Journal of Motor Behavior, 2002, Vol. 34, No. 2, 197–207

Quiet Eye Duration, Expertise, and Task Complexity in Near and Far Aiming Tasks

A. Mark Williams
Research Institute for Sport and Exercise Sciences
Liverpool John Moores University
Liverpool, England

Robert N. Singer
Department of Exercise and Sport Sciences
University of Florida
Gainesville

Shane G. Frehlich
Department of Kinesiology
California State University
Northridge

ABSTRACT. Skilled (*n* = 12) and less skilled (*n* = 12) billiards players participated in 2 experiments in which the relationship between quiet eye duration, expertise, and task complexity was examined in a near and a far aiming task. Quiet eye was defined as the final fixation on the target prior to the initiation of movement. In Experiment 1, skilled performers exhibited longer fixations on the target (quiet eye) during the preparation phase of the action than their less skilled counterparts did. Quiet eye duration increased as a function of shot difficulty and was proportionally longer on successful than on unsuccessful shots for both groups of participants. In Experiment 2, participants executed shots under 3 different time-constrained conditions in which quiet eye periods were experimentally manipulated. Shorter quiet eye periods resulted in poorer performance, irrespective of participant skill level. The authors argue that quiet eye duration represents a critical period for movement programming in the aiming response.

Key words: action, billiards, perception, visual search

Because of its highly complex and often unpredictable nature, the sporting arena provides an excellent context in which to test theoretical assumptions related to movement control (Williams, Davids, & Williams, 1999). In sports such as billiards, darts, golf, and pistol shooting, the ability to program precise aiming movements appears crucial (Vickers, 1996). In those sports, the processing of critical visual information and the ability to self-regulate cognitive and emotional activity are keys to successful execution of self-paced movement skills. More specifically, many sports involve an aiming component to some degree. The majority of those require far aiming skills in which an object is directed toward a distant target located in extrapersonal space (e.g., archery, basketball free throw, volleyball serve), but several sports combine both near and far aiming requirements (e.g., billiards, putting in golf). In motor behavior investigations, researchers have focused primarily on near aiming tasks, that is, tasks in which the hand or an object controlled by the hand is moved to a target located within intrapersonal space (e.g., Abrams, 1994; Gauthier, Semmlow, Vercher, Pedrono, & Obrecht, 1991; Prablanc & Pellison, 1990; Zelaznik, Hawkins, & Kisselburgh, 1983). Only limited research has been conducted on how vision and action interact during far aiming tasks, and even less on the requirements of tasks that combine near and far aiming skills.

In the present research, the visual gaze behaviors of skilled and less skilled players were recorded as they performed successful and unsuccessful billiards shots of varying complexity levels. The billiards shot is a complex targeting skill that involves both near and far aiming components. To execute shots successfully, players must accurately align the billiards cue with the cue ball (near aiming task) and then propel that ball toward a target ball and ultimately the pocket (far aiming tasks). To execute the shot, players must successfully integrate visual information from the cue, cue ball, target ball, and pocket.

Few researchers have examined visual search and motor behavior during aiming tasks performed in a sport setting. However, Vickers (1996) examined the gaze behavior of national-level basketball players during a far aiming task, the basketball free throw. The less expert free-throw shooters shifted their gaze early in the movement and fixated on the target during execution. Experts took significantly longer to prepare the free throw, made fewer fixations than near-experts during the preparation and impulse phases of the shot, and generated a greater frequency of fixations during the execution phase. More important, the duration of final fixation before initiation of the movement was significantly

Correspondence address: A. Mark Williams, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, The Henry Cotton Campus, 15-21 Webster Street, Liverpool, L3 2ET, UK. E-mail address: m.williams@livjm.ac.uk

longer in expert shooters. Finally, experts suppressed vision to a greater extent during the execution phase than near-experts. Experts either blinked or diverted their gaze to areas other than the hoop, the ball, or their hands during the shooting action.

As a consequence of those results, Vickers (1996) proposed a location-suppression hypothesis for aimed limb movements to distant targets. In the location aspect of her hypothesis, she suggested that fixations of relatively long duration must be made to specific target locations during the preparatory phase of the movement. That period of time is considered to be essential for programming parameters of the movement. The direction, force, and velocity of the movement are programmed, as are the timing and coordination of limbs necessary to produce optimal movement (Newell, Hoshizaki, Carlton, & Halbert, 1979; Spijkers, 1989; Spijkers & Steyvers, 1984). As the movement is initiated (the impulse phase), players need relatively slow movements to maintain fixation on the target and complete the final structuring of the aiming commands.

During the execution phase, Vickers (1996) suggested, players use a suppression mechanism to block out interfering visual information arising as a consequence of their movement (e.g., hands and ball appearing in front of the eye during a basketball free throw, thus occluding the target). Expert performers, she contended, have developed the ability to divert their visual attention from the target during execution by blinking or orienting their gaze to other elements of the visual field. Because the parameters of movement have already been planned in the preparation phase, and modified in the impulse phase, she deemed that visual attention is unnecessary in the execution phase for successful completion of the task. Some degree of support for Vickers's suppression hypothesis can be inferred from the results of experiments demonstrating that intermittent occlusion of vision does not disrupt performance during walking (Assaiante, Marchand, & Amblard, 1989) and ball-catching tasks (Elliott, Zuberec, & Milgram, 1994).

Two critical components related to performance were outlined in Vickers's (1996) location-suppression hypothesis. The first is associated with the duration of the final fixation on the target during the preparatory phase of the movement. Vickers termed that duration the *quiet eye period* and defined it as the final fixation on the target before the initiation of movement. Longer quiet periods are assumed to be associated with better performance in aiming to a far target. In that time period, the performer presumably sets the final parameters of the movement to be executed. The key principle is that quiet eye duration is associated with the amount of cognitive programming required for successful aiming to a target. Second, Vickers (1996) argued that better performance is characterized by suppression of vision during the execution phase of the movement. Poorer performance is presumed to occur when players maintain fixation on the target; however, expert shooters tend to terminate their fixation on the target during the execution phase.

In the sports context, support for Vickers's (1996) location hypothesis has been obtained in basketball, pistol shooting, and golf, with expert athletes displaying longer fixations on the target than their less expert counterparts (Ripoll, Bard, & Paillard, 1986; Ripoll, Papin, Guezennec, Verdy, & Philip, 1985; Vickers, 1992). The visual-suppression component of Vickers's (1996) hypothesis is more contentious. Results of previous research, particularly from studies of near aiming tasks, suggest that the target is fixated throughout the movement (e.g., Abrams, Meyer, & Kornblum, 1990; Guitton & Volle, 1987; Prablanc & Pellison, 1990). Moreover, vision appears to be used continuously during interceptive tasks such as catching or striking balls (Bootsma, Fayt, Zaal, & Laurent, 1997; Bootsma & van Wieringen, 1990; Tresilian, 1997).

In the present research, we examined the validity of Vickers's (1996) hypotheses by using a billiards task that involved near and far aiming components. In Experiment 1, the relationships between the final fixation duration on the target before initiation of movement (quiet eye period), shot complexity, and performance in skilled and less skilled billiard players were assessed. According to Vickers's hypotheses for far aiming tasks, skilled players should generate longer quiet eye periods during the preparation phase, whereas the duration of this final fixation should increase as a function of task complexity for both groups of participants. Because more complex motor responses require longer preprogramming times (e.g., Henry, 1980; Henry & Rogers, 1960; Kerr, 1978; Klapp, 1977, 1980), more complex aiming behaviors should be characterized by longer quiet eye durations if the final fixation on the target is related to cognitive programming. We also expected visual suppression during the execution phase of the movement, as indicated by an increase in eye blinks and in shifts of gaze to less pertinent areas of the visual environment.

In Experiment 2, we examined further the validity of Vickers's (1996) quiet eye period as a measure of cognitive programming by manipulating temporal aspects of billiards shots. We expected performance and mean quiet eye duration to decrease as the time apportioned for initiating the billiards stroke was reduced. Shapiro (1977) and Summers (1977) have demonstrated that performance decrements occur in hand aiming movements when participants are required to execute the movement under time constraint. Those researchers and others (e.g., Vickers, 1996) have argued that reductions in the time allotted for shot preparation result in a concomitant decrease in the time available for response programming, thereby negatively affecting performance.

EXPERIMENT 1

Method

Participants

Twenty-four right-handed men were tested. They were categorized as either skilled or less skilled billiards players on the basis of their experience level and an initial performance test. The skilled group consisted of 12 players (M = 23.17 years of age, SD = 3.01 years) who had an average of 9.1 years of experience (SD = 2.64 years) and played 3.33 days per week (SD = 0.98 days). The group had competed in an average of 14.25 (SD = 14.97) sanctioned tournaments. Each member of the group successfully completed the performance test in fewer than 12 shots (M = 10.67 shots, SD = 2.46 shots). The less skilled group also consisted of 12 players (M = 21.83 years of age, SD = 1.85 years), averaging 2.67 years of playing experience (SD = 0.65 years). Those participants had no competitive experience, played only 1.25 days per week (SD = 0.45 days), and required an average of 26.67 shots (SD = 3.17 shots) to complete the initial skills test.

Apparatus

Eye movement measurement. We collected eye movement data by using a mobile corneal reflection unit (Applied Science Laboratories; Waltham, MA, Model ASL 4000 SU). That video-based monocular system measures eye line of gaze with respect to a head-mounted camera by computing the relative positions of two features of the eye, the pupil and the corneal reflex (a reflection of a near-infrared light source from the surface of the cornea), in relation to the optics. Both the infrared beam and the image of the participant's eye were reflected from a visor mounted on the helmet, which was coated to be reflective in the near-infrared region and transparent to visible light. The ASL system computes the line of gaze by measuring the vertical and horizontal distances between the center of the pupil and the corneal reflection after correcting for second-order effects.

The resulting displacement data were recorded and processed by an external Gateway 2000 486SX/166 computer connected via a 30-m cable to the participant's waist. To record the field of view as observed by the participant, we positioned an Elmo MP481 color scene camera near the eye. That positioning allowed us to obtain a view of the scene from the same position observed by the participant while avoiding the problems of parallax error and the mounting of stationary cameras in the field of view.

To assess the exact location of gaze, the 4000 SU processor superimposed a white cursor representing 1º of visual angle on the video image produced by the scene camera. Those images were recorded by a video recorder (Akai Electric Co., Tokyo, Japan, Model VS-X9EGN S-VHS) and used for data analysis. The 4000 SU possesses an accuracy of ±1º in both the vertical and horizontal directions and a precision of better than 0.5˚. The system sampled at a rate of 60 Hz, and point of gaze was updated for each frame of video (every 33.3 ms).

Vision-in-action approach. Participants' gaze behaviors were recorded simultaneously with the action phases of the billiard stroke. Using a Panasonic WJ-MX10 digital production mixer (Matsuchita Electric Corp., Secaucus, NJ), we obtained simultaneous records by interfacing data from the 4000 SU system with the image recorded by an external Panasonic WV-PS03/B S-VHS video camera (Matsuchita Electric Corp., Secaucus, NJ), which was positioned perpendicular to the player. The mixer created a split-screen effect in which the lower-left portion of the frame showed the participant performing the billiard stroke while the right portion of the frame displayed his gaze position as recorded by the eye and the scene cameras. Both the gaze locations and the temporal aspects of each phase of the stroke were analyzed frame by frame.

Billiards arrangements. A Brunswick 4.5- × 9.0-ft (1.37- × 2.74-m) billiards table, which had a playing surface area of 100 × 50 in. (254 × 127 cm), was used for all the testing. The corner pockets were 5 in. (12.7 cm) wide, and the side pockets were slightly wider (5.5 in., 13.97 cm). Standard modern composition balls measuring 2.25 in. (5.72 cm) in diameter and weighing 6 oz (170 g) were used. Players were required to use a standard 57-in. (144.78 cm) billiards cue, weighing 18 oz (510 g). We controlled the arrangement of the balls for the initial skill test, as well as for each of the three tasks of varying complexity levels, by placing small colored markers on the table surface.

Procedure

Initial performance test for skill classification. After obtaining informed consent, we gave participants the billiards cue and showed them to the table where we had placed an arrangement of balls similar to those that might occur in a typical game of nine-ball. Participants were asked to pocket the balls (in order from 1 to 9) in as few shots as possible. On the basis of an initial pilot study, we arranged the balls in such a fashion that high caliber players were expected to complete the test in less than 12 shots and the less skilled participants in 20 or more shots.

Performance trials. Once the initial test was completed, participants were fitted with the eye-tracking system, and initial calibration procedures were performed. The calibration procedure consisted of having the player fixate on a sequence of nine equidistant points located on a target board placed on top of the billiards table. Upon completion of the calibration procedure, a series of shots of three levels of complexity (easy, intermediate, and hard) were performed. Each player was instructed on the correct type of speed and english (spin) to place on the cue ball, and three practice trials for each level of complexity were allowed. They then performed consecutive shots until 10 successful and 10 unsuccessful outcomes per complexity condition were achieved. Shots were considered unsuccessful if the object ball was not sunk or if the cue ball was inadvertently pocketed (scratch shot).

After 10 successful and 10 unsuccessful shots were recorded at a particular complexity level, a 3-min rest period was given, followed by a recalibration of the eye-tracking system. The players then progressed to the next series of shots of a different complexity level. The sequence of task complexity was randomly assigned and counterbalanced across participants. The total time to complete the task for each participant depended on the number of shots that enabled the experimenters to record 10 hits and 10 misses. Typically, participants completed the experiment in 45 min or less.

Shots of varying complexity. For the performance task, participants were required to pocket a series of balls with shots of three levels of complexity. In the easy condition (EC), the object ball lay near the corner pocket, and the player could make the shot by using a cut shot with bottom-left english (Martin & Reeves, 1993). The intermediate condition (IC) featured a "cushion first" approach to sinking the object ball (Martin & Reeves); that is, the object ball lay near the cushion while the cue ball sat on the opposite side of the table. The object ball was partially occluded by another ball so that the player had no way of hitting the object ball directly. To sink the object ball, the player needed to strike the cue ball with straight-follow english and hit the cushion before hitting the object ball. Finally, the hard condition (HC) featured a "carom draw" shot, in which the cue ball had to be struck sharply with straight-bottom english so that it would carom off the object ball into another ball located near the corner pocket (Martin & Reeves). The difficulty of the shot lay in the especially precise angle of the carom and the fact that a number of other balls were located on the table, limiting the options available to the player.

Dependent Measures

Performance. The performance measure consisted of the number of shots required to achieve the criterion level of 10 successful and 10 unsuccessful shots for each of the conditions. Specifically, the ratio of successful shots to unsuccessful shots was calculated as a percentage, with higher values indicating better performance.

Visual behaviors. Five successful and five unsuccessful shots were randomly selected for analysis at each complexity level. We performed a frame-by-frame analysis of each shot by using an Akai VS-X9EGN S-VHS video recorder. A fixation was defined as three or more consecutive frames (99.9 ms or more) in which the cursor was located in the same space in the visual environment (Ripoll, 1991; Vickers, 1992, 1996; Williams & Davids, 1998). The dependent measures included number of fixations per location, mean fixation duration per location, mean quiet eye duration, and number of blinks present for distinct phases. Quiet eye duration was defined as the final duration of fixation on a target before the onset of movement time (cf. Vickers, 1996). The values recorded were averaged across all trials. On trials where there were no fixations on a particular location, we included a value of zero when calculating mean values across trials for each of the dependent measures.

For fixation location, we examined the number of fixations allocated to four areas of interest: cue ball, object ball, target cushion (or second object ball in the hard condition only), and the intended pocket. Any remaining fixations (e.g., on the cue stick or the felt surface) were defined in a category labeled *other areas*. For the dependent measure of mean fixation duration, the time spent (in milliseconds) fixating each location across trials was calculated. The quiet eye duration in the preparatory phase of the stroke was recorded for each participant across the three complexity conditions. The number of eye blinks, recorded by the eye camera and the system software, was assessed during the backswing, foreswing, and flight phases of the stroke.

Temporal components of the billiards stroke. Four distinct phases were identified from the external camera image that provided a sagittal view of the performer: the preparatory phase, that is, the time from the start of the task until the first observable movement toward the cue ball (i.e., the duration in which the billiards player leaned over the table to begin the shot until the moment he initiated the final backswing motion of the cue); the backswing phase, that is, the time from the final backswing movement until the cue began to move forward toward the cue ball; the foreswing phase, that is, the time from foreswing initiation until the tip of the cue came into contact with the cue ball; and the flight phase, which was defined as the time the cue ball was in motion before striking the object ball.

Total time (in milliseconds) spent in each phase of the stroke was calculated for each participant across the varying complexity conditions. We accomplished those calculations by analyzing the total number of video frames (each frame equated to 33.3 ms) corresponding to each phase of the stroke.

We analyzed all data by using various factorial analyses of variance (ANOVAs), with the alpha level set at < .05. Simple main effects and Scheffé's post hoc tests were used as follow-up analyses, as appropriate. For each repeated measures variable, violations of the assumptions of sphericity were assessed, and, where appropriate, we calculated Greenhouse–Geisser adjustments to the level of significance.

Results

Performance

A 2 (skill) × 3 (complexity) ANOVA with repeated measures on the second variable was undertaken so that we could assess differences in performance between skilled and less skilled participants. Significant main effects for skill, $F(1, 22) = 75.99$, $p < .001$, and complexity, $F(2, 44) = 116.28$, $p < .001$, were observed. Post hoc analyses revealed that skilled players made significantly more shots (M = 67.53) than less skilled players (M = 47.88%). There were significant reductions in performance for both groups as the level of complexity increased, from M = 74.13% in the EC to M = 65.01% in the IC and M = 47.88% in the HC. The skilled players had a higher ratio of successful to unsuccessful shots at all levels of complexity than the less skilled players. The manipulations of shot complexity affected members of each group in a proportionate manner. The interaction was not significant. The results are presented in Table 1.

Temporal Components of the Billiards Stroke

To determine whether manipulations of task complexity led to specific changes in duration for the four phases of the billiards stroke, we conducted a 2 (skill) × 3 (complexity) × 4 (phase) × 2 (accuracy) × 5 (trial) ANOVA with repeated measures on the last four variables. Significant main effects were found for accuracy, $F(1, 22) = 4.78$, $p < .05$, and complexity, $F(2, 44) = 78.17$, $p < .001$. In both groups, accurate shots were associated with longer durations (M = 3,093.06 ms) than were missed shots (M = 2,885.69 ms). Overall shot duration increased significantly as complexity level increased (EC, M = 2,489.38 ms; IC, M = 2,656.67 ms; HC, M = 3,822.08 ms). In addition, a significant main effect was found for phase, $F(3, 66) = 12.73$, $p < .01$. Both groups of participants spent significantly more time in preparing the stroke (M = 1,731.46 ms) than in any other phase. The means for the other phases included backswing (M = 491.84 ms), foreswing (M = 125.32 ms), and flight (M = 597.87 ms).

Significant Phase × Complexity, $F(6, 132) = 4.32$, $p < .03$, and Skill × Complexity, $F(2, 44) = 5.33$, $p < .05$, interactions were observed. Follow-up tests indicated that there were no significant differences in the duration of the backswing, foreswing, and flight phases across each level of complexity. The duration of the preparation phase was significantly longer in the HC (M = 2,532.16 ms) than in the EC or the IC, however (Ms = 1,240.72 and 1,421.52 ms, respectively). Both groups of participants required significantly more time to prepare their shots in the most complex condition than in the other two levels of complexity. The total movement duration was significantly longer in the HC than in the EC or IC for both groups, whereas stroke durations in the EC and the IC did not differ significantly from each other. The skilled players took longer than their less skilled counterparts to complete the stroke under the HC. The data are presented in Table 2.

Visual Behaviors

To assess whether manipulations of task complexity were associated with concomitant changes in visual behavior, we analyzed the number of fixations and mean fixation duration per location, using separate 2 (skill) × 5 (location) × 2 (accuracy) × 5 (trial) ANOVAs with repeated measures on the last three variables. A separate ANOVA was undertaken for each level of complexity.

Easy Complexity Level

Significant main effects of location, $F(2, 44) = 579.48$, $p < .001$, and skill, $F(1, 22) = 54.35$, $p < .01$, were observed for number of fixations per location. Specifically, more fixations per trial on average were directed to the cue ball (M = 3.00) and the object ball (M = 2.83) than to the cushion (M = 0.00), pocket (M = 0.00) or to other areas of the display (M = 0.50). Less skilled players typically made more fixations (M = 1.48) to each location than skilled players (M = 1.06). A significant interaction between skill and location was observed for the number of fixations per location, $F(2, 44) = 20.44$, $p < .01$. Less skilled participants made significantly more fixations per trial to the cue ball (M = 3.54) and the object ball (M = 3.33) than the skilled participants (M = 2.46 and M = 2.33 fixations, respectively).

A similar pattern of results was observed for mean fixation duration per location. A significant main effect for location, $F(2, 44) = 204.87$, $p < .001$, indicated that the longest fixations were directed to the cue ball (M = 396.02 ms) and the object ball (M = 418.26 ms) than to any other locations. The main effect for skill was significant, $F(1, 22) = 7.57$, $p < .05$. Skilled performers made longer mean duration fixations per location (M = 197.47 ms) than less skilled players (M = 161.24 ms). A significant interaction between skill and location was found, $F(2, 44) = 6.41$, $p < .05$. Post hoc tests revealed that skilled performers fixated on the target ball for a longer time period (M = 498.96 ms) than less skilled players (M = 337.57 ms). The results are summarized in Table 3.

Intermediate Complexity Level

Significant differences in number of fixations were observed for location, $F(4, 88) = 53.01$, $p < .001$, and skill, $F(1, 22) = 22.56$, $p < .01$. Follow-up tests revealed that less skilled players used a greater number of fixations per location (M = 1.49) than their more skilled counterparts (M = 1.18).

TABLE 1
Performance Means and Standard Deviations (in %) for Skilled and Less Skilled Groups for Each Level of Shot Complexity

	Skilled		Less skilled	
Complexity	*M*	*SD*	*M*	*SD*
EC	83.30	6.74	64.97	11.15
IC	74.84	6.17	55.19	13.19
HC	44.47	7.52	23.47	10.52

Note. EC = easy condition, IC = intermediate condition, and HC = hard condition.

TABLE 2
Total Duration (in ms) of the Billiards Stroke for Skilled and Less Skilled Groups for Each Level of Shot Complexity

	Skilled		Less skilled	
Complexity	*M*	*SD*	*M*	*SD*
EC	2,322.50	435.60	2,656.25	795.10
IC	2,587.50	511.30	2,725.83	569.90
HC	4,021.25	568.20	3,622.92	632.70

Note. EC = easy condition, IC = intermediate condition, and HC = hard condition.

Moreover, both groups of participants directed more fixations to the cue ball (M = 2.65), cushion (M = 2.08), and object ball (M = 1.33) than to the pocket (M = 0.25) or to other areas of the display (M = 0.35). In addition to those main effects, a significant Skill × Location interaction was found, $F(4, 88) = 5.18$, $p < .02$. The less skilled players directed significantly more fixations to the cue ball (M = 3.00) than the skilled players. The number of fixations to other locations was similar for both groups.

An analysis of mean fixation duration per location showed significant differences for location, $F(4, 88) = 156.77$, $p < .001$. Both groups fixated longer on the cushion (M = 445.66 ms), the cue ball (M = 406.32 ms), and the object ball (M = 364.06 ms) than on the pocket (M = 51.56 ms) or on other areas (M = 53.54 ms). No other main effect or interaction was significant. The results are presented in Table 4.

Hard Complexity Level

An analysis of the number of fixations and mean fixation duration per location for HC yielded results similar to those of the other complexity conditions. The three- and four-way interactions were not significant for either dependent variable. For number of fixations, significant main effects were demonstrated for location, $F(4, 88) = 377.41$, $p < .001$, and skill, $F(1, 22) = 17.09$, $p < .01$. Less skilled performers made more fixations per location (M = 1.78) than their more skilled counterparts (M = 1.50). The greatest number of fixations were directed toward the cue ball (M = 3.60), followed by the object ball (M = 2.71), and the second target ball (M = 1.04). Only a minimal number of fixations were allocated to the pocket (M = 0.44) or to other areas (M = 0.40). Post hoc analysis indicated that each of those means was significantly different from each other, except for the comparison between the pocket and other areas. A significant Skill × Location interaction, $F(4, 88) = 8.26$, $p < .03$, revealed that the less skilled participants generated more fixations to the cue ball (M = 4.04) and the object ball (M = 3.00) than the skilled players (Ms = 3.17 and 2.42 fixations, respectively).

An analysis of mean fixation duration per location showed significant main effects for location, $F(4, 88) = 113.60$, $p < .001$, and skill, $F(1, 22) = 14.87$, $p < .01$. The more advanced players used longer fixations (M = 347.56 ms) than the less skilled participants (M = 274.99 ms), and the longest fixation for both groups was directed at the cue ball (M = 582.21 ms), followed by the object ball (M = 447.38 ms), and the second target ball (M = 365.10 ms). Shorter mean fixation durations were found for the pocket (M = 89.17 ms) and the other areas (M = 72.50 ms). Post hoc analyses revealed that each of the means was significantly different from one another, save for the pocket and other areas comparison. Finally, the Location × Skill interaction was significant, $F(4, 88) = 3.57$, $p < .05$. The skilled players had longer mean fixations to the cue ball (M = 678.47 ms) and the object ball (M = 504.93 ms) than the less skilled players (Ms = 485.95 and 389.83 ms). Those results are displayed in Table 5.

Quiet Eye Duration and Number of Eye Blinks

We assessed quiet eye duration (in milliseconds) and suppression of gaze (defined as the number of blinks) by using separate 2 (skill) × 3 (complexity) × 2 (accuracy) × 5 (trial) ANOVAs with repeated measures on the last three variables. For the quiet eye dependent variable, significant main

TABLE 3
Mean Number of Fixations and Mean Fixation Duration (in ms) per Trial for Skilled and Less Skilled Groups in the Easy Condition

	Skilled		Less skilled	
Location	No. fixations	Duration	No. fixations	Duration
Cue ball	2.46	418.82	3.54	373.23
Object ball	2.33	498.96	3.33	337.57
Cushion	0.00	0.00	0.00	0.00
Pocket	0.00	0.00	0.00	0.00
Other	0.50	69.58	0.50	95.42

TABLE 4
Mean Number of Fixations and Mean Fixation Duration (in ms) per Trial for Skilled and Less Skilled Groups in the Intermediate Condition

	Skilled		Less skilled	
Location	No. fixations	Duration	No. fixations	Duration
Cue ball	2.29	428.47	3.00	384.17
Object ball	1.01	397.08	1.67	331.04
Cushion	2.04	470.14	2.13	421.18
Pocket	0.21	38.33	0.29	64.58
Other	0.33	46.67	0.38	60.42

TABLE 5
Mean Number of Fixations and Mean Fixation Duration (in ms) per Trial for Skilled and Less Skilled Groups in the Hard Condition

	Skilled		Less skilled	
Location	No. fixations	Duration	No. fixations	Duration
Cue ball	3.17	678.47	4.04	485.95
Object ball	2.42	504.93	3.00	389.83
Second ball	1.04	376.88	1.04	353.33
Pocket	0.46	102.92	0.42	75.42
Other	0.42	74.58	0.38	70.42

effects were found for skill, $F(1, 22) = 68.41$, $p < .001$; complexity, $F(2, 44) = 76.25$, $p < .001$; and accuracy $F(1, 22) = 165.19$, $p < .001$. Successful shots were characterized by longer quiet eye durations (M = 561.94 ms) than were unsuccessful shots (M = 213.61 ms). Skilled players had significantly longer quiet eye measures (M = 499.86 ms) than less skilled players (M = 275.69 ms), and quiet eye duration increased linearly with increases in task complexity (Ms = 229.79 ms in the EC, 314.17 ms in the IC, and 619.38 ms in the HC). A significant three-way Accuracy × Complexity × Skill interaction was observed, $F(2, 44) = 5.05$, $p < .05$. The mean values for the respective measures are displayed in Figure 1.

There were no significant main effects or interactions for the eye blink variable. Very few eye blinks were observed throughout the experiment; the skilled players averaged 0.17 and the less skilled group 0.24 blinks per shot. It appears that blink rate was not related to skill level, performance accuracy, or level of shot complexity.

EXPERIMENT 2

Method

Participants

Participants were the same as in Experiment 1.

Apparatus

All apparatus, including the eye-tracking unit, video recording and mixing devices, and billiards table, cue, and balls, were identical to those described in Experiment 1. However, only the arrangements of balls in the intermediate complexity condition (IC) were included in Experiment 2.

We used the countdown timing mechanism feature of the ReAction Coach (S.T.A.R.T. Technologies, New York) movement timing system to direct the participants as to the time they were allotted for the task. The ReAction Coach presents auditory and visual cues so that quicker and more explosive motor abilities can ostensibly be evoked (see Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1993). Auditory cues are provided as a series of beeps, and those cues can be adjusted in volume and sensitivity. The countdown mode of the ReAction Coach was used in Experiment 2: Three preliminary auditory beeps were presented (priming cues indicating that the trial was imminent), followed by a tone of longer duration (indicating the initiation of the trial). Once that tone sounded, the internal timer in the device was activated, and it was terminated when a loud sound was generated by the participant (i.e., the striking of the cue ball with the billiard cue). We recorded and used durations (in milliseconds) between onset of the final tone and termination of the timer to provide feedback to participants.

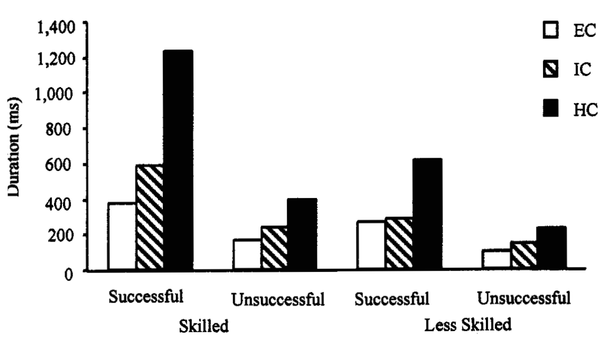

FIGURE 1. Mean quiet eye duration (in ms) for successful and unsuccessful shots for skilled and less skilled groups across shot complexity. EC, IC, and HC = easy, intermediate, and hard conditions, respectively.

Procedure

Participants were required to perform under two different conditions presented in a randomly assigned and counterbalanced order. In the 25% constrained condition, the shooter was required to initiate his stroke within 75% of the average time spent in the initiation of the stroke as recorded in an unconstrained condition. The unconstrained-condition times were based on data obtained from Experiment 1, where the participant was allowed to take as much time as required to perform the IC task. For example, if a particular participant took an average of 4 s to execute the entire shot in the unconstrained condition, he was required to perform the shot in 3 s in the 25% constrained condition. In the 50% constrained condition, the player had to execute the shot within a duration of 50% of the average time he had used to initiate the shot in the unconstrained condition. To use the same example, a player averaging 4 s per shot in the initial testing session had to initiate the shot in 2 s in the 50% constrained condition. Three practice trials were given in each condition.

To aid participants in determining when they would be allowed to initiate a stroke, we used the countdown timing mechanism feature of the ReAction Coach movement timing system. Players stood in a ready position over the shot and closed their eyes, and were informed that an experimental trial would begin upon their hearing the initial warning tones produced by the ReAction Coach. At that time, the timer was activated and the participants were allowed to open their eyes and begin preparatory motions to execute the shot. The experimenter, through observation and use of the video images, ensured that the participants did not open their eyes before the signal. On the basis of the times recorded by the ReAction Coach, the experimenter provided feedback to the participants after each trial as to whether they were initiating the stroke within the allotted time frame. Less than 2% of trials had to be repeated because participants had failed to do so. The players performed consecutive shots until they reached 10 successful and 10 unsuccessful outcomes in each condition. Trials initiated after the constrained period were not included in the analyses.

Dependent Measures and Statistical Analyses

The dependent measures and statistical analyses were identical to those described in Experiment 1.

Results

Performance

A 2 (skill) × 3 (shot duration) ANOVA with repeated measures on the last variable indicated significant main effects for skill, $F(1, 22) = 32.32$, $p < .001$, and duration, $F(2, 44) = 6.83$, $p < .003$. Post hoc analyses revealed that skilled players made significantly more successful shots ($M = 67.39\%$) than less skilled players ($M = 52.07\%$). There were significant reductions in performance for both groups as the time available to execute the shot decreased, from $M = 65.01\%$ for the 100% (unconstrained) condition, to $M = 61.11\%$ for the 25% constrained condition, and to $M = 53.06\%$ in the 50% constrained condition. The interaction was not significant. The skilled players sank more shots under each condition than the less skilled players. Also, the manipulations in duration affected members of both groups in a proportionate manner. Overall performance for each group is presented in Table 6.

Phase Duration

To determine whether constraining the time allowed to complete the billiard stroke led to specific changes in duration for each of the four phases of the stroke, we conducted a 2 (skill) × 3 (duration) × 4 (phase) × 2 (accuracy) × 5 (trial) ANOVA with repeated measures on the last four variables. Significant main effects were found for phase, $F(3, 66) = 9.90$, $p < .01$, and duration, $F(2, 44) = 7.29$, $p < .02$. Both groups spent significantly more time in the preparation phase of the stroke ($M = 742.51$ ms) than in any of the other phases. Means for the other phases included backswing, $M = 397.48$ ms; foreswing, $M = 118.53$ ms; and flight, $M = 537.66$ ms. The 100% unconstrained condition led to a longer mean phase time ($M = 664.17$ ms) than the 25% ($M = 398.02$ ms) or the 50% constrained conditions ($M = 284.95$ ms). No other main effects were significant.

A significant Phase × Duration interaction was observed, $F(6, 132) = 4.68$, $p < .05$. Follow-up tests indicated that the backswing, foreswing, and flight phases for each level of constraint did not differ across the constrained and unconstrained conditions. However, the duration of the preparation phase was significantly greater ($M = 1{,}476.19$ ms) in the 100% unconstrained condition than in the 25% or the 50% constrained conditions (Ms = 548.00 ms and 203.33 ms, respectively). No other interactions were significant. It appears that the reduction in overall duration of the billiards stroke came at the expense of only the preparation phase for both groups. The backswing, foreswing, and flight phases all remained relatively similar for each condition.

TABLE 6
Performance Means (in %) and Standard Deviations for Skilled and Less Skilled Groups for Each Movement Condition

	Skilled		Less skilled	
Condition	*M*	*SD*	*M*	*SD*
Unconstrained	74.84	6.17	55.19	13.18
25% constrained	68.00	7.74	54.23	14.58
50% constrained	59.33	10.42	46.78	13.83

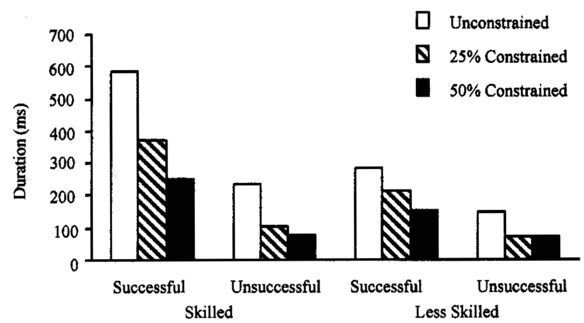

FIGURE 2. Mean quiet eye duration (in ms) for successful and unsuccessful shots across skilled and less skilled groups for each task duration level.

Quiet Eye Duration

We assessed quiet eye duration by using separate 2 (skill) × 3 (duration) × 2 (accuracy) × 5 (trial) ANOVA with repeated measures on the last three variables. Significant main effects were found for skill, $F(1, 22) = 72.21$, $p < .001$, duration, $F(2, 44) = 61.50$, $p < .001$, and accuracy $F(1, 22) = 208.55$, $p < .001$. Successful shots were characterized by longer quiet eye durations ($M = 310.42$ ms) than were unsuccessful shots ($M = 118.06$ ms), skilled players had significantly longer quiet eye measures ($M = 270.83$ ms) than less skilled players ($M = 157.64$ ms), and quiet eye duration decreased linearly with increases in time constraints (Ms = 314.17 ms for the 100% unconstrained, 190.63 ms for the 25% constrained, and 137.92 ms for the 50% constrained conditions).

A significant three-way Accuracy × Duration × Skill interaction was observed, $F(2, 44) = 9.91$, $p < .01$. For both the skilled and the less skilled groups, quiet eye duration was significantly longer for accurate than for inaccurate shots at each level of complexity. The longest quiet eye duration was observed for successful shots in the 100% unconstrained condition. Moreover, for accurate shots, skilled players had significantly longer mean quiet eye durations—nearly double that of their less skilled counterparts. For both skill levels, missed shots in the 25% and the 50% constrained conditions were characterized by short quiet eye durations. Finally, in the skilled group, missed shots were associated with mean quiet eye durations that were less than half those associated with successful shots. The mean values are displayed in Figure 2.

GENERAL DISCUSSION

In this research, we examined the relationships among quiet eye duration, expertise, and task complexity in a billiards task involving near and far aiming requirements. Our primary intention was to examine the explanatory power of Vickers's (1996) location-suppression hypotheses in far aiming tasks. According to Vickers's hypotheses, the present participants should fixate predominately on the target during the preparatory phase of the movement and should exhibit longer quiet eye periods than their less expert counterparts. We expected that during the execution phase of the movement, participants would suppress visual input from the target either by an increase in the number of eye blinks or by shifts in gaze toward other potentially less pertinent areas. We also examined the potential value of Vickers's quiet eye period as an index of cognitive programming by manipulating the complexity of the task and the time available to execute the stroke. We expected quiet eye duration to increase with greater task complexity, whereas we expected task proficiency to decrease as we reduced the duration of quiet eye by placing various time constraints on performance. Finally, the potentially mediating effects of expertise on quiet eye period during manipulations of shot complexity and time available for preprogramming were examined.

Eye–Hand Coordination

Participants focused primarily on the near target (i.e., cue ball), irrespective of task complexity or shot phase, with secondary fixations directed toward the object ball. The second ball and cushion were also of importance in the IC and HC, respectively. There were surprisingly few fixations on the pocket, limbs, or billiards cue (classified as *other areas*). The data provided support for the location aspect of Vickers's (1996) hypothesis. Most interesting, more fixations of longer duration were directed at the cue ball than at the object ball or other areas, particularly for the skilled players in the IC and HC conditions, indicating that the billiards shot may be primarily seen as a near rather than a far aiming task.

No evidence was obtained for the suppression aspect of Vickers's hypothesis. Vickers (1996) noted that expert free-throw shooters suppressed their gaze immediately following the initiation of movement toward the target by either blinking or shifting their visual attention to areas away from the target. In the sport of billiards, very few eye blinks or shifts of gaze to locations other than the cue ball, object ball, or target cushion were observed. Regardless of skill level, participants appeared to fixate only on the pertinent aspects of the display and did not make any eye blinks throughout each phase of the billiards stroke. Once the backswing phase was initiated, both groups focused on either the cue or the object ball and then tracked the cue ball until it came into contact with the object ball.

Vickers's (1996) suppression hypothesis may be specific to the basketball free-throw task. When performing that task, the hands, ball, and arms all come into view of the eyes and occlude the target (the hoop) during the execution phase. The appearance of potentially distracting stimuli in the visual field may cause players to blink or shift their gaze away from the target. To that end, Vickers's suppression hypothesis may apply only to tasks in which a body part or a piece of equipment interferes with the participant's view of the target.

Quiet Eye Period as an Index of Preprogramming

Longer quiet eye periods were recorded on successful than on unsuccessful shots, regardless of task complexity or participant skill level. Quiet eye duration averaged 561.94 ms for successful shots, compared with only 213.61 ms for unsuccessful shots. That finding provides support for the results of previous research by Vickers and her colleagues and suggests that quiet eye duration is an important element of successful performance in various aiming tasks. Our assumption is that the quiet eye period reflects a critical period of cognitive processing during which the parameters of the movement such as force, direction, and velocity are fine-tuned and programmed.

As expected, the quiet eye period increased proportionally with the difficulty of the shot, particularly for successful attempts. Quiet eye duration in the EC averaged 230 ms, with 314 ms in the IC and almost 620 ms in the HC. In previous research, longer reaction times have been observed for more complex tasks (e.g., Klapp, 1980; Sternberg, Monsell, Knoll, & Wright, 1978); therefore, the finding of an increase in quiet eye duration with shot complexity was predicted. If quiet eye duration reflects a period of cognitive response programming, then more complex tasks should be characterized by longer quiet eye periods.

In the second experiment, externally imposed time constraints led to reductions in the preparation phase of only the shot. The reduction in the relative amount of time available for shot preparation had a concomitant affect on the quiet eye period for both groups. Mean quiet eye values dropped from 314 ms in the unconstrained condition to 138 ms in the 50% constrained condition. Quiet eye duration, therefore, appears to reflect underlying cognitive processes that are highly influential in the preparation of effective billiard stroke responses. As proposed by Vickers (1996), the quiet eye period is related to the amount of time spent in the response-programming stage of the information-processing model and may serve as evidence that higher order cognitive processes control gaze behavior.

Mediating Effects of Expertise on Performance

Skilled players performed significantly better than their less skilled counterparts across the three complexity conditions. They had a higher ratio of successful to unsuccessful shots in each condition. More accurate shots were characterized by longer overall movement duration, with successful shots taking approximately 210 ms longer to complete. In general, skilled players took more time to execute their shots than less skilled players, particularly in the HC. The level of shot complexity also influenced the overall duration, with shots in the HC having the longest duration. The duration of the backswing, foreswing, and flight phases of the stroke did not differ significantly across the three levels of task complexity, although increases were observed during the shot preparation phase. That result provides support for the finding in other studies that reaction time measures are related to task complexity (e.g., Klapp, 1980) and suggests that changes in task complexity influence response programming.

Skilled and less skilled players were differentiated on the basis of their visual search behaviors. The less skilled players used more fixations of shorter duration per trial, particularly to the cue and object balls, than the skilled participants. In contrast, the skilled players fixated for longer on the cue and object balls than the less skilled participants. The less skilled players seemed to allocate their visual attention equally to the cue ball, the object ball, and the second target ball. It appears that the skilled performers' visual search behaviors were more economical, with longer fixations to only one or two key areas of the display. That efficient search strategy is similar to what has been observed in experts engaged in other motor skills such as golf putting (Vickers, 1992), baseball batting (Bahill & LaRitz, 1984), and volleyball service reception (Vickers & Adolphe, 1997).

Skilled players used longer quiet eye durations than their less skilled counterparts did, regardless of shot complexity or the time constraints imposed. The average quiet eye duration for the skilled players was around 500 ms, compared with 275 ms for the less skilled participants. That finding provides support for previous results involving the basketball free throw and volleyball service reception (Vickers, 1996, 1997; Vickers & Adolphe, 1997). Quiet eye duration appears to be a key factor in explaining differences in performance between and within each of the skill level groups.

More investigation is needed so that the exact nature of the quiet eye duration can be determined. Vickers (1996) contended that the parameterization of variables associated with successful far aiming movements is delineated during the quiet eye period. Those variables may include temporal, distance, force, and velocity measures. It is still unclear, though, whether the quiet eye duration is indeed reflective of underlying cognitive processing. Although the present results suggest that quiet eye duration is influenced by factors known to have an impact upon the programming of a motor response, further research investigating manipulations in each parameter of the aiming movement might provide more detailed information as to the exact nature of the quiet eye measure. An alternative perspective needs to be explored as well. Perhaps a longer target fixation period serves primarily as a means of self-regulation enabling the performer to enter and sustain an optimal attention state; consequently, the quiet eye period may be part of the athlete's preperformance routine. The performer presumably fixates his or her visual attention on the target but does not initiate the action until a state of mental readiness is achieved (Singer, 2000).

Finally, research is needed to determine whether training programs can be designed to enable performers to enhance the control of visual attention in near and far aiming tasks. Because the expert's perceptual superiority over the novice is the result of enhanced computational sophistication and improved strategic processing of information rather than differences in visual abilities (Williams et al., 1999), researchers should determine whether those skills could be developed through instructional training programs (see Williams & Grant, 1999). For example, Adolphe, Vickers, and Laplante (1997) developed a 6-week training program to improve ball-tracking and -passing skills in high skilled volleyball players. The results indicated that the training program resulted in faster tracking onset times, a longer ball tracking duration, and longer quiet eye periods. The improvements were still observed after a 3-year follow up, whereas performance statistics demonstrated that those skills transferred from laboratory to field settings. Further research is necessary so that we can increase our understanding of the mechanisms underlying the training of visual attention control during near and far aiming tasks.

REFERENCES

Abrams, R. A. (1994). Eye–hand coordination: Spatial localization after saccadic and pursuit eye movements. *Journal of Motor Behavior, 26,* 215–224.

Abrams, R. A., Meyer, D., & Kornblum, S. (1990). Eye–hand coordination: Oculomotor control in rapid aimed limb movements. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 248–267.

Adolphe, R. M., Vickers, J. N., & Laplante, G. (1997). The effects of training visual attention on gaze behavior and accuracy: A pilot study. *International Journal of Sports Vision, 4,* 28–33.

Assaiante, C., Marchand, A. R., & Amblard, B. (1989). Discrete visual samples may control locomotor equilibrium and foot positioning in man. *Journal of Motor Behavior, 21,* 72–91.

Bahill, L. T., & LaRitz, T. (1984). Why can't batters keep their eyes on the ball? *American Scientist, 72,* 249–253.

Bootsma, R. J., Fayt, V., Zaal, F. T. J. M., & Laurent, M. (1997). On the information-based regulation of movement: What Wann (1996) may want to consider. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1282–1289.

Bootsma, R. J., & van Wieringen, P. C. W. (1990). Timing an attacking forehand drive in table tennis. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 21–29.

Elliott, D., Zuberec, S., & Milgram, P. (1994). The effects of periodic visual occlusion on ball catching. *Journal of Motor Behavior, 26,* 113–122.

Gauthier, G. M., Semmlow, J. L., Vercher, C., Pedrono, C., & Obrecht, G. (1991). Adaptation of eye and head movements to reduced peripheral vision. In R. Schmid & D. Zambarbieri (Eds.), *Oculomotor control and cognitive processes* (pp. 179–196). New York: Elsevier Science.

Guitton, D., & Volle, M. (1987). Gaze control in humans: Eye–head coordination during orienting movements to targets within and beyond the oculomotor range. *Journal of Neurophysiology, 58,* 427–459.

Henry, F. M. (1980). Use of simple reaction time in motor programming studies: A reply to Klapp, Wyatt, and Lingo. *Journal of Motor Behavior, 12,* 163–168.

Henry, F. M., & Rogers, D. E. (1960). Increased response latency for complicated movements and a "memory drum" theory of neuromotor reaction. *Research Quarterly, 31,* 448–458.

Kerr, B. (1978). Task factors that influence selection and preparation for voluntary movements. In G. E. Stelmach (Ed.), *Information processing in motor control and learning* (pp. 55–69). New York: Academic Press.

Klapp, S. T. (1977). Reaction time analysis of programmed control. *Exercise and Sport Sciences Reviews, 5,* 231–253.

Klapp, S. T. (1980). The memory drum theory after twenty years: Comments on Henry's note. *Journal of Motor Behavior, 12,* 169–171.

Martin, R., & Reeves, R. (1993). *The 99 critical shots in pool*. New York: Times Books.

Newell, K. M., Hoshizaki, L. E. F., Carlton, M. J., & Halbert, J. A. (1979). Movement time and velocity as determinants of movement timing accuracy. *Journal of Motor Behavior, 11,* 49–58.

Prablanc, C., & Pellison, D. (1990). Gaze saccade orienting and hand pointing are locked to their goal by quick internal loops. In M. Jeannerod (Ed.), *Attention and performance, XIII* (pp. 653–676). Hillsdale, NJ: Erlbaum.

Ripoll, H. (1991). The understanding–acting process in sport: The relationship between the semantic and the sensorimotor visual function. *International Journal of Sport Psychology, 22,* 221–243.

Ripoll, H., Bard, C., & Paillard, J. (1986). Stabilization of the head and eyes on the target as a factor in successful basketball shooting. *Human Movement Science, 5,* 47–58.

Ripoll, H., Papin, J., Guezennec, J., Verdy, J., & Philip, M. (1985). Analysis of visual scanning patterns of pistol performers. *Journal of Sport Sciences, 3,* 93–101.

Shapiro, D. C. (1977). A preliminary attempt to determine the duration of a motor program. In D. M. Landers & R. W. Christina (Eds.), *Psychology of motor behavior and sport* (pp. 17–24). Champaign, IL: Human Kinetics.

Singer, R. N. (2000). Performance and human factors: Considerations about cognition and attention for self-paced and externally-paced events. *Ergonomics, 43*, 1661–1680.

Singer, R. N., Cauraugh, J. H., Chen, D., Steinberg, G. M., & Frehlich, S. G. (1993). *Mental quickness in tennis: Project I: Comparisons of advanced and beginning players. Project II: A quickness training program*. Tech rep. (Contract #37025) submitted to the United States Tennis Association, Miami, FL.

Spijkers, W. A. C. (1989). Effect of average movement velocity on reaction time and spatiotemporal accuracy in single-aiming and rapid-timing movement tasks. *Journal of Motor Behavior, 23,* 207–224.

Spijkers, W. A. C., & Steyvers, F. (1984). Specification of direction and duration during programming of discrete sliding movements. *Psychological Research, 46,* 59–71.

Sternberg, S., Monsell, S., Knoll, R. L., & Wright, C. E. (1978). The latency and duration of rapid movement sequences: Comparisons of speech and typewriting. In G. E. Stelmach (Ed.), *Information processing in motor control and learning* (pp. 117–152). New York: Academic Press.

Summers, J. J. (1977). The relationship between the sequencing and timing components of a skill. *Journal of Motor Behavior, 9,* 49–59.

Tresilian, J. R. (1997). A revised tau hypothesis: Consideration of Wann's analyses. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1272–1281.

Vickers, J. N. (1992). Gaze control in putting. *Perception, 21,* 117–132.

Vickers, J. N. (1996). Visual control when aiming at a far target. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 342–354.

Vickers, J. N. (1997). Control of visual attention during the basketball free throw. *The American Journal of Sports Medicine, 24,* 93–97.

Vickers, J. N., & Adolphe, R. M. (1997). Gaze behavior during a ball tracking and aiming skill. *International Journal of Sport Vision, 4,* 18–27.

Williams, A. M., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer. *Research Quarterly for Exercise and Sport, 69*(2), 111–128.

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport.* London: E. & F. N. Spon.

Williams, A. M., & Grant, A. (1999). Training perceptual skill in sport. *International Journal of Sport Psychology, 30,* 194–220.

Zelaznik, H., Hawkins, B., & Kisselburgh, L. (1983). Rapid visual feedback processing in single-aiming movements. *Journal of Motor Behavior, 15,* 217–236.

Submitted November 19, 2000
Revised June 26, 2001