measures.

Hypothesis 1

Cognitive and somatic anxiety (MRF-L) and heart rate (BPM) data were evaluated using separate one-way repeated measure ANOVAs to determine if the presentation of a monetary incentive, video camera, and written release would modulate anxiety levels under the high anxiety condition.

Hypothesis 2

Given that the LH group was expected to outperform and exhibit a prolonged QE period as compared to the HH group across anxiety conditions, both putting performance (RE, GRE, BVE) and QE duration were evaluated using a repeated-measures multivariate analysis of variance (RM MANOVA). Given the reported association of QE duration to performance, MANOVA procedures were preferred over separate univariate ANOVAs. Putting performance and QE duration were analyzed using a 2 (*Skill*: LH, HH) x 2 (*Anxiety*: High, Low) MANOVA with repeated measures on the last factor. Post hoc procedures included univariate ANOVAs, each at the .05 level (Stevens, 2002). The success to failure ratio between LH and HH groups was assessed using the Chi square statistic. Furthermore, to specifically address expertise, performance, and anxiety differences on QE duration a 2 (*Skill*: LH, HH) x 2 (*Accuracy*: Hit, Miss) x 2 (*Anxiety*: High, Low) ANOVA with repeated-measures on the last two factors was conducted. Lastly, a Pearson Product Moment Correlation was calculated to explore the relationship between QE duration and RE.

Hypothesis 3

Quiet-eye duration has been demonstrated to account for both inter and intra-group performance variability (Janelle et al, 2000; Vickers, 1992,1996a, 1997, 1998; Vickers et al., 1997, 1998). Accordingly, both inter and intra-group differences in QE duration were analyzed using a 2 (*Accuracy*: Hits, Misses) x 2 (*Skill*: LH, HH) ANOVA.

Hypothesis 4

Given that the LH group was expected to exhibit a greater BP_{late} amplitude coupled with a greater BP_{peak} amplitude compared to the HH group collapsing across anxiety conditions, BP data were evaluated using a repeated-measures multivariate analysis of variance (RM MANOVA). Given the anticipated association of the three BP components (i.e., Early, Late, Peak) across cortical regions (i.e., C3, Cz, C4, P3, P4), MANOVA procedures were preferred over separate univariate ANOVAs. Cortical activation in each of the BP components across skill level and cortical region was analyzed using a 2 (*Skill*: LH, HH) x 3 ($BP_{component}$: Early, Late, Peak) MANOVA with repeated measures on the last factor. Post hoc procedures included univariate ANOVAs, each at the .05 level.

Hypotheses 5 and 6

The various components of the BP were predicted to account for intra-group (i.e., collapsing across skill) performance variability. That is, the amplitude of the BP_{early}, BP_{late} and BP_{peak}, across cortical regions, were predicted to discriminate between putts made and putts missed regardless of skill level. The mean amplitude of the BP_{early}, BP_{late} and the BP_{peak}, were analyzed using 2 (*Accuracy*: Hits, Misses) x 3 ($BP_{component}$: Early, Late, Peak) MANOVA with repeated measures on the last factor. Furthermore, as perceived levels of anxiety increase, a relative increase in the mobilization of cognitive resources was expected to occur in order to successfully complete the task at hand. To assess relative changes in cortical activity under varying levels of perceived anxiety, the mean amplitude of the BP_{early}, BP_{late} and the BP_{peak}, were analyzed using 2 (*Anxiety*: High, Low) x 3 ($BP_{component}$: Early, Late, Peak) MANOVA with repeated measures on the last factor. Post hoc procedures included univariate ANOVAs, each at the .05 level.

Hypothesis 7

The relationship between the amplitude of the BP_{peak} and QE duration was evaluated using a Pearson Product Moment correlation. Additionally, Pearson Product Moment correlations were conducted to assess the relationship between relative anxiety and QE duration and anxiety and cortical activation within each of the $BP_{components}$ across cortical regions.

Hypothesis 8

As anxiety increased it was expected that both the LH and HH groups would exhibit a longer QE period. To evaluate the mean QE duration differences in the high anxiety condition as compared to the low anxiety condition, across skill levels, a repeated measures ANOVA was employed. Specifically, QE duration was analyzed using a 2 (*Skill*: LH, HH) x 2 (*Anxiety*: High, Low) ANOVA with repeated measures on the last factor.

CHAPTER 4
RESULTS

Participants

Ten expert (low handicap) and 10 near-expert golfers (high handicap) golfers were recruited from various golf clubs in the Southeastern United States. To ensure that performance differences were not attributable to random moderating effects participant characteristics were held constant with the exception of handicap, practice, and competitive playing experience. Specifically, although the number of years of golf experience ($t_{(18)} = .884$, $p < .360$, $d = .20$) were similar between the participants, the LH group engaged in significantly more practice ($t_{(18)} = 4.191$, $p < .001$, $d = .70$) and competitive playing experience ($t_{(18)} = 3.892$, $p < .001$, $d = .68$), completing an average of 10.80 ($SD = 4.64$) competitive events compared to 3.2 events for the HH group ($SD = 4.07$).

Pre-Putt Levels of Cognitive Anxiety, Somatic Anxiety, and Heart Rate

To assess the effectiveness of the anxiety manipulation (i.e., use of monetary incentive, video camera, and a written release) for evoking changes in both cognitive and somatic anxiety levels, and to determine the impact of anxiety and arousal on quiet eye duration, cortical activity and subsequent golf putting performance, pre-putt levels of cognitive and somatic anxiety were measured using the Mental Readiness Form – Likert (MRF-L; Krane, 1994). To provide an estimate of arousal differences across anxiety conditions, heart rate (HR) was analyzed.

The analysis revealed a significant *Condition* main effect for the dependent variables: *Cognitive Anxiety* ($F_{(1, 895)} = 132.18$, $p < .001$, $d = .77$), *Somatic Anxiety* ($F_{(1, 895)} = 121.93$, $p < .001$, $d = .74$) and *HR* ($F_{(1, 895)} = 172.99$, $p < .001$, $d = .88$). Suggesting that across skill conditions, both *Cognitive Anxiety* and *HR* was greater in the high anxiety condition as compared to the low anxiety condition. Moreover, a significant *Skill* x *Condition* interaction for *Somatic*

Anxiety ($F_{(1, 895)} = 27.41$, $p < .001$, $d = .35$) was evident indicating that the LH group reported greater somatic anxiety in the high anxiety condition as compared to the low anxiety condition. In comparison, the HH group reported greater somatic anxiety in the low anxiety condition than their LH counterparts and more anxiety in the low anxiety condition relative to the high anxiety condition.

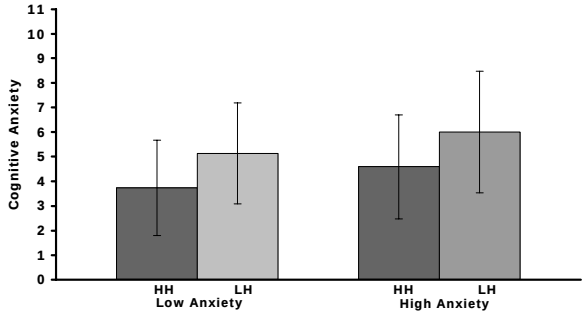

Figure 4-1a

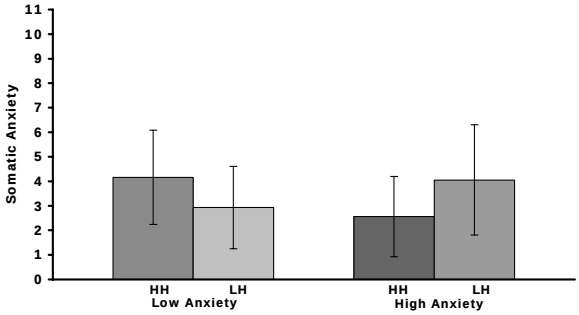

Figure 4-1b

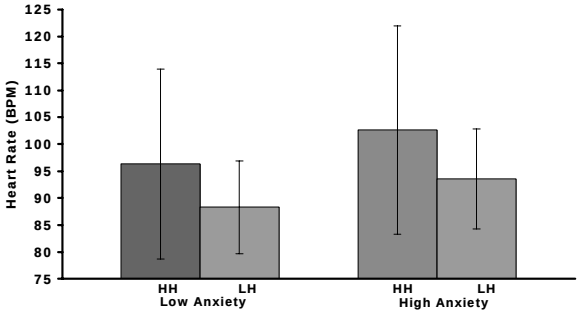

Figure 4-1c

Figure 4-1 Mean cognitive anxiety (Figure 4-1a), somatic anxiety (Figure 4-1b), and heart rate (Figure 4-1c) across skill and anxiety conditions.

Significant *Skill* main effects for *Cognitive Anxiety* ($F_{(1, 895)} = 131.60$, $p < .001$, $d = .77$), *Somatic Anxiety* ($F_{(1, 895)} = 68.37$, $p < .001$, $d = .55$) and *HR* ($F_{(1, 895)} = 97.57$, $p < .001$, $d = .66$) were also found. Follow-up univariate analyses revealed that the HH group reported lower levels of *Cognitive Anxiety* than the LH group in both the low anxiety ($F_{(1, 898)} = 113.45$, $p < .001$, $d = .71$) and high anxiety ($F_{(1, 895)} = 85.06$, $p < .001$, $d = .62$) conditions. Conversely, the HH group reported greater levels of *Somatic Anxiety* than the LH group in the low anxiety condition ($F_{(1, 898)} = 107.34$ $p < .001$, $d = .69$), yet significantly lower ratings in the high anxiety condition ($F_{(1,}$

$_{895)}$ = 14.94, $p < .001$, $d = .26$). Lastly, elevated *HR* was evident among the HH group relative to the LH group in both the low anxiety ($F_{(1, 898)} = 84.64$, $p < .001$, $d = .62$) and high anxiety ($F_{(1, 895)} = 90.07$, $p < .001$, $d = .63$) conditions. Figure 4-1 provides a graphic representation of these findings.

Skill Based Putting Performance and Quiet-Eye Differences Across Anxiety Conditions

It was hypothesized that across both the low and high anxiety conditions, the LH group would perform better than the HH group as measured by RE, BVE, and total number of putts made. Furthermore, the expert participants were expected to exhibit a longer QE period than the near-expert group. The LH group was more successful than the HH group ($\chi^2 = 33.59$, $p < .001$, $d = .19$) but did not differ in the magnitude of their bias (GRE). Pillai's Trace was used to interpret the MANOVA results for putting performance and QE duration since it is deemed more robust than the alternative test statictics (Liu, 2002). The omnibus test for putting performance and QE duration between the LH and HH participants across anxiety conditions was significant, Pillai's Trace = .089, ($F_{(3, 893)} = 28.90$, $p < .001$, $\eta^2 = .089$). Follow-up univariate analyses of variance for *QE* ($F_{(1, 895)} = 41.509$, $p < .001$, $d = .43$), *RE* ($F_{(1, 895)} = 36.305$, $p < .001$, $d = .40$), and *BVE* ($F_{(1, 895)} = 34.753$, $p < .001$, $d = .39$) yielded significant differences between skill levels, indicating that the LH group was more accurate and consistent, while demonstrating a longer QE duration relative to the HH group (Figures 4-2 and 4-3). However, no significant differences were noted for *Anxiety*, Pillai's Trace = .006, ($F_{(3, 893)} =1.735$, $p < .158$, $\eta^2 = .006$). Figure 4-2 and 4-3 provide a graphic representation of the results.

Furthermore, the analysis of expertise, performance, anxiety differences, and QE duration revealed a significant main effect for *Skill* ($F_{(1, 379)} = 35.211$, $p < .001$, $d = .61$) suggesting that the LH group engaged in a longer QE period relative to the HH group across conditions. Despite

the notable *Skill* differences in QE duration, no differences were noted for *Accuracy* ($F_{(1, 379)}$ = 2.628, p = .106, d = .17), suggesting that QE duration was relatively consistent for both putts made and putts missed while controlling for skill. Although QE duration increased from the low anxiety to the high anxiety condition for both the LH and HH participants, this finding was not significant, (*Anxiety*, $F_{(1, 379)}$ = .101, p = .750, d = .03). No other differences were noted (i.e, *Skill* x *Accuracy* x *Anxiety*, $F_{(1, 379)}$ = .045, p = .832, d = .02).

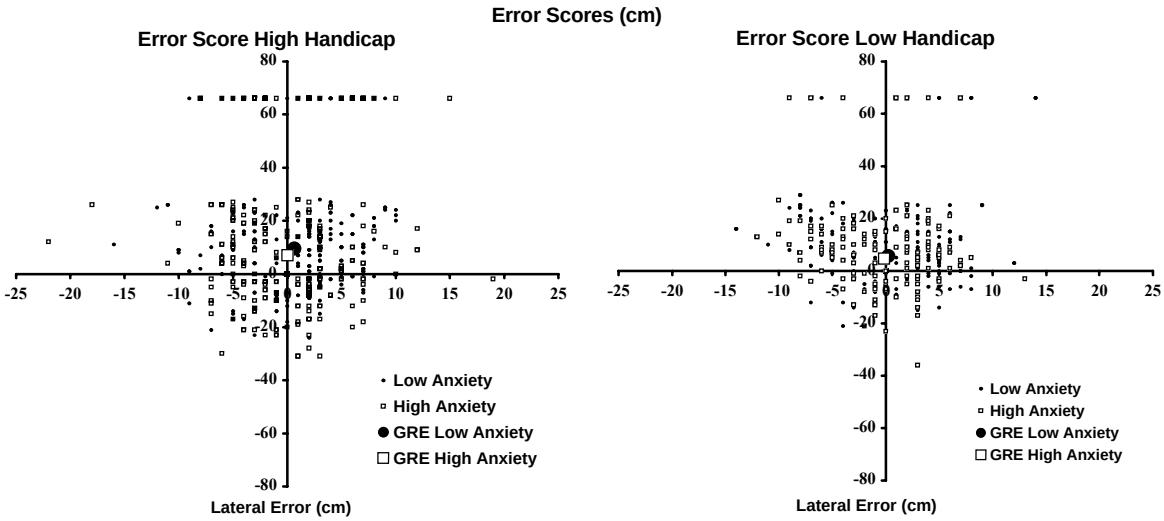

Figure 4-2 Performance variability of the HH and LH groups are indicated as the distance from the target and the magnitude of performance bias across anxiety conditions (i.e., Group Centroid Radial Error [GRE]).

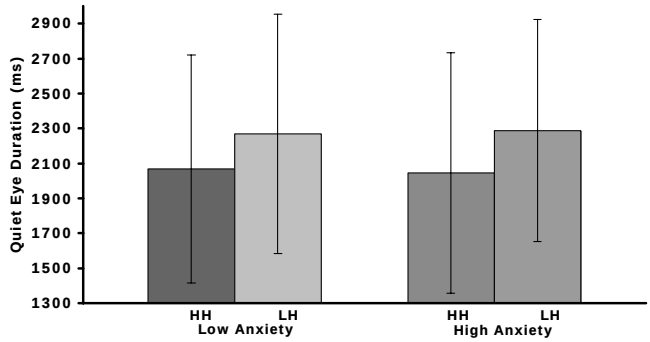

Figure 4-3 Prolonged QE duration across skill but not anxiety highlights the trend supporting the expert advantage.

Lastly, Pearson Product Moment correlations were conducted to explore the relationship between QE duration and RE, and QE duration and anxiety. Results indicated a non-significant correlation (r = .046, p = .389, d = .09) between QE and RE, and a non-significant correlation between QE and anxiety (r = -.059, p = .359, d = -.12).

Inter- and Intra-Group Performance Variability in Quiet-Eye Duration

Assesssing both inter- and intra-group QE differences while controlling for anxiety, it was hypothesized that the QE duration of both the LH and HH groups for successful putts would exceed the QE duration for missed putts. Furthermore, after collapsing across skill, a prolonged QE duration was expected for succesful putts relative to missed putts. The results yielded a significant main effect for *Skill* ($F_{(1, 1793)}$ = 51.989, p < .001, d = .34) but not for *Accuracy* ($F_{(1, 1793)}$ = 3.323, p = .068, d = .08), suggesting that expertise is reflected by a prolonged QE duration. No other differences were noted (i.e., *Accuracy* x *Skill* interaction, $F_{(1, 1793)}$ = .304, p = .581, d = .03, Figure 4-4).

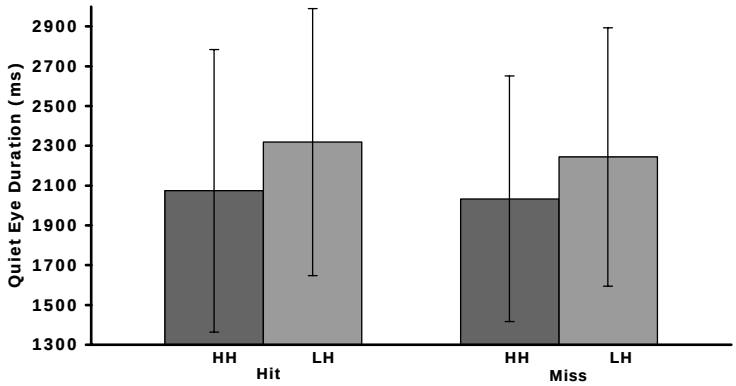

Figure 4-4 When controlling for anxiety, the LH participants demonstrate longer quiet eye durations for successful putts as compared to missed putts. Conversely, minimal variability in quiet eye duration is evident for the HH participant as a function of performance, controlling for anxiety.

BP Activity Across Skill Level and Cortical Region

To investigate the hypothesis that both increased negativity in mean BP_{late} and BP_{peak} amplitude are characteristics of greater movement preparation and cerebral efficiency, cortical activation levels in each of the BP components (i.e., early, late, peak) across skill level and cortical region (i.e., C3, Cz, C4, P3, P4) was assessed. As anticipated, a non-significant *Skill* x $BP_{component}$ interaction was found (Pillai's Trace = .177, ($F_{(10, 66)}$ = .640, p = .774, η^2 = .177). An overall significant difference in cortical activity was evident for the main effect of *Skill*, Pillai's Trace = .690, ($F_{(5, 14)}$ = 6.245, p = .003, η^2 = .690) and $BP_{component}$, Pillai's Trace = .483, ($F_{(10, 66)}$ = 2.103, p = .036, η^2 = .242). Combined, the significant *Skill* and significant $BP_{component}$ main effects suggest that not only did the LH group demonstrate more BP negativity relative to the HH group, cortical negativity also increased from the BP_{early} to BP_{late} component for both groups, reaching maximal negativity immediately prior to movement execution (i.e., BP_{peak}). Follow-up univariate analyses of variance for the main effect of *Skill* revealed significant cortical region differences for C4 ($F_{(1, 18)}$ = 14.171, p = .001, d = 1.77) and P4 ($F_{(1, 18)}$ = 8.304, p < .010, d = 1.36). Given the relative degree of relatedness among BP components, a multivariate analysis of variance was used to examine the temporal location of the cortical region differences between groups (Figure 4-5). Results indicated that for C4, the LH group exhibited greater negativity for each $BP_{component}$ ($C4_{early}$, $F_{(1, 18)}$ = 6.023, p = .025, d = 1.16; $C4_{late}$, $F_{(1, 18)}$ = 17.519, p = .001, d = 1.97; and $C4_{peak}$, $F_{(1, 18)}$ = 27.425, p < .001, d = 2.47) compared to the HH group, while parietal differences were only evident between the two groups during the early component, $P4_{early}$ ($F_{(1, 18)}$ = 7.661, p = .013, d = 1.30).

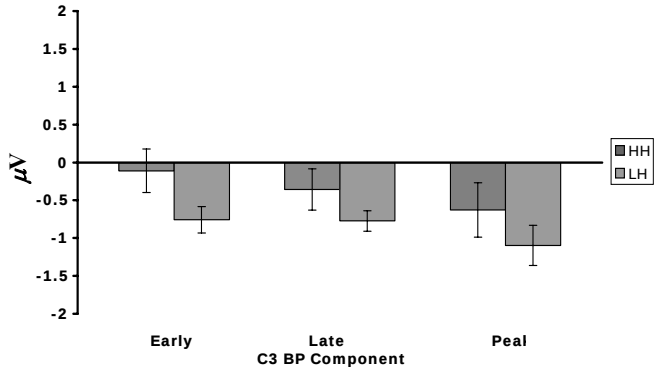

Figure 4-5a

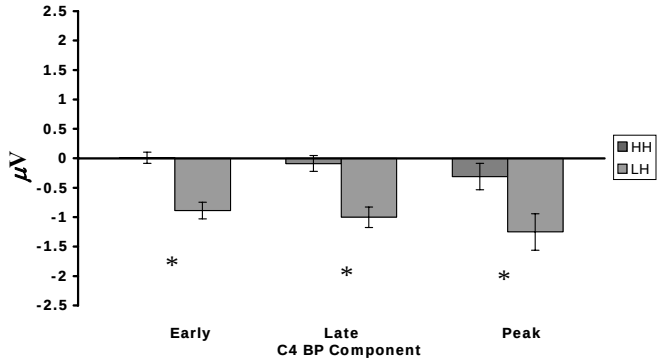

Figure 4-5b

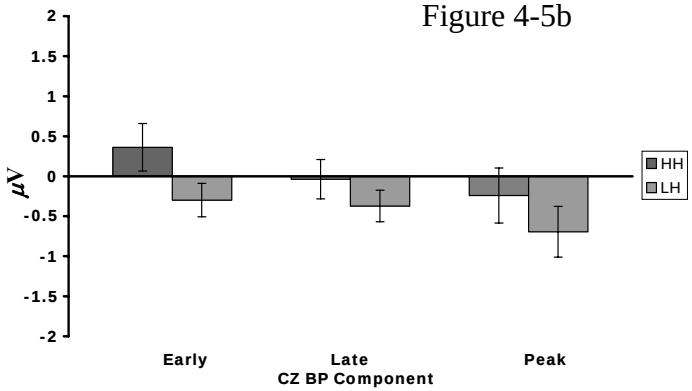

Figure 4-5c

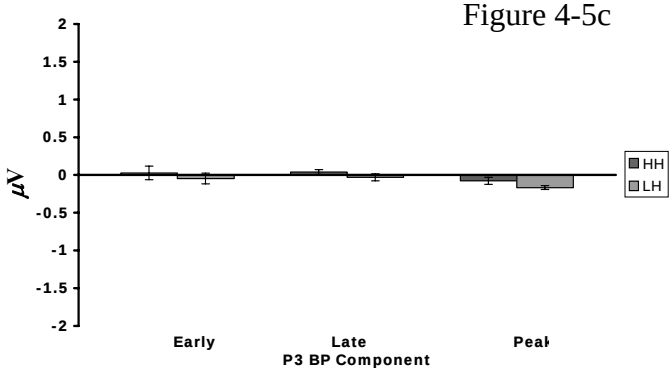

Figure 4-5d

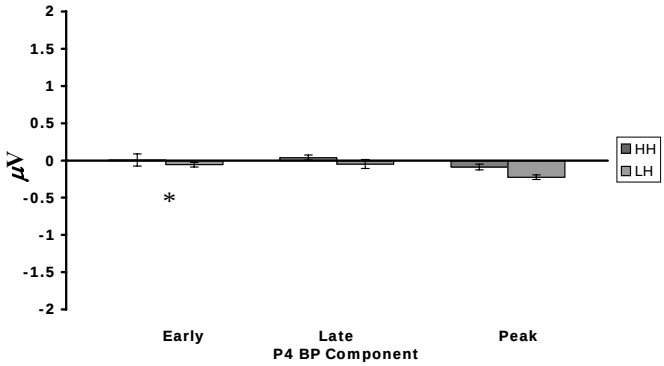

Figure 4-5e

Figure 4-5 Skill based differences (i.e., mean, SE) across cortical regions and BP components. Figure 4-5a displays a marked increase in left-central negativity across BP components for the LH group. Figure 4-5b illustrates a significant increase in right-central negativity across BP components for the LH group. Figure 4-5c displays a marked increase in negativity at the vertex across BP components for the LH group. Figure 4-5d illustrates minimal hemispheric differences in the left-parietal region between skill. Figure 4-5e illustrates an increase in right-parietal cortical negativity for the BP_{early} component (* represents $p < .05$).

BP Activation and Putting Outcome

To investigate the hypothesis that an increase in BP_{peak} amplitude is characteristic of greater task involvement and sensorimotor efficiency, cortical activation levels in each of the BP components (i.e., BP_{early}, BP_{late}, and BP_{peak}) for putts made and missed served as the dependent measures of interest for each cortical region. Although cortical negativity increased across each of the $BP_{components}$, reaching maximal negativity immediately prior to movement execution (Pillai's Trace = .449, ($F_{(10, 146)}$ = 4.223, p < .001, η^2= .224), the omnibus test for *Accuracy* failed to reach significance, (Pillai's Trace = .031, ($F_{(5, 34)}$ = .219, p = .952, η^2 = .031), suggesting that BP negativity did not vary as a function of putting accuracy (i.e., hit or miss). No other differences were noted. Figure 4-6 provides a graphical depiction for accuracy and BP.

Anxiety and BP Activity

Given that anxiety may serve to increase motivation and thus result in greater task involvement, it was hypothesized that an increase in anxiety would result in greater cortical negativity across each $BP_{components}$ (i.e, BP_{early}, BP_{late}, and BP_{peak}). As such, cortical negativity was assessed under high and low anxiety conditions for each cortical region (i.e., C3, Cz, C4, P3, P4). Although cortical negativity increased across each of the $BP_{components}$, maximal negativity was achieved immediately prior to movement execution (Pillai's Trace = .433, ($F_{(10, 146)}$ = 4.223, p < .001, η^2 = .216). The omnibus test for *Anxiety* failed to reach significance, (Pillai's Trace = .113, ($F_{(5, 34)}$ = .864, p = .515, η^2 = .113), suggesting that BP negativity was similar across anxiety conditions when controlling for skill or accuracy. However, Pearson a Product Moment correlation was conducted to address the relationships between anxiety and BP negativity. A significant positive relationship between anxiety and BP was evident across several cortical regions and BP components (Table 4-1), suggesting that relative increases in anxiety may be

reflected cortically. Figure 4-7 provides a graphical depiction of the relationship between cortical activation and anxiety.

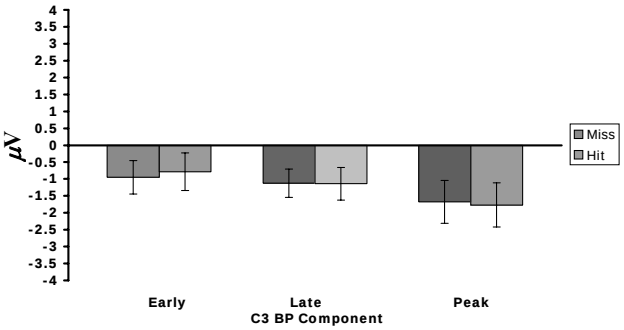

Figure 4-6a

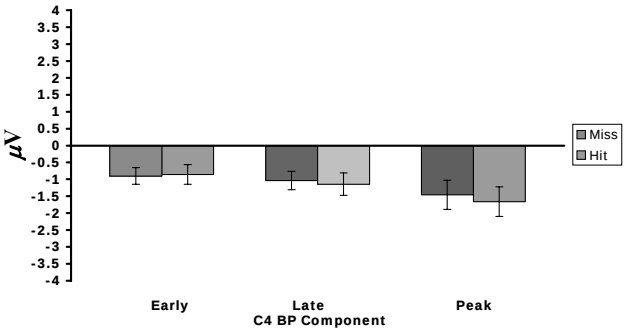

Figure 4-6b

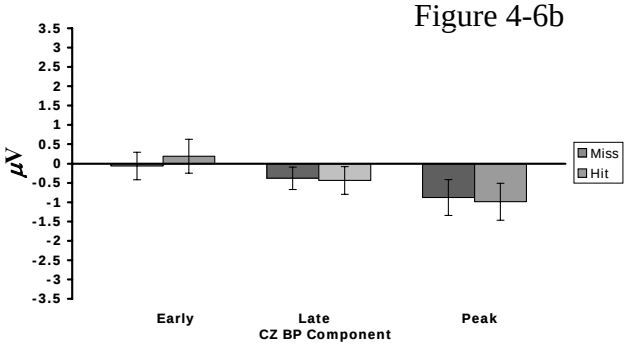

Figure 4-6c

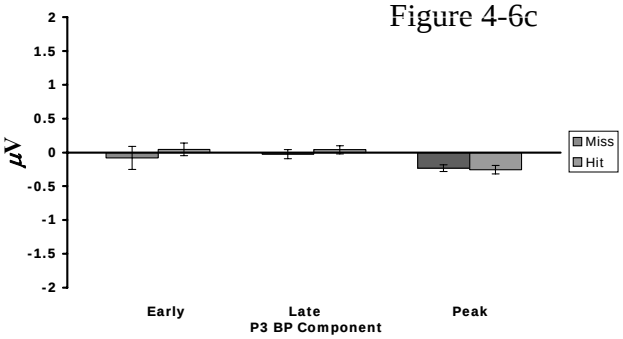

Figure 4-6d

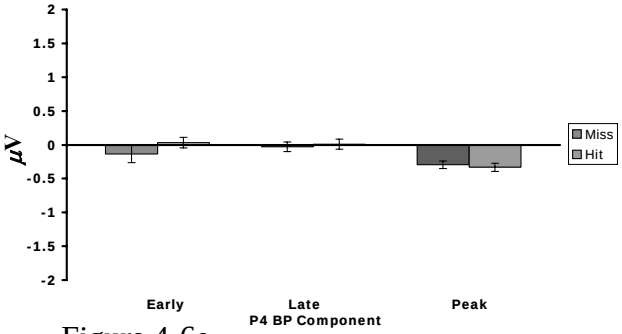

Figure 4-6e

Figure 4-6 Performance differences across cortical regions and BP components. Figure 4-6a and Figure 4-6b display marked BP negativity across components with minimal differences between hits and misses for left-central and right-central regions respectively. Figure 4-6c illustrates pronounced BP_{peak} negativity at the vertex. Figure 4-6d and Figure 4-6e illustrate greater BP_{peak} negativity for left and right parietal regions.

Quiet-Eye Duration and $BP_{component}$ Activation

It has been documented that both the QE period and the cortical and sub-cortical generators associated with the BP are responsible for the orientating of visual attention and the

execution of a self-paced task. As such, a Pearson Product Moment correlation was conducted to explore the relationship between QE duration and BP. Although emphasis is placed on the BP_{peak} - *Quiet-Eye* duration relationship, the asssociation between each component of the BP and QE was assessed. Results indicated a significant correlation between QE duration and $C3_{peak}$ (r = .3096, p = .026, d = .65), $C4_{peak}$ (r = .2874, p = .036, d = .60), and Cz_{peak} (r = .2901, p = .035, d = .61), suggesting that as QE duration increased so too did BP negativity within the specified regions. No other significant correlations were found ($P3_{peak}$ (r = .1696, p = .148, d = .34); $P4_{peak}$ (r = .1574, p = .166, d = .32).

Table 4-1 Pearson Product Moment correlations demonstrating the regional specificity associated with the relationship between anxiety and cortical activation.

Left-Central	$C3_{peak}$	r = 0.28	p = 0.04*	d = 0.58
	$C3_{late}$	r = 0.354	p = 0.013*	d = 0.76
	$C3_{early}$	r = 0.339	p = 0.016*	d = 0.72
Right-Central	$C4_{peak}$	r = 0.306	p = 0.027*	d = 0.64
	$C4_{late}$	r = 0.466	p < 0.001*	d = 1.05
	$C4_{early}$	r = 0.343	p = 0.015*	d = 0.73
Midline	Cz_{peak}	r = 0.211	p = 0.096	d = 0.43
	Cz_{late}	r = 0.288	p = 0.036*	d = 0.6
	Cz_{early}	r = 0.326	p = 0.02*	d = 0.69
Left-Parietal	$P3_{peak}$	r = 0.392	p = 0.006*	d = 0.85
	$P3_{late}$	r = 0.11	p = 0.249	d = 0.22
	$P3_{early}$	r = 0.005	p = 0.487	d = 0.01
Right Parietal	$P4_{peak}$	r = 0.482	p < 0.001*	d = 1.1
	$P4_{late}$	r = 0.112	p = 0.246	d = 0.23
	$P4_{early}$	r = -0.073	p = 0.328	d = -0.15

*Denotes significant correlation $p<.05$.

Quiet-Eye Duration and Anxiety

It was hypothesized that both the LH and HH group would exhibit a longer QE duration across both the low and high anxiety conditions. That is, an increase in the QE duration is believed to circumvent the deleterious effects of anxiety while maintaining performance. Results indicated that no significant differences were noted for *Anxiety*, ($F_{(1, 18)}$ = .002, p =.963, d = .02). Figure 4-3 shows the null differences in which QE duration was stable for each skill group across anxiety conditions.

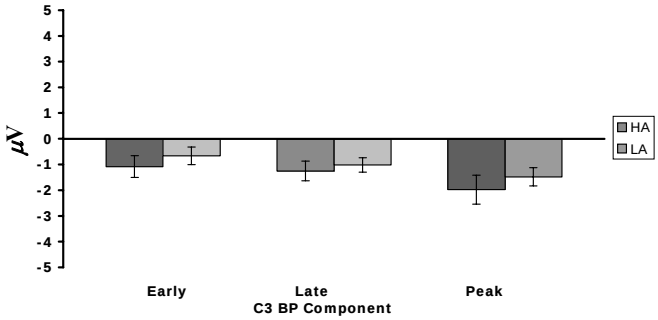

Figure 4-7a

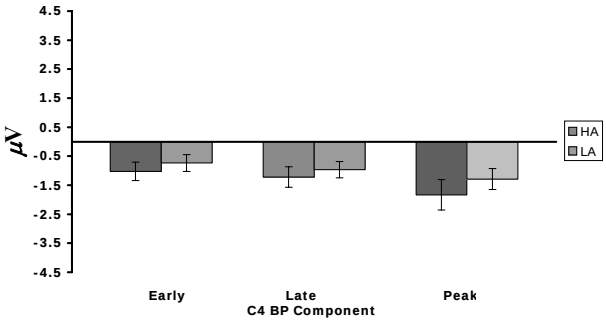

Figure 4-7b

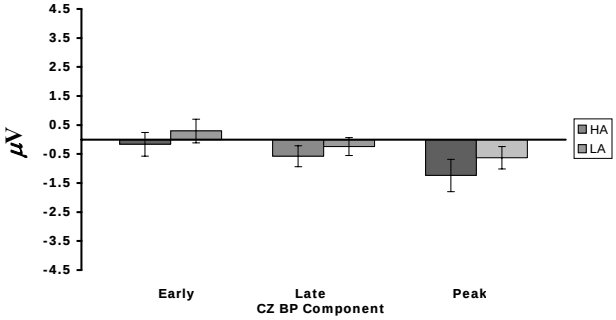

Figure 4-7c

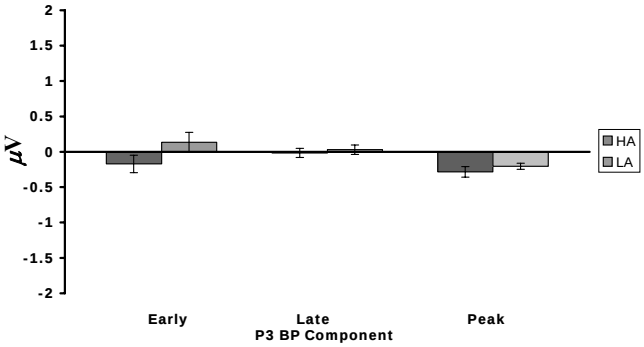

Figure 4-7d

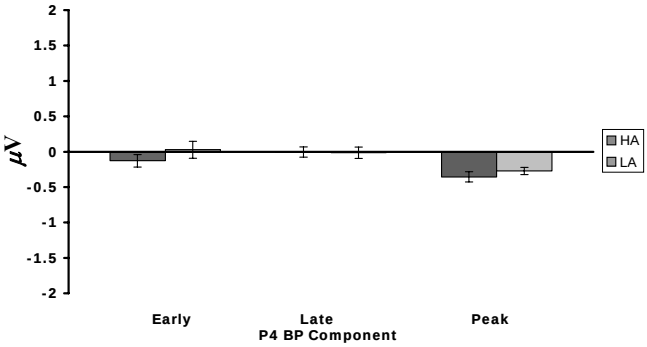

Figure 4-7e

Figure 4-7 Depicts nonsignificant trends in cortical negativity within the three components of the BP for each cortical region for the HA condition as compared to the LA condition across skill level.

CHAPTER 5
DISCUSSION, APPLIED IMPLICATIONS, AND FUTURE DIRECTIONS

The quest to understand the nature of sport expertise has lead researchers to explore the psychophysiological characteristics of superior performance. The resulting evidence suggests that psychological efficiency underlies expert performance (Hatfield et al., 1999), which is characterized by both regional cortical deactivation (i.e., increased alpha power, Haufler et al., 2000) and effective and efficient cue utilization (i.e., fewer fixations of longer duration and prolonged QE, Mann et al., 2006). However, with the exception of the early work of Janelle, Hillman and Hatfield (2000) and Janelle et al., (2000) these two components of expertise have not been simultaneously explored.

According to Vickers (1996a), the "quiet-eye" is a temporal period when task relevant environmental cues are processed and motor plans are coordinated for the successful completion of an ensuing task. As such, the QE period theoretically represents the time needed to organize the neural networks and visual parameters responsible for the orienting and control of visual attention to promote cerebral efficiency (Vickers, 1996a). In addition to its motor planning function, researchers have suggested that the QE period may reflect an opportunity for emotion regulation, thereby minimizing the deleterious effects of anxiety and/or arousal by permitting the recruitment of task specific resources (Janelle, Hillman, & Hatfield, 2000; Janelle et al., 2000; Vickers et al., 1999).

Performance varies with the length of the QE period, with prolonged periods generally resulting in increased performance. The importance of understanding the complex *integration* of systems associated with expert performance, however, is essential for the advancement of both theory and practice. Therefore, I sought to better understand the mechanisms that underlie the efficacy of the QE period by concurrently assessing QE duration, anxiety, and a premotor,

electrophysiological index of cerebral efficiency (i.e., the BP) among HH and LH golfers who performed a putting task under high and low anxiety.

Discussion

The use of a monetary incentive, video camera, and written release to manipulate levels of cognitive and somatic anxiety and physiological arousal was integral to the overall success of this investigation. The effectiveness of this manipulation is addressed next.

Pre-Putt Levels of Cognitive Anxiety, Somatic Anxiety, and Heart Rate

A central tenet of this investigation was to address the potential arousal regulation function of the QE period. Moreover, I explored the impact of heightened anxiety on the neural networks and visual parameters needed for effective performance. The anxiety manipulation was predicted to elevate levels of cognitive and somatic anxiety as measured by the Mental Readiness Form – Likert (MRF-L, Krane, 1994), and physiological arousal as measured by heart rate (i.e., BPM).

The HH and LH groups reported significantly higher cognitive anxiety ratings under the high anxiety condition as compared to the control (i.e., low anxiety) condition. Somatic anxiety scores revealed a similar pattern for the LH group, but the HH group reported less somatic anxiety in the high anxiety condition relative to the control condition. Furthermore, the high anxiety condition promoted heightened levels of arousal across skill level, as indicated by substantial increases in HR from the control condition. Although the HH group's scores on somatic anxiety were not in the hypothesized direction, the elevated heart rate exhibited during the high anxiety condition by both skill groups supports the link between increased anxiety and corresponding changes in physiological arousal, and provides further support for the efficacy of the manipulation used in this investigation.

It is clear that the anxiety manipulation was successful. Given that the each of the primary hypotheses put forth in this investigation were dependent on the anxiety manipulation, it would

have been impossible to draw any conclusions regarding the role that the QE period may have in emotion regulation without a successful anxiety manipulation. Therefore, the changes in anxiety and arousal permit a direct comparison of the effects of anxiety on the cortical and visual mechanisms deemed characteristic of expert performers.

Skill Based Putting Performance and Quiet-Eye Differences Across Anxiety Conditions

Since the seminal work of Vickers (1996a), a growing body of evidence has been compiled supporting the notion that fixations of relatively longer duration are evident during the preparatory stages of a self-paced task, and can differentiate the expert from the near-expert performer (Mann et al., 2006). Given that many of the hypotheses outlined in this investigation are dependent on overt and measurable skill based differences, several performance variables were of interest. Putting performance was measured as a function of "hits" and "misses," and missed putts were additionally assessed for radial error (RE) and bivariate variable error (BVE). I hypothesized that the LH group would make more putts than the HH group, with reduced variability on missed putts and in turn, a longer QE period than the HH group across anxiety conditions.

Results confirmed the hypothesized effects of *Skill* but not *Anxiety*. That is, the LH group successfully holed more putts under both the low and high anxiety conditions while exhibiting a longer QE duration than the HH group. As expected, the LH group was also more consistent (i.e., less error) with "nearer misses" than the HH group. *Anxiety* failed to significantly alter putting accuracy when considered absolutely (i.e., hit, miss) and qualitatively (i.e., RE, BVE). However, for both the HH and LH groups, absolute and qualitative performance was superior in the high anxiety condition, although not statistically significant. In retrospect, the anxiety manipulation may have actually *facilitated* motivation and concentration in both groups. In other words, the high anxiety condition may not have been severe enough to promote performance

decrement, but influential enough to enhance resource recruitment and subsequent performance (Eysenck, 1982; Eysenck & Calvo, 1992). A similar finding was evident for QE duration, with the LH group exhibiting a slight increase in the QE duration in the high anxiety condition, while a slight decrease in the QE period was noticeable for the HH group.

Contrary to expectations, the interaction of skill, performance, and anxiety, on QE duration failed to support the notion that QE duration would increase across skill levels in the high anxiety condition. It has been postulated (Janelle, Hillman, & Hatfield, 2000) and tenuously supported (Vickers et al., 1999; Williams, Singer, & Frehlich, 2002) that increases in anxiety and arousal result in a prolonged temporal window necessary for the regulation of emotion. Despite both groups improving their putting performance under the heightened anxiety condition, the QE duration increased only marginally for the LH group while it decreased for the HH group. Two explanations for this unexpected finding are plausible: 1) QE duration does not serve an emotion regulation function but rather serves solely as a motor programming/movement preparation function; or 2) the anxiety condition did not adequately induce deleterious effects often associated with elevated cognitive and somatic anxiety (Jones & Hardy, 1990) to effectively determine the extent to which QE may serve an emotion-regulating function.

Three distinct pieces of information favor the motor programming/movement preparation function over the latter interpretation. First, a non-significant correlation between anxiety and QE duration was reported, suggesting that QE duration varied irrespective of anxiety. Second, a significant correlation was found between QE duration and BP. More specifically, as QE duration increased, cortical negativity increased around the primary motor cortex (i.e., C3, Cz, C4). Thus, although the assessment of QE duration for hits and misses failed to reveal statistically significant differences, the aforementioned relationships provide insight into the

utility of the QE's temporal window for organizing relevant cognitive and perceptual cues for improving performance. Third, because both the BP and QE duration are believed to have motor programming implications and were significantly related in the current study, further support for the motor programming hypothesis is evident. Furthermore, the lack of relationship between the QE period and anxiety suggests that the QE duration may not serve an emotion regulation function, but that such regulation may take place in the complex pathways linking the cortical and subcortical generators of the motor program. Although speculative, the BP has been shown to reflect changes in arousal and motivation (Andreassi, 1980; McAdam & Seales, 1969), which may circumvent the need for additional regulatory processes. As a result, the QE period may simply regulate the type and amount of visual information needed to evoke the requisite motor program, rather than modulate the effects of anxiety itself.

Inter- and Intra-Group Performance Variability on Quiet-Eye Duration

Research with golfers (Vickers, 1992), marksmen (Janelle et al, 2000), basketball players (Vickers, 1996b), biathletes (Vickers et al., 1999), and volleyball players (Vickers, 1997, 1998) indicates that experts not only demonstrate a longer QE when compared to near-expert performers, but that the QE is associated with within group performance differences. I therefore hypothesized that variability in the duration of the QE period would account for inter and intra-group performance variability. The LH group was hypothesized to exhibit a longer QE period relative to HH group, and the QE duration of both the LH and HH groups was predicted to exceed the QE duration for missed putts compared to successful ones.

In accord with expectation, the LH group not only performed better on the putting task, but also engaged a longer QE duration relative to the HH group. Contrary to previous research however, QE duration did not account for within group performance differences across skill levels. Caution however, must be taken when interpreting these statistical findings. Despite the

non-significant differences, the mean QE duration was longer for successful putts compared to missed putts for both the HH and LH groups.

BP Activity Across Skill Level and Cortical Region

The BP reflects the cortical mechanisms involved in movement preparation (Brunia & van Boxtel, 2000). In line with previous research that suggests an increase in mean BP_{peak} and mean BP_{late} negativity characterize greater movement preparation and cerebral efficiency (Chiarenza, Vasile, & Villa, 1990; Papakostopoulos, 1978; Taylor, 1978), it was hypothesized that the LH group would show a greater BP_{late} and BP_{peak} amplitude compared to the HH group.

Congruent with previous research (Deecke, 1987; Konttinen & Lyytinen, 1992; Shibasaki et al., 1980), data from the current study indicated that cortical negativity continued to increase across each BP component, reaching maximal negativity in the temporal window immediately prior to movement execution. Furthermore, as hypothesized, *Skill* based differences were discernible across cortical regions and BP components. Specifically, cortical differences were evident over the right-central ($C4_{early}$, $C4_{late}$, and $C4_{peak}$) and right-parietal regions ($P4_{early}$), indicating the relative increase in attention allocation to the visuo-spatial cues for the LH group to the HH group. Given the cortical specificity of these findings, it is reasonable to conclude that the LH group allocated more attention to the visuo-motor components of the putting task than their HH counterparts. A distinguishing feature between experts and near-experts is the distinct cortical patterns of the expert performer. The fact that the cortical differences are evident before the golfer actually executes the stroke suggests the efficient organization of task related neural networks (Milton, Solodkin, Hlustik, & Small, 2007).

The initial increase in cortical negativity associated with the BP_{early} component as evidenced here (i.e., $C4_{early}$ and $P4_{early}$) reflects the activation of the supplementary motor area, which may serve to retrieve and/or augment the requisite motor commands from memory

(Roland, 1984). This finding supports the contention that the BP may play a role in the detection and pairing of task relevant information with the necessary components of movement (Brunia & van Boxtel, 2000), while reflecting the activation of a neural path linking perception to action (Toni & Passingham, 2003). More recently, whole brain MRI data lend further support to the results presented here, suggesting that experts develop a specialized motor program evidenced by right brain activation that integrates visual information with the necessary motor commands for performance (Milton et al., 2007).

The preparatory set of the performer may also be reflected in BP_{late} changes. For example, Taylor (1978) reported increases in BP_{late} negativity in the hemisphere contralateral to the active limb. In contrast, the cortical differences revealed here (i.e., $C4_{late}$) are ipsilateral to the dominant limb. The golf putt is a bimanual task by nature, however, it is often argued that an expert right-handed golfer will control the putt with his or her right hand, with the left hand simply providing support. Although the ipsilateral cortical differences reported here apparently contradict those of Taylor (1978), they may be explained by the bimanual coordination required for the golf putt.

Data regarding the significant difference in activation of the BP_{peak} component of the right-central region (i.e., $C4_{peak}$) for the LH group relative to the HH group is congruent with previous research (Deecke, 1987; Shibasaki et al., 1980). Of the three BP components, the BP_{peak} component is believed to reflect the coordinated activation of the SMA and MI. Combined, activation of these structures play a critical role in the organization of complex motor sequences that are rehearsed from memory and fit into a precise timing plan (Gerloff et al., 1988). As such, this finding is not altogether surprising, given that the LH group engages in significantly more practice and competition than the HH group. Indeed, the elite group should have a more refined cortical representation of the task that facilitates the movement and timing patterns of the golf

putt. Practice and experience may contribute to the elevated right-central cortical activation of the LH group relative to the HH group, such that the preparatory period of the LH player reflects an attentional process that permits the assessment, organization, and recall of the requisite motor program from memory. The HH player likely has not developed such refined control, therefore resulting in more deliberate cognitive processes.

The majority of sport psychophysiological research (Haufler et al., 2003) has adopted spectral techniques for inferring the cortical role in psychomotor performance. Although this investigation used a class of ERP (i.e., BP) to examine skilled-based differences, complimentary findings attained from both approaches can be garnered to implicate common cortical mechanisms. As indexed by the collective spectral findings to date, as individuals become more skilled, the cognitive strategies used during the preparatory process and movement execution stage become more routine, demanding fewer cognitive resources (Fits & Posner, 1967; Hatfield et al., 1984). Direct comparisons of expert and near-expert performers have revealed cortical asymmetry differences, such that the expert performer demonstrates a relative decrease in left compared to right hemisphere cortical activity (i.e., increased alpha power or cortical quieting). This finding suggests that near-expert performers require greater conscious processing of the task and its demands. The BP data reflect greater cortical activation in the right hemisphere relative to the left, and moreover, that the LH golfers maintain greater activation in the right hemisphere relative to the HH golfers. Corroborating the extant spectral work, BP evidence gathered in the current study suggests that the LH players allocate more resources to the visual-spatial processing of the task and fewer resources to the conscious processing of the movement, linking the visual-spatial area of the cortex to movement preparation and performance.

BP Activation, Performance and Anxiety

It has been suggested that the amplitude of the BP_{peak} is more pronounced with greater task involvement (McCallum, 1976) and is a cortical reflection of the preparatory set of the participant (Loveless & Sanford, 1974) indicative of sensorimotor efficiency. It was therefore hypothesized that an increase in mean BP_{early} amplitude, mean BP_{late} amplitude, coupled with an increase in BP_{peak} amplitude would be evident for putts made as compared to putts missed. Furthermore, because an increase in perceived anxiety can increase the relative complexity of a given task (Eysenck & Calvo, 1992), it is reasonable to expect that additional cognitive resources may be recruited to accommodate the increased effort necessary to sustain performance (Eysenck, 1982). In accord with Eysenck and Calvo (1992), an increase in anxiety can result in a decrease in processing efficiency due to the additional cognitive/attentional demands imposed of the performer necessary to complete the desired task. As a result, it was hypothesized that an increase in cortical negativity would be evident across BP components (i.e., BP_{early}, BP_{late}, and BP_{peak}) in the high anxiety condition as compared to the low anxiety condition due to a relative increase in task complexity and resource mobilization (i.e., motivation) needed to successfully complete the task under elevated anxiety (Lang, et al., 1989).

Unexpectedly, the BP differences between “hits” and “misses” and between the low and high anxiety conditions were minimal. Although these differences are not statistically significant, data were broadly congruent with the original hypotheses. For example, BP_{peak} amplitude was invariably more negative across cortical regions (i.e., C3, C4, Cz, P3, and P4) for successful trials relative to unsuccessful trials, a finding that parallels the earlier work of Crews and Landers (1993) with golfers, Landers et al., (1991) with archers, and Konttinen and Lyytinen (1992) with marksmen. However, the inverse was true for the BP_{early} amplitude; greater negativity was apparent for unsuccessful trials. With respect to anxiety, both BP_{early} and BP_{peak} amplitude were

more negative in the high anxiety condition as compared to the low anxiety condition, again suggesting that additional cognitive effort may have been necessary to offset the increased task demands imposed by the relative increase in anxiety. Empirical support of this contention is provided by the positive and significant correlations between anxiety and BP negativity across cortical regions, suggesting that as anxiety increased so too did BP activity (Table 4-1). The nature of the *Anxiety-BP* trend lends credence to the notion that changes in anxiety can result in greater task involvement and resource mobilization, which can be reflected cortically. This finding corroborates the early work of Andreassi (1980) and McAdam and Seales (1969) who demonstrated increased BP negativity with enhanced motivation and in the presence of a monetary incentive.

Although the aforementioned trend is in the desired direction, the magnitude of the BP difference across performance conditions (i.e., hits and misses) was not significant. This lack of statistical difference may be accounted for in the dichotomy (i.e., hit, miss) used to classify putting performance. For example, it is not unreasonable for a well-executed putt to result in a "miss" and similarly for a poorly executed putt to result in a "hit", a pattern that may confound the comparison. Moreover, all misses were classified together, so a ball that missed the target by a mere fraction was scored the same as a ball that missed the target by several feet. This methodological decision may have confounded the data analysis and subsequent findings. That being said, the magnitude of the true cortical differences across task performance may have been lost in "classification".

Furthermore, one plausible explanation for the lack of within subject associations between QE and putting outcome is the relative homogeneity of the groups. Although the groups in this study clearly differed in putting ability, the relative difference in ability between the LH (0-2

handicap) and the HH (10-12 handicap) groups may not be as covertly evident. Previous research employing the expert-novice paradigm has typically assessed the overt and covert behaviors of vastly disparate groups (i.e., national, international level performers versus absolute beginners). As a result, the existing literature base is comprised of research that has capitalized on the pure magnitude of expected differences, and as a result, practical inference is often futile. This study however, has revealed both overt and covert differences between groups that differ in skill, but are similar in ability. As such, both the noted differences and lack thereof, may more accurately represent the true mechanisms of the expert advantage.

Alternatively, the extent to which the anxiety manipulation was effective may be subject to debate. That is, although both the LH and HH groups reported anxiety differences, and these differences were supported by objective physiological changes, the additional cognitive demands imposed may not have been sufficient enough to warrant changes in the recruitment and allocation of cognitive resources that would be reflected in distinct cortical patterns.

Practical Implications and Future Directions

To obtain expert status, athletes must excel in no less than four domains: physiological, technical, cognitive (tactical/strategic; perceptual/decision-making), and emotional (regulation/coping; psychological) (Janelle & Hillman, 2003). This investigation corroborates the notion that expert and near-expert athletes not only differ in their performance proficiency, but they also differ in their underlying psychological mechanisms responsible for performance (i.e., cognitive). The extended QE period of the LH group relative to the HH group speaks to the cognitive advantage of the expert. The significant relationship between right-central (i.e., C4) cortical activation and QE duration support the notion of relative sensorimotor efficiency of expert athletes. It is well understood that expert performers maintain cortical activation levels that permit a more efficient and effective performance outcome. The visual search literature

contends that the active search of the environment beyond a certain point provides redundant and often distracting sources of information. However, prolonged fixations, such is the case with the QE period, permit the detailed processing of information and even the cortical organization necessary for performance. As such, once a basic understanding of the requisite environmental cues and movement sequences have been learned, QE training may facilitate the relative cortical quieting necessary to perform at a higher level. In other words, although deliberate practice is believed to result in the automaticity of movement, systematically training the QE may augment practice effectiveness by allowing the mind to process the visual-spatial characteristics of the task while permitting the organization of the neural networks responsible for movement.

With specific reference to golf, when addressing the putt, the typical golfer will spend a brief moment estimating the distance, speed, and line of putt to the target. However, at the onset of the putting stroke, most non-expert players revert to conscious processing of the putting stroke. For example, Vickers (2004) reported that non-expert golfers often track the putter-head as it traverses back and through ball contact, a behavior not as evident in highly skilled putters. Arguably, this ineffective behavior can interfere with the visual-spatial cues previously attended. Encouraging and/or training the QE in this case can alleviate such inefficient gaze behavior, thereby rendering the performer more effective.

This investigation was the first to assess the mechanisms responsible for skill-based QE differences. As previously mentioned, the results from this study support the motor programming/movement preparation function of the QE duration over the emotion regulation function. Given that this is a seminal investigation, replication of these findings would lend to the empirical and theoretical support of the QE period for movement preparation and to determine whether these findings are generalizable to other self-paced tasks.

The anxiety manipulation used in this investigation successfully modulated both self-report and physiological indices of anxiety and arousal. However, the lack of statistical support for the emotion regulation function of the QE period may have been underestimated based on the current results. For example, data trends suggest that as anxiety increased so too did QE, yet the reported differences between high and low anxiety conditions were not significant. Perhaps future studies should consider including multiple manipulations varying in relative anxiety. For example, the current manipulation included a monetary reward for performing well, coupled with the anxiety provoking experience of performing in front of a camera. In either case, there was very little at risk for the participants. Considering that most people are more adversely affected by the thought of losing money and welcome the chance to win money, future research may consider implementing a monetary penalty for unsuccessful or poor performance.

The expert-near-expert paradigm that was used here has proven successful, providing insightful information into the relative skill based differences. However, as previously alluded to, a practical implication of these findings is to train the QE in a manner that would facilitate information processing and sensorimotor efficiency. Although it is reasonable to expect that the QE and BP differences found here would correspond with the very best players (i.e., professional), without explicitly testing them, the magnitude and direction of the QE period and relative cortical changes associated with them remain uncertain. Until such observations can be made, the development of a QE training protocol should be cautiously undertaken.

Summary

The purpose of this investigation was to clarify the role of the QE period in the preparatory process of a self-paced motor skill. The concurrent exploration of the BP and QE period under varying levels of anxiety was designed to assess the underlying mechanisms that link QE duration and performance. Twenty golfers were classified by their USGA handicap

rating as either a high handicap (near-expert) or low handicap (expert), to permit skill-based inferences. Participants completed 45 putts in both the low and high anxiety conditions during which cognitive anxiety, somatic anxiety, heart rate, QE duration, BP activity, and putting performance were recorded.

As expected, the LH group's putting performance was superior to the HH group's, with the LH group successfully completing more putts while missing closer in proximity to the target across anxiety conditions. Moreover, the QE period of the LH group was longer than the HH group's, yet this relationship was not maintained across anxiety conditions. Furthermore, QE duration did not differ for successful (i.e., hits) and unsuccessful (i.e., misses) putts both across and within participants. As expected however, the LH group displayed greater BP negativity in the right-central, right-lateral, and the right-parietal regions relative to the HH group and this increase was significantly related to an increase in QE duration.

Taken together, these results suggest that expert players operate with a greater level of automaticity and less conscious processing of the requisite movements than their near-expert counterparts. Moreover and paramount to this investigation, the data lend empirical support to the motor programming implications of the QE duration over the arousal regulation function as indicated by the relationships between QE and radial error and QE and BP negativity around the primary motor cortex, as well as the lack of a demonstrable relationship between anxiety and QE.

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BIOGRAPHICAL SKETCH

Born in 1973, in York, Ontario, Canada, Derek Thomas Yonge Mann, brother to Darlene, and son of Diane and Daniel Mann, equally pursued both athletic and academic endeavors. After graduating from Richview Collegiate Institute in Etobicoke, Ontario, Derek earned the Bachelor of Arts degree in psychology from York University while playing three years for the York Yeomen ice hockey team. After graduating from York in 1998, Derek left Canada to pursue a master's degree in sport psychology at San Diego State University under the guidance of Dr. Brent Rushall. Upon completion of his master's degree, Derek was accepted into the doctoral program at the University of Florida in sport and exercise psychology under the direction of Dr. Christopher M. Janelle. Specializing in the perceptual-cognitive advantage of experts in sport, Derek completed his dissertation and was awarded his Ph.D. degree in December 2007.