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Aiming at a far target under different viewing conditions: Visual control in basketball jump shooting

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Abstract

Most research on visual search in aiming at far targets assumes preprogrammed motor control implying that relevant visual information is detected prior to the final shooting or throwing movements. Eye movement data indirectly support this claim for stationary tasks. Using the basketball jump shot as experimental task we investigated whether in dynamic tasks in which the target can be seen until ball release, continuous, instead of preprogrammed, motor control is possible. We tested this with the temporal occlusion paradigm: 10 expert shooters took shots under four viewing conditions, namely, no vision, full vision, early vision (vision occluded during the final ± 350 ms before ball release), and late vision (vision occluded until these final ± 350 ms). Late-vision shooting appeared to be as good as shooting with full vision while early-vision performance was severely impaired. The results imply that the final shooting movements were controlled by continuous detection and use of visual information until ball release. The data further suggest that visual and movement control of aiming at a far target develop in close correspondence with the style of execution.

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1. Introduction

Hitting a jump shot in basketball is an amazing accomplishment. Unlike in other far aiming tasks (such as rifle shooting, pistol shooting and archery), the body is in full motion and, the distance to the target is never exactly the same from one shot to the next. Yet shooters make quick arm movements during their jump to propel the ball with a high curved trajectory to and through the target, the hoop. Moreover, jump shots are often executed under high time pressure. In the midst of allocating attention to fast moving fellow players and opponents, at some point in time, it is essential for the shooter to visually attend to the appropriate information for releasing an accurate shot (Ripoll, Bard, & Paillard, 1986).

In the current study we investigated the relation between visual attention and motor control in basketball jump shooting by experts. In contrast to more cognitive interpretations of attention in the information-processing approach (see Abernethy, 2001; for a review), we take an ecological point of view in which attention is seen as the control of detection of information (Michaels & Carello, 1981). This view fits well with the sports literature regarding perceptual expertise, in which it is found that experts have learned to efficiently attend to and detect those information sources that are relevant for their actions, while leaving unattended and undetected those sources that are irrelevant and potentially distracting (e.g., Abernethy, 1996; Williams, Davids, & Williams, 1999; Williams & Grant, 1999). Before we turn our attention to the visual control in basketball jump shooting and other far aiming tasks, we will discuss in some detail the various styles¹ that exist in basketball shooting, as these shooting styles have consequences for the visual control of the aiming movements.

1.1. Basketball shooting styles

There is a good deal of literature on basketball shooting, most of it concerning the kinematics, biomechanics and physics of free throw and jump shooting (e.g., Brancazio, 1981; Elliott, 1992; Elliott & White, 1989; Hay, 1993; Hudson, 1985; Kirby & Roberts, 1985; Knudson, 1993; Knudson & Morrison, 1997; Miller & Bartlett, 1993, 1996; Penrose & Blanksby, 1976). In search for determining factors of success, the role of variables such as release height, angle and speed are discussed and investigated, sometimes together with biomechanical variables as shoulder angle and trunk inclination. Different shooting styles are reported. Although vision is likely to be an important factor in basketball shooting, only rarely (e.g., Elliott, 1992) is the link made between vision and shooting style. Yet different shooting styles may have dif-

¹ With shooting style we refer to the movements that are made with the hands and the ball. We do not refer to what the feet do as these could remain set on the floor, as in the set shot or free throw, or jump up as in a jump shot. In the jump shot one could land with a one-count or two-count stop referred to as two shooting techniques by Penrose and Blanksby (1976). Hay (1993) indicates that the arm techniques used in the set shot and the jump shot are essentially the same. This also follows from the descriptions given by Kirby and Roberts (1985).

ferent consequences for the visual control of the shot, as will become apparent in the following discussion of shooting styles in basketball.

In the 1950s, 1960s and 1970s both the overhand push shot and the underhand loop shot were used (Tan & Miller, 1981). In the overhand push shot, “the ball is moved in a straight line from near the shoulder to the release point” (Tan & Miller, 1981, p. 542). In the underhand shot, “the ball is swung in an arc from above the knees to the release point” (p. 542). Since the beginning of the 1980s the underhand shot has fallen into disuse, leaving the overhand style as the major shooting style (Tan & Miller, 1981). But even within the overhand style various sub-styles can be distinguished. A style that is often described is the overhead-back-spin style (e.g., Hay, 1993; Kirby & Roberts, 1985; term from Hamilton & Reinschmidt, 1997) with which (for a right-handed shot) the ball is lifted up “past the face into a position from which the shot is completed with an extension of the right elbow and a flexion of the wrist and fingers” (Hay, 1993, p. 240). Thus, the ball is elevated high overhead to the “shooting position” (Hay, 1993; Kirby & Roberts, 1985, p. 342) also called the “ready position” by Penrose and Blanksby (1976, p. 17), the term we will use in the remainder of this paper. The left hand is merely used for support at the side of the ball while the right hand executes the main shooting action. Advantages of this shooting style are that it allows backspin and a relative high point of release, both of which appear to be critical in shooting performance (Brancazio, 1981; Hamilton & Reinschmidt, 1997; Hudson, 1985). Moreover, with this high style the shooter can look at the basket from underneath the ball when it is held in the ready position, as can be clearly seen from the film frames presented by Penrose and Blanksby (1976) (see also Hay, 1993; Kirby & Roberts, 1985).

Next to the high style a lower style is also reported (e.g., Elliott, 1992; Kreighbaum & Barthels, 1981; Miller & Bartlett, 1996; Vickers, 1996a,b; Walters, Hudson, & Bird, 1990). This is a pushing style (Kreighbaum & Barthels, 1981) during which the ball and hands remain below or at eye level for almost the entire shooting action (apart from perhaps the final propulsion phase). When the ball is in the ready position ball and hands are in front of the face and, hence, in the field of view. Walters et al. (1990) describe this as the style used by their participants, female collegiate basketball players. This is the style that was also used by almost all (with one exception) of the participants of Vickers (1996a,b), in her study of gaze behavior in basketball shooting.

Thus, in basketball shooting, be it the set shot (as is most often used with the free throw) or the jump shot (see Footnote 1), two major shooting styles may be distinguished, a high and a low style, a main difference being whether or not the shooter can look at the basket from underneath the ball during the final shooting movements until ball release.² In a study by Elliott (1992) it was found that the height above the ear to which the ball was brought before initiating the final shooting movements was

² A third style may be distinguished, namely, when the shooter brings the ball more or less to the side of the head so that s/he can look passed the ball at the basket. As we have found no description of this style in the literature, nor empirical support for the use of this style, we did not address it separately in this study.

significantly higher for the male than the female shooters he tested. In Appendix A we present a method to estimate whether a shooter can look underneath the ball at the basket in the ready position. When this method is applied to the different ready positions reported by Elliott, it appears that the male shooters used a high style with which they could look underneath the ball at the basket when the ball was held in the ready position. The female shooters on the other hand used a lower style with which they could not look underneath the ball for two of the three shooting distances that were tested. These results confirm the idea that a high and a low shooting style may be distinguished depending on whether the shooter can or cannot look underneath the ball at the basket when the ball is in the ready position.

1.2. Visual control in basketball shooting

Of all the available literature on basketball shooting, only a few studies consider the relation between vision and shooting accuracy, most notably the studies by Ripoll et al. (1986) and by Vickers (1996a). Ripoll et al. investigated eye–head coordination in the dynamic task of basketball jump shooting by expert, intermediate and beginning shooters. They monitored eye and head movements during the execution of jump shots and found that eye–head stabilization toward the target is critical in the dynamic situation of taking jump shots. The duration of head stabilization and eye–head stabilization toward the target was longer for successful shots than for misses.

Vickers (1996a,b) also investigated the relation between vision and basketball shooting. She examined free throw shooting performance by elite female basketball players and she collected detailed information about where and when relative to the shooting movements, shooters fixated their gaze. She found that experts fixated their gaze at the hoop relatively long before initiating the final shooting movements resulting in a long duration of what she called “quiet eye”, the final fixation on the target before delivering the shot (between 800 and 1000 ms). Fixation lasted approximately until the final forward and upward shooting movements of hands and arms were initiated, a moment at which, as Vickers (1996a,b) reports, ball and hands were in the field of view occluding the basket. While executing the final shooting movements, no eye fixations occurred and participants often blinked. Near-experts, who were found to miss more often, fixated later and, thus, had shorter quiet eye durations (between 300 and 400 ms). On the basis of these results, Vickers (1996a,b) hypothesized that it is essential that after long early fixation vision be suppressed during the final shooting movements in order to prevent vision from negatively interfering with the motor program. She called this the location-suppression hypothesis in aiming at a far target.

On the basis of her results Vickers (1996a) asked whether quiet eye duration is critical, and whether the location-suppression mechanisms also occur in other far aiming tasks, for instance, when the target is not occluded during the final aiming movements. Other studies have also identified quiet eye duration as a key factor in other tasks such as playing billiards (Williams, Singer, & Frehlich, 2002), rifle shooting (Janelle et al., 2000), volleyball serve reception (Vickers & Adolphe, 1997), golf putting (Vickers, 1992), and dart throwing (Vickers, Rodrigues, & Edworthy, 2000). Williams et al. (2002) proposed that 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” (p. 22). However, the aiming tasks investigated thus far were mostly static tasks in which the actor aims and executes the movements from a stationary position with relatively little time pressure. As explained above, the basketball jump shot is dynamic in nature with severe time constraints especially when the shot is taken following locomotion. It is therefore unfortunate that in the study by Ripoll et al. (1986), in which basketball jump shooting was investigated, it remained unclear whether the shooters used a high or a low shooting style and, more important, whether eye–head stabilization on the target was maintained until ball release or that it ceased in the ready position (as would be expected with a low style because ball and hands occlude the target). When a high shooting style is used it is possible, in principle, to remain fixation on the basket until ball release. Although the study by Vickers (1996a) showed that with the low style, shooters should have looked at the hoop before the final shooting movements are initiated, it may be the case that her results and conclusions are restricted to the use of this style only. One of the aims of the present study was to find answers to the questions posed by Vickers (1996a,b) using basketball jump shooting with the high style.

It is conceivable that looking at the basket during the final shooting movements allows for a different type of motor control including final error correction of the movements up until ball release (Abrams, Meyer, & Kornblum, 1990; Elliott, Binsted, & Heath, 1999). Work by Elliott and colleagues (e.g., Elliott, Chua, Pollock, & Lyons, 1995; Elliott, Lyons, Chua, Goodman, & Carson, 1995; see Elliott et al., 1999, for a review) seems to suggest that very rapid corrective closed-loop processes on the basis of vision play a role in manual aiming and pointing movements: “part of motor learning appears to involve the development of rapid and efficient feedback processing procedures” (Elliott et al., 1999, p. 124). It appears that with intermittent viewing, when visual information is available for even the briefest period of time (e.g., for 20 ms every 100 ms), the performer structures his or her movement trajectory to optimally use visual information (Elliott et al., 1999). Elliott et al. (1999) describe the possibility of continuous control in aiming at a near target involving extremely fast graded adjustments of muscle gain on the basis of dynamic visual information.

Given that with the high shooting style visual information is in principle available until ball release we expected that seeing the hoop late only, can be used for the visual control of the jump shot. To examine this expectation, we investigated the effect of early and late viewing of the hoop on basketball jump shooting with the high style. In particular, we hypothesized that with the high style, late viewing is more appropriate for the visual control of the basketball jump shot than early viewing because with late viewing final error corrections in the shooting movements are possible. Confirmation of this hypothesis would imply that quiet eye duration is not always critical, because late viewing is of limited duration by definition, namely between 300 and 400 ms (see later). In addition, it would suggest that the visual location-suppression mechanisms do not occur in all far aiming tasks.

More specifically, we investigated shooting performance of expert male shooters with vision occluded either before or after ball and hands moved passed the line of

sight. Thus, in contrast to the visual search literature in which gaze behavior is always recorded (e.g., Savelsbergh, Williams, Kamp van der, & Ward, 2002; Vickers, 1992, 1996a; Vickers & Adolphe, 1997; Williams, Davids, Burwitz, & Williams, 1994; see also Williams et al., 1999), we used a different methodology in which we temporally occluded vision during shooting. By doing this we imposed constraints on vision that made visual information for shooting available and unavailable during specific phases of the shooting action, particularly, before or after ball and hands moved passed the line of sight using the high shooting style. This methodology is in keeping with the description of constraints as “grantors of information” (Runeson, 1988; see also Jacobs, Runeson, & Andersson, 2001; Jacobs, 2001). We expect that experts will have educated their attention in such a way that they will pick up the information that is relevant for their actions when this information is granted to them by the constraints of the situation. In this particular case, we wish to find out whether expert shooters with a high style take advantage of the information that is available to them during the final moments before ball release. By occluding vision either before or after ball and hands are moved passed the line of sight it is possible to find out not only whether late or early viewing is sufficient for accurate shooting, but also whether late or early vision is necessary. If both late and early vision are sufficient we expect that under late and early viewing conditions shooting performance will be just as good as with full vision. If however early vision is sufficient and necessary as was the case for the shooters with the low style investigated by Vickers (1996a,b), then we expect early vision performance to be the same as with full vision, while late viewing performance is severely impaired. If on the other hand, late vision is sufficient and necessary we expect a severe drop in performance with early vision while with late vision performance remains just as good as with full vision. This would leave open the possibility of rapid closed-loop (continuous or pseudo-continuous; Elliott et al., 1999) control of the final shooting movements in this dynamic task.

Vision was manipulated by using Plato Liquid Crystal (LC) goggles. LC goggles have a great potential for more ecologically valid forms of temporal occlusion tests, for example, in field settings (Abernethy, Wann, & Parks, 1998; Starkes, Edwards, Dissanayaka, & Dunn, 1995). In the present study the goggles were controlled on the basis of the shooter’s movements. Movement registrations of hand and head were fed back online to the computer that used the data to either shut or open the glasses when hand and ball were moved through the line of sight. To the best of our knowledge, this method of manipulating vision on court using online movement registration has not been applied before.

2. Method

2.1. Participants

Ten experienced male basketball players (all right-handed) participated in the experiment. Their age ranged from 17 to 38 years, and their basketball experience from 9 to 24 years. Nine of the players played, or at least, had experience playing in the

professional league in the Netherlands; one had played several years in the league just under the professional league. All participants played either at the guard or forward position and were the shooters in their team. Average free throw and 3-point shooting percentages during games were 78% (S.D. = 8) and 38% (S.D. = 6), respectively. These percentages fall within the first five of regular season team averages (out of 29) in the National Basketball Association (NBA; USA, 2001/2002 regular season, see www.nba.com). These free throw and 3-point percentages are also close to or in the top-50 of NBA regular season league leader percentages.

2.2. Task

The task of the shooters was to each time take a jump shot after a dribble, a step, and a jump stop from approximately the same position (see Fig. 1A and Section 2.4). The movement sequence before the jump was included to guarantee that the shots were not taken from the exact same position each trial so that visual information processing and perhaps the accompanying calibration procedures had to be executed each time anew.

2.3. Design

Each player was tested in four viewing conditions. Each condition consisted of about five practice trials and 25 experimental trials, resulting in a total of 100

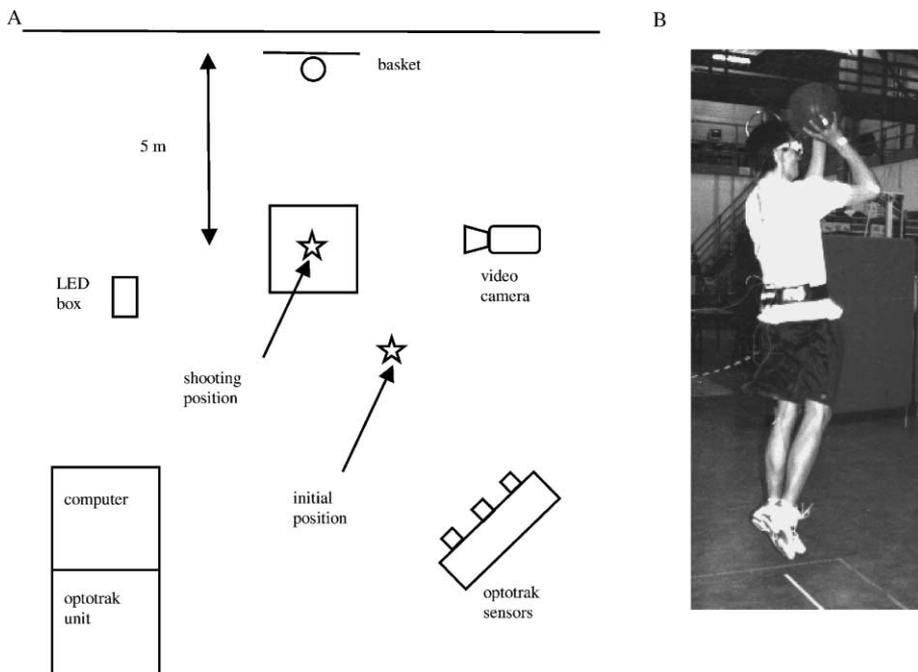


Fig. 1. (A) Schematic representation of experimental setup (top view). (B) Shooter in action wearing the LC goggles and OPTOTRAK markers.

experimental trials. In one condition, vision was occluded during the shooting movement after the ball had been moved passed the line of gaze (early-vision condition see Fig. 2 and Section 2.4 for more details). This meant that the shooter had clear vision up until the moment he moved the ball passed his line of sight to the ready position. Vision was blocked after this moment when the ball was in the ready position and during the final shooting movements. In the second condition, vision was occluded after initiation of the trial until the ball was moved passed the line of gaze (late-vision condition see Fig. 2 and Section 2.4). In this case the shooter only had clear vision when the ball was brought in the ready position and during the final shooting movements. In addition, there were two control conditions, one in which vision was not occluded (full-vision condition) and one in which the glasses remained shut during the entire execution of the task (no-vision condition).

With each new participant a new order of conditions was selected randomly (without replacement) from the 24 possible orders of conditions.

2.4. Experimental setup

In a large laboratory (height 7.5 m) a basket was placed with a standard-size multiplex backboard (1.80×1.05 m; white background with black lines) and regulation rim (0.45 m diameter; height 3.05 m). The initial distance from basket to the shooting

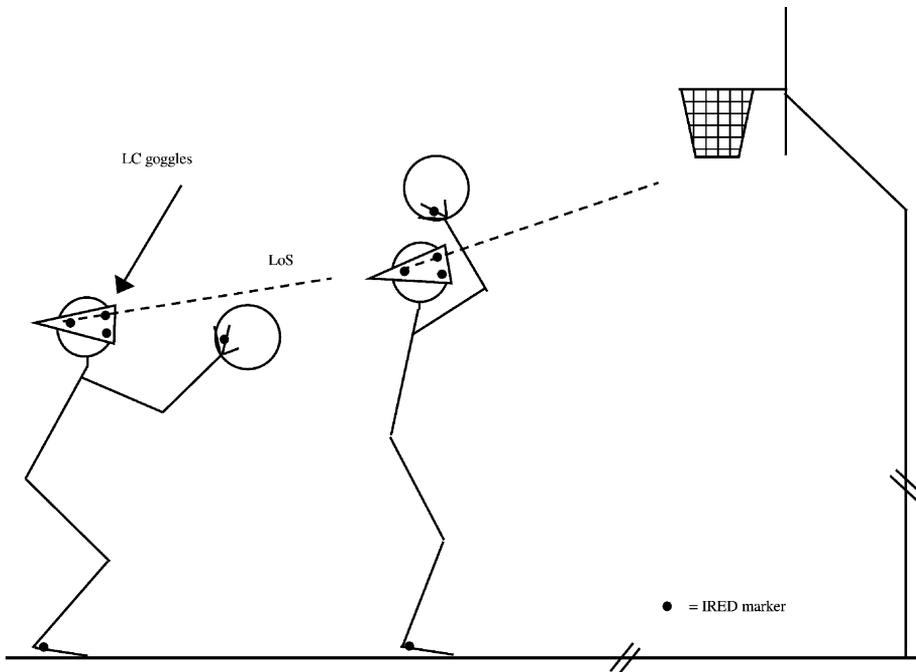


Fig. 2. Schematic representations (side view) of a shooter with ball before (left stick figure) and after (right stick figure) hands and ball are moved through the line of sight (LoS).

spot was approximately 5 m, slightly more than free throw distance (see Fig. 1A). The player wore Plato LC goggles (Translucent Technologies, Toronto, Canada), which could be shut and opened with good temporal precision (1–3 ms). The initial position of the shooter was at a perpendicular distance of 6–7 m from the basket about 1–2 m to the right of it (see Fig. 1A). The exact task of the shooter was to take a jab step to the right, make a cross-over step to the left, make one dribble with the left hand, land in a 1-by-1 m square marked on the floor with white tape at about 5 m from the basket (see Fig. 1A), jump up and take a jump shot.

To allow control of the LC goggles on the basis of the shooter's movements, head movements, heel movements of the right foot, and movements of the right hand were registered in 3D using OPTOTRAK 3020 (Northern Digital Inc., Waterloo, Canada), a motion measurement system with small active infrared emitting diodes (IREDs) or markers. OPTOTRAK detects the markers and for each calculates in real-time accurate 3D positions. Marker identification is warranted at all times because the markers are activated one at a time. If markers go out of view, they will be automatically identified by the system when they return into view due to this known sequential order. The configuration that was used (Fig. 1A) consisted of: a PC host computer (Pentium II 233 MHz, 64 MB SDRAM with Windows'98) with an interface card, an OPTOTRAK Control Unit connected by cable to the PC, a position sensor linked to the control unit, 2 strobers and 5 IRED markers. The position sensor was placed 5 m obliquely behind the shooting spot at a height of 2.65 m. The control unit and PC were positioned a few meters behind the shooting spot (Fig. 1A). A digital video camera was set up perpendicularly to the plane of shooting in order to determine the moment the ball left the hand. The video recordings were synchronized with the registration of OPTOTRAK via two visible red light emitting diodes (LEDs), one that indicated when a trial started and ended and one indicating when the glasses opened or shut. In this way the video recordings that were used to determine ball release could be synchronized with the OPTOTRAK data.

A sample frequency of 100 Hz was used for the OPTOTRAK registration. Three markers forming a rigid triangle were placed on the right leg of the LC goggles, one just above the eye, one just below it and one just in front of the ear. One marker was placed at the right side of the right shoe near the heel. One marker was placed at the ring finger of the right hand (see Figs. 1B and 2). Two marker strobers (5.5 × 7 cm) and the battery case (11 × 7 × 2.5 cm) for the glasses were attached to the waistband of the shooter's trunks. Two long cables coming from the shooter, one from the marker cases and one from the LC battery case, were led to OPTOTRAK's control unit and the PC via a pulley system to make sure that there was no danger for the shooter to become entangled in them. In this way the cables could not interfere with the execution of the task. The ball used was a new leather Spalding official NBA regulation size ball.

2.5. Control of the goggles on the basis of online movement registration

The experiment was designed in such a way that the goggles could be shut or opened (or they could remain unchanged) depending on condition approximately

when the ball and hands were moved passed the line of sight to bring the ball to the ready position. This procedure was operationalized as follows. The top marker on the goggles above the eye and the marker on the leg of the goggles (see Fig. 2) were used as an indication of the line of sight (LoS, defined by the orientation of the head, irrespective of eye movements). Algorithms were programmed that could detect when the marker on the ring finger passed this so defined LoS. This detection occurred during shooting on the basis of online movement registrations of the positions of these markers using OPTOTRAK. The duration of the processes to recognize the kinematic pattern of the three markers and to change the state of the goggles was build up in the following way.

1. Getting a new sample of OPTOTRAK data lasted 10 ms (sample frequency = 100 Hz).
2. Calculations of algorithms executed on one sample of OPTOTRAK data lasted 3 ms. Calculations were executed soft real-time by the PC. Variations in time sometimes occurred due to the spooling process of data to the hard disk of the PC or to activity of the Windows operating system as a result of which there was a delay of one sample. Therefore, this process could last between 3 and 20 ms. By registering and subtracting the sample number before and after each calculation it could be determined whether a delay of a sample had occurred. Sample number differences per calculation were displayed on the computer screen at trial termination. Almost always each of these calculations was finished within 10 ms, so without delay.
3. Physical delay of shutting or opening of the goggles lasted 1–3 ms.

This time chain resulted in a total latency period from 14–33 ms. In most cases the delay was below 20 ms which is faster than a standard PAL video field. Note that due to the physical dimensions of the ball (a diameter of 24 cm), it also takes some time for the entire ball to pass the LoS during shooting. Therefore, in almost all cases the state change of the goggles was finished within the natural boundaries of the task. The sample number in the OPTOTRAK registration at which the marker on the hand had passed the LoS was saved to the hard disk of the PC. As a result, the moment at which the hand marker passed the LoS could be computed in all four conditions, thus, also in the full-vision and no-vision conditions, when the goggles did not change state during a trial.

After the termination of a trial a graphical display of movement trajectories was visible on the PC monitor. The display also showed which coordinates of the markers on the goggles and the hand were used to change the state of the goggles.

2.6. Procedure

After the experiment was explained to the participant he gave his written informed consent. The OPTOTRAK markers and the LC glasses were then placed. Subsequently, the participant was given detailed instructions about how to execute the task. Each time, one of the experimenters indicated to the shooter when he could

start. This was also the moment that the OPTOTRAK registration started. After the signal from the experimenter the shooter started the task at his own pace and he executed the jump shot. Four seconds after initiation the registration ended. This registration period of four seconds had been shown in pilot testing to give the shooters more than enough time to execute the task without time pressure. After each throw, another experimenter retrieved the ball and returned it to the shooter for the next trial.

After all instructions were given the shooter took several practice shots with full vision to warm up and to get used to the equipment and cables. When the shooter indicated he was warmed up the experiment started with the practice trials of the first viewing condition. After each condition, there was a short break of 2–5 min. In the early- and no-vision conditions, when the shooters could not see the results of their shots, knowledge of results was provided verbally both with regard to whether it was a hit or a miss, and with regard to landing position (left/right and front/back of hoop).

2.7. Data reduction

As main dependent variable the numbers of hits and misses were registered in each condition. In addition, the final period durations (the period after ball and hands were moved passed the LoS until ball release) were computed. Ball release was obtained from the video recordings and the moment that the hand marker passed the LoS was retrieved from the OPTOTRAK data. The final periods were statistically tested using a one-within (viewing condition) repeated measures analyses of variance (ANOVA). Shooting percentages were first tested using a one-within (viewing condition) analysis of covariance with years of experience as a covariate. Subsequently, shooting percentages were tested using a similar ANOVA as with the final periods. Pairwise comparisons between different viewing conditions were made using the Bonferroni correction procedure when a significant main effect was found. The p -values that are reported on the basis of this Bonferroni method are scaled to the 0.05 alpha-level, so that, as usual, p -values smaller than 0.05 indicate a significant effect.

3. Results and discussion

3.1. Shooting style

Before proceeding with the final period durations and shooting percentages we determined whether the shooters indeed had a high shooting style. In Appendix A we present a method to estimate whether the shooters could see the basket from underneath the ball in the ready position (see Fig. 3). It appeared that seven of the ten shooters could look at the basket from underneath the ball in all four viewing conditions (see Table 1). These shooters clearly had a high shooting style. Two shooters, Shooters 2 and 4, could not look at the basket from underneath the ball, in neither of the viewing conditions (see Table 1). Because our main interest in this study was

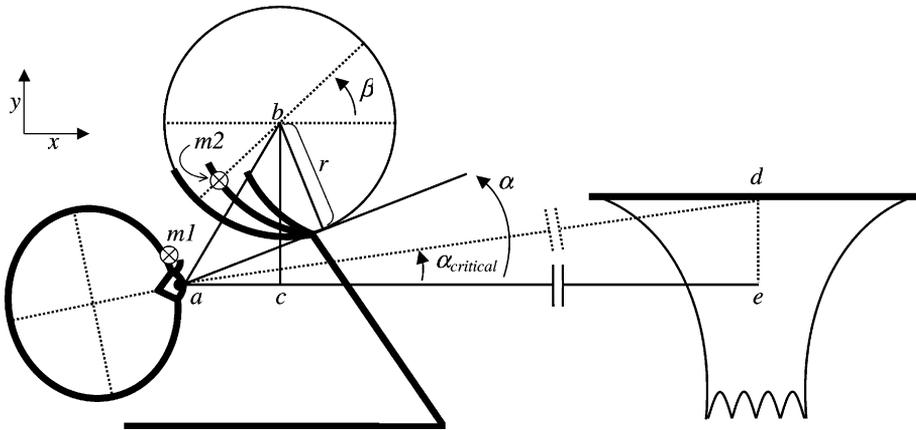


Fig. 3. Schematic display of positions in the ready position of the ball, the rim, the shooter's hand, head and eye. *m1* = marker on goggles; *m2* = marker on shooting hand; *a* = eye position; *b* = center of ball; *c* = point at intersection of horizontal line through *a* and vertical line through *b*; *d* = center of rim; *e* = point at intersection of horizontal line through *a* and vertical line through *d*; *r* = radius of ball (12 cm); α = angle of tangent line to ball through *a* with positive *x*-axis; $\alpha_{critical}$ = angle of line through *a* and *d* with positive *x*-axis; β = angle of line through *m2* and *b* with positive *x*-axis. α and $\alpha_{critical}$ can be calculated using the equations given in Appendix A.

Table 1
Values of $\alpha - \alpha_{critical}$ in degrees in the ready position

	Condition			
	No-vision	Early-vision	Late-vision	Full-vision
<i>Shooter</i>				
1	39.70	45.57	45.19	47.36
2	-34.20	-31.69	-27.36	-37.53
3	16.01	10.27	22.50	7.21
4	-5.77	-9.98	-5.64	-8.99
5	-8.26	-6.88	2.32	-7.01
6	34.82	32.31	32.39	33.89
7	41.20	34.36	36.45	34.40
8	43.73	51.33	54.39	41.38
9	21.61	19.61	16.37	17.65
10	21.15	12.48	15.57	4.92

Positive values indicate that the shooter could look underneath the ball at the basket when the ball was in the ready position. Negative values indicate that the shooter could not.

performance with a high shooting style, we excluded these shooters from the ANOVAs of the final period durations and the shooting percentages. However, as a comparison between the high and low style of shooting may be relevant to gain insight into visual control in aiming at a far target, an additional analysis of these two shooters in which they were compared with two high style shooters is provided later. Shooter 5 appeared to be a borderline case: while he could look underneath the ball

in the late-vision condition, he could not in the other conditions (see Table 1). Because we were interested in high shooting style performance, especially in the late-vision condition, we included him in the group analyses. As an aside, excluding him gave similar results with respect to shooting percentages and final period durations.

3.2. Final period durations

To determine how much viewing time shooters actually had when they had to rely on late viewing, we computed the durations of the final periods, that is, the periods between the moment that the hand marker passed the LoS (defined by the line through two top markers on the goggles) and the moment of ball release. As this also provided a second check on whether the shooters really used a high shooting style, this was done in all conditions. These durations, as well as the average durations per condition, are presented in Table 2. Looking at the average durations, a first observation is that with a high shooting style the final period duration lasted 300–400 ms.

Next, it can be seen that Shooters 2 and 4 (two bottom rows) stood out with durations of about 150 ms or less which is consistent with a low shooting style because with this style the ball is not elevated above the LoS before the final shooting movements unfold. It is during the final extension of the elbow that hand and ball passed the LoS just before ball release. Further analyses indicated that these final period durations were outliers as they were more than two standard deviations lower than the average durations. This confirmed that these shooters had to be excluded from the ANOVAs.

Most important, it can be noted that in the late-vision condition the average final period duration of the eight shooters with the high style appeared to be somewhat

Table 2
Individual and average final period durations in ms

	Condition							
	No-vision		Early-vision		Late-vision		Full-vision	
<i>Shooter (high style)</i>								
1	362	(18)	354	(22)	384	(26)	369	(27)
3	308	(28)	272	(22)	386	(37)	282	(31)
5	317	(19)	342	(15)	401	(18)	359	(13)
6	375	(15)	369	(16)	428	(14)	372	(13)
7	392	(26)	385	(25)	410	(25)	386	(44)
8	351	(17)	350	(18)	383	(18)	356	(16)
9	325	(21)	339	(19)	368	(17)	339	(16)
10	396	(15)	402	(18)	420	(16)	396	(14)
Mean	353		352		397		357	
S.D.	34		39		21		35	
<i>Shooter (low style)</i>								
2	107	(22)	136	(21)	136	(24)	118	(20)
4	125	(21)	152	(20)	149	(26)	128	(22)

S.D. per shooter are provided between parentheses.

longer compared the durations of the other viewing conditions. A one-within (viewing condition) ANOVA was carried out to determine whether these differences were significant. Because Mauchly's test indicated that the assumption of sphericity was violated, Mauchly's $W(5) = 0.12$, $p < 0.05$, the Huynh–Feldt corrected test is reported. There was a main effect of viewing condition, $F(2.1, 14.70) = 14.21$, $p < 0.001$, $\eta^2 = 0.67$, observed power = 0.995. Multiple pair-wise comparisons using the Bonferroni correction procedure revealed that the final period durations of the late-vision condition were indeed significantly longer than those of the other three viewing conditions, $t(7) = 4.91$, $t(7) = 4.13$, $t(7) = 3.95$ for no-vision, early-vision and full-vision, respectively, all $ps < 0.05$. This indicates that shooters extended the final period durations when needed.

3.3. Shooting percentages

In Table 3 the average shooting percentages for the eight high style shooters are presented. As the range of basketball experience of these eight shooters was rather large (9–24 years) a one-within (viewing condition) analysis of covariance was executed on the shooting percentages with years of experience as covariate, in order to check whether experience had affected the shooting percentages. Years of experience appeared to have no effect; for the main effect $F(1, 6) = 0.33$, $p = 0.58$, for the interaction with viewing condition $F(3, 18) = 1.58$, $p = 0.23$. Therefore, a one-within (viewing condition) ANOVA was then executed on these shooting percentages. It revealed a significant main effect of viewing condition, $F(3, 21) = 34.29$, $p < 0.001$, $\eta^2 = 0.83$, observed power = 1.00. Multiple pair-wise comparisons using the Bonferroni correction procedure revealed the following significant differences. No-vision performance was significantly worse than full-vision, $t(7) = 9.98$, $p < 0.001$, and late-vision, $t(7) = 6.67$, $p < 0.005$, performance. No-vision and early-vision performance did not differ significantly, $t(7) = 2.74$, $p = 0.17$. Furthermore, early-vision performance was significantly worse than full-vision, $t(7) = 5.45$, $p < 0.01$, and

Table 3
Individual and average shooting percentages for the different viewing conditions

	Condition			
	No-vision	Early-vision	Late-vision	Full-vision
<i>Shooter</i>				
1	32	24	44	56
3	8	20	44	52
5	0	24	52	56
6	16	40	80	64
7	20	44	64	64
8	32	52	64	60
9	4	0	72	64
10	28	36	64	76
Mean	17.5	30.0	60.5	61.5
S.D.	12.6	16.4	12.9	7.4

late-vision, $t(7) = 4.63$, $p < 0.05$, performance while late-vision and full-vision performance did not differ significantly, $t(7) = 0.28$, $p = 1$. Thus, with a high-style, shooting performance with late vision only, was just as good as with full vision, while early vision was equally detrimental to performance as no vision.

3.4. High versus low shooting style

Although Shooters 2 and 4 with the low shooting style had to be excluded from the previous analysis, their performance deserves separate attention. Shooters 2 and 4 are two very experienced and good shooters (20 and 14 years of experience at the highest level, and free throw percentages of 76 and 84, respectively). In Table 4 their shooting percentages are contrasted with those of two of the best shooters of the Netherlands over the past 15 years with similar experience (Shooters 6 and 9; 15 and 24 years of experience at the highest level, and free throw percentages of 88 and 86, respectively). As can be seen, the shooters with the low style performed well in the early-vision condition and relatively poor in the late-vision condition. In contrast, the shooters with the high style performed very well with late vision and very poor in the early-vision condition. Especially, the 80% performance of Shooter 6 (15 years experience) with late vision, that is, with on average only 428 ms visibility of the basket, and the 0% of Shooter 9 (24 years of experience) with early vision, that is, with on average only 339 ms occluded, stand out.

The number of hits in the late- and early-vision conditions, contrasted with respect to style (high or low), were tested using a χ^2 -test. The test confirmed that there were significant differences between conditions and styles, $\chi^2 = 17.89$, $p < 0.001$. Thus, what is striking is that expert shooters using a low style appeared to have developed a kind of visual control, early-looking combined with preprogrammed control of the shooting movements without final error correction, that fits well with their style. They performed well with early vision and poor with late vision. The latter was to be expected because the goggles only opened when they made their final shooting movements. But remember that in the ready position the ball and hands blocked

Table 4
Shooting percentages for Shooters 2, 4, 6 and 9 in the different viewing conditions

	Condition			
	No-vision	Early-vision	Late-vision	Full-vision
<i>Low style</i>				
Shooter 2	20	56	44	76
Shooter 4	12	68	28	60
Mean	16	62	36	68
<i>High style</i>				
Shooter 6	16	40	80	64
Shooter 9	4	0	72	64
Mean	10	40	76	64

their view to the basket (see Appendix A). The expert shooters with the high style also appeared to have developed a kind of visual control appropriate for their shooting style, with late viewing and final-error-correction movement control. They performed poor with early vision and well with late vision, which gave them only the last 400 ms before ball release to look at the hoop.

4. General discussion

The goal of this study was to find out whether late vision would provide sufficient and necessary viewing time for basketball players with a high shooting style to visually control taking jump shots. This appeared to be the case for the eight shooters who were identified to have a high shooting style. Shooting percentages with late vision only, were just as high as those with full vision, while early-vision performance was severely impaired. That the shooters had high percentages with late vision only, must mean that they used relevant visual information during the brief period that the goggles were open. Thus, contrary to what the findings of Vickers (1996a, 1996b) would imply for players with a low shooting style, having early vision did not result in good performance for the high style shooters in the present study. In contrast, when these shooters were given vision late a good shooting performance followed. That this difference between our findings and those of Vickers (1996a, 1996b) seems to be the result of different shooting styles, rather than, for instance, a difference in task (free throw versus jump shot) or gender, is supported by the comparison of the two high style and low style shooters in the present study (Table 4). Apparently, shooting style (co-)determines what type of visual control is optimal. It seems that shooting style and visual control develop in close correspondence.

Before discussing the implications of our results, an alternative explanation must be considered. A side effect of our viewing manipulations was that in the late- and full-vision conditions visual feedback about the entire ball trajectory was available (the goggles were open), whereas it was not in the early and no-vision conditions (the goggles remained shut until after the ball had landed). This could have been a crucial factor in impairing shooting performance in the latter two conditions. However, the plausibility of this explanation can be disputed on the basis of at least three accounts. First, if visual flight feedback or a lack thereof would account for the performance differences over conditions visual feedback would also be expected to affect the shooting performance of the shooters with the low style in a similar manner. This was not the case (see Table 4). Second, with a lack of visual feedback in the early- and no-vision conditions one would expect that performance in these conditions would gradually deteriorate. However, an additional ANOVA comparing the shooting percentages of the first 12 with the last 13 shots in each condition, did not reveal any significant differences between these shots, $F_s < 1$, ns. Third, research in the 1970s by Newell (1973, 1975) showed that in learning a projectile task visual flight feedback (seeing the ball trajectory) “provides redundant information for response selection on the next trial when KR (knowledge of results) is available” (1975, p. 241). In addition, Henderson (1975) found support for the notion that skilled ath-

letes often “know” where a shot or throw has landed without visual feedback. Finally, Jagacinski, Newell, and Isaac (1979) did not find consistent decreases in basketball shooting performance without visual feedback of the flight of the ball. For those participants whose performance was impaired when they shot without visual flight feedback, a drop of about 10% was observed, while in our early- and no-vision conditions decreases of no less than 30% and 40% were found, respectively. Together these arguments and findings make it unlikely that our results are due to a difference in visual flight feedback between conditions.

4.1. Open-loop versus closed-loop control

Just as for aiming at near targets (Abrams et al., 1990; Elliott et al., 1999), an important question concerning the motor control of aiming at far targets is whether open-loop or closed-loop processes are involved (Vickers, 1996a). The results by Vickers (1996a) provided indirect support for the idea that shooting movements of a free throw are controlled via open-loop rather than closed-loop processes. Ripoll et al. (1986) also concluded for jump shooting that movements are preprogrammed and that the motor program proceeds “in an automatic fashion, without requiring any more visual and head stabilization during the throwing action itself (execution phase)” (p. 57). Ripoll et al. reported that the execution phase of the experts lasted 310 ms on average. The shooting phase Vickers (1996a) reported even lasted 476 ms on average for the experts. Ignoring, for now, the large difference in shooting duration between the two studies, it must be concluded on the basis of our results that online processing of visual information must have been necessary for late-vision shooting with the high style. Recall that on average the late-vision condition provided the shooters with only the final 400 ms of viewing before ball release, which implies that the shooters must have been detecting visual information for the control of the final shooting movements when these movements were already unfolding. The shooters even actively extended the final period duration (with approximately 50 ms) probably to ensure that enough information could be obtained. This active adaptation, which must have had consequences for the precise sequence of movements, demonstrates the flexibility of movement execution, yet another indication of closed-loop control including final error corrections.

There is one catch, however. In the study of Ripoll et al. (1986) it is unclear how exactly the shooting phase is defined. It begins with the propulsion movement of the arms, but this leaves open several options. Is that when the first upward movement of the ball is initiated (close to the situation depicted by the left stick figure in Fig. 2) or is that when the final extension of the elbow is initiated (closer to the right stick figure in Fig. 2)? In the study by Vickers (1996a) the shot phase begins with the first upward movement of the ball (thus, close to the situation as depicted in the left stick figure of Fig. 2). As described in Section 1, with the high style the upward movement, which brings the ball passed the line of sight above the head can be clearly distinguished from the final extension movement of the elbow, and the flexion movements of wrist and fingers. Unfortunately, the literature on basketball shooting stays mute on how long these final extension and flexion movements last (e.g., Elliott, 1992;

Elliott & White, 1989; Miller & Bartlett, 1993, 1996; Penrose & Blanksby, 1976). The final period durations of the two low style shooters provides us with an estimate of the duration of the final shooting movements, as their goggles switched when the final extension movements had just started. This would mean that the final extension movements lasted between 120 and 150 ms, which corresponds with the final extension movement of the dart throw that is also reported to last about 150 ms (Vickers et al., 2000). Even then it remains questionable whether open-loop control would have been possible within the very brief time span of the late-vision condition (about 400 ms). After occlusion the shooters must have needed minimally 100 ms (Carpenter, 1977; Kowler, 1990) to orient their gaze to the basket. Then, another 135 ms would at least have been necessary to use any information that was detected to control subsequent movements (Carlton, 1981; Elliott et al., 1999). This would leave less than 165 ms for the visual control of the final shooting movements. If we take these movements to last about 150 ms, this would leave only 15 ms to preprogram all parameters, a highly unlikely course of affairs. It is still more likely that online processing of visual information was used to make corrections to the final movements until ball release.

One of the findings by Vickers (1996a,b) that provided support for the hypothesis that open-loop control was used in the free throw was that vision was suppressed during the shooting phase. One of the questions posed by Vickers (1996a) was whether the location-suppression mechanisms also occur in other far aiming tasks. Although the study by Williams et al. (2002) provided support for early fixation on the target in playing billiards, it showed that suppression of vision did not occur in this task. The present results confirm that suppression of vision does not seem to occur when the target remains visible. The shooting performance in the late-vision condition could not have been as good when vision would have been suppressed during the time the goggles were open. What remains to be seen is whether an absence of suppression of vision during aiming when the target remains visible is also always indicative of closed-loop movement control including final error correction. Despite the absence of suppression in billiards, Williams et al. (2002) conclude that the quiet eye periods they found reflect a critical period of cognitive processing during which the parameters of movement such as force, direction, and velocity are fine-tuned and programmed. As must be clear by now, our results leave open the possibility of a continuous detection and use of visual information during the final shooting movements. Further research to test this hypothesis more precisely must be executed in the future. This research would necessarily include a detailed analysis of the kinematics of the final shooting movements (especially the final elbow extension and flexion of wrist and fingers) or of release parameters of the ball, to find out whether final error corrections actually occur (e.g., Dupuy, Mottet, & Ripoll, 2000; Elliott et al., 1999; Kudo, Tsutsui, Ishikura, Ito, & Yamamoto, 2000).

4.2. Quiet eye duration versus optimal timing of looking at the target

Our results also provide an answer to Vickers' (1996a) question whether quiet eye duration is critical in all far aiming tasks. Although it is a relatively consistent finding

that quiet eye duration is longer for successful than unsuccessful shots or throws for various aiming tasks (Janelle et al., 2000; Vickers et al., 2000; Williams et al., 2002), the present results suggest this does not always have to be the case. The viewing durations in the late-vision condition (350–450 ms) that were sufficient for successful shooting were just as long as the “not-sufficient” quiet eye durations (300–400 ms) of the near-experts tested by Vickers (1996a). This implies that when the target is visible when the final movements are unfolding, quiet eye duration is not always critical. It may be critical when movements are preprogrammed rather than when movements are controlled using online information detection. In fact, there is some reason to believe that optimal quiet eye duration is very much task dependent given the different quiet eye durations found for different tasks (Janelle et al., 2000; Vickers, 1996a; Vickers et al., 2000; Williams et al., 2002). The present results imply that the timing (relative to movement execution) of looking at the target rather than quiet eye duration may be critical for optimal aiming, a suggestion that is corroborated by the findings with respect to dart throwing (Vickers et al., 2000). Our results show that vision during the final shooting movements is necessary with the high style, while it is not with the low style, which requires early looking. Thus, the relative timing of looking at the target (when to look) may sometimes be more important in aiming at a far target than the duration of looking.

4.3. *Task differences*

In contrast to the existing literature on visual search we may carefully conclude that when vision is allowed, seeing the target briefly before and until ball release is sufficient as well as necessary for accurate aiming at a far target in a dynamic aiming task such as basketball jump shooting. Recall that most visual search studies into far aiming tasks tested stationary tasks such as golf putting (Vickers, 1992), dart throwing (Vickers et al., 2000), rifle shooting (Janelle et al., 2000), and billiards (Williams et al., 2002) in which aiming and the execution of the aiming task are done from a stable position. In such tasks preprogramming is more likely to be possible due to the relative lack of time constraints, but also as a result of a stable frame of reference for the execution of the task. Ripoll et al. (1986) already showed that eye–head stabilization toward the target is even more critical when the body is moving (as in the jump shot) than when there is more postural stability (as in the free throw). During the jump shot it is only at and around the peak of the jump that relatively the most stable frame of reference exists as velocity in the vertical direction is almost zero (see also Elliott & White, 1989). It is also during this brief period that ball release in the basketball jump shot by expert shooters is often reported to occur (from approximately 0.08 s before to 0.04 s after ball release; Elliott, 1992; Miller & Bartlett, 1993; Penrose & Blanksby, 1976; see also Knudson, 1993). It is possible that shooters with the high style make use of this relatively stable frame of reference in the midst of motion by virtue of the detection and use of visual information until ball release.

A difference between the low and high style of shooting that might prove important for theories of visual information processing is the following. With the low style control of shooting seems to be preprogrammed on the basis of seeing the target

early, with release of the ball taking place some time after having seen the target, that is, after a certain delay (e.g., Vickers, 1996a). With the high style there is no delay between seeing the target and controlling the movements. This difference resembles the distinction made by Rossetti (2000) and Rossetti and Pisella (2002) in visual control of near aiming tasks on the basis of two different streams of visual information processing in the central nervous system, the ventral and the dorsal stream. There is now considerable evidence that these two anatomically distinct streams also serve quite different functions, with the dorsal stream being mainly “concerned with acting on the world” and the ventral stream “with representing it” (e.g., Milner & Goodale, 1995, p. 1). In near aiming and pointing tasks it appears that when actions are briefly delayed after target presentation ventral stream processing comes into play whereas it does not when actions are immediate (see Rossetti, 2000; Rossetti & Pisella, 2002). This suggests in a very speculative vein that there might be parallels between the visual and motor control of the high and low shooting styles and the dissociation between the dorsal and ventral stream for information processing that has recently become a hot topic in psychology (e.g., Michaels, 2000), neuroscience (Milner & Goodale, 1995; Rossetti, 2000) and sport science (Keil, Holmes, Bennett, Davids, & Smith, 2000; Williams et al., 1999). Future research should clarify whether the differences in visual and motor control in jump shooting and perhaps other far aiming tasks are indeed manifestations of differences in dorsal and ventral stream processing of target information. This could provide valuable insights into the interactions between the dorsal and the ventral stream in healthy humans (see Rossetti, 2000).

4.4. Practical implications

The finding that with the high style late viewing is sufficient and necessary for good shooting has at least two practical advantages. First, and already mentioned, online processing, also found in aiming at near targets (Abrams et al., 1990; Elliott et al., 1999; Starkes, Helsen, & Elliott, 2002), is still possible. This would be an advantage in the game of basketball as it allows for adjustments of the movements to the very fast changing circumstances (e.g., a blocking defender) up until the final instances before ball release. Thus, as looking late seems to provide a sufficient basis for accurate shooting with the high style one may attend to other relevant aspects of the developing play until the final shooting movements unfold. Second, it allows for a higher point of release (Hamilton & Reinschmidt, 1997) guaranteeing a more optimal release angle (Hudson, 1985; Rojas, Cepero, Oña, & Gutierrez, 2000). This also makes it easier to shoot over an opponent (Rojas et al., 2000).

In addition to these advantages of the high shooting style, our results may provide a starting point for improving shooting performance using visual attention training. In sport science, visual attention training is currently a hot topic (for reviews see Abernethy et al., 1998; and Williams & Grant, 1999). It appears that *generalized* visual training programs do not help very much in improving sports performance (Abernethy, 1996; Abernethy et al., 1998; Abernethy & Wood, 2001; Wood & Abernethy, 1997). It is not the visual “hardware” (Williams & Grant, 1999), referring to the visual system and its general functioning that leads to differences in sports

performance. However, advantages are to be gained, so it seems, from sport specific training of the visual “software” (Williams & Grant, 1999), referring to the pick-up and processing of task- and situation-specific information that may guide an athlete’s actions. Unfortunately, most research was done in laboratory settings using film displays. Only two perceptual training studies (of the 10 mentioned by Williams & Grant, 1999) tested in on-court situations (Adolphe, Vickers, & Laplante, 1997; Vickers & Adolphe, 1997). Adolphe et al. (1997) perceptually trained the serve reception of expert volleyball players with non-optimal looking behavior in a task- and situation-specific way. Both looking behavior and serve reception improved, suggesting that there is a potential gain in visual attention training. Similarly, Harle and Vickers (1993) trained quiet eye in the basketball free throw, and found some indication that training quiet eye is possible and that it improves accuracy of free throw shooting.

In most sports, practice is often mainly directed at endurance training, learning movement techniques and game tactics. Visual attention and the pick-up of relevant information are rarely addressed (for exceptions see Williams et al., 1999). In basketball jump shooting, visual attention training might prove beneficial by forcing shooters with a high style to attend to the hoop during the final instances before ball release (late viewing). This could be achieved by having players shoot from behind a screen so that the hoop is only visible during the jump. Or, when available, one could use LC goggles. Especially, when remotely controlled by the coach these could be helpful in visual attention training in field settings (Abernethy, 1996; Starkes et al., 1995).

Appendix A. High and low shooting style

To distinguish a high from a low shooting style, we analyzed the jump shot in the ‘ready position’ (Penrose & Blanksby, 1976) after take off and prior to the final propulsion phase of the shot. The shooting style was considered to be high when the participant could see the rim in the ready position and low when he could not. We made the assumption that the center of the rim, the center of the ball, and the eyes were in the same sagittal plane. In this plane, we constructed the tangent line to the ball through the eyes and defined α as the angle of this line with the positive x -axis. Moreover, we defined α_{critical} as the angle of the line through the eyes and the center of the rim with the positive x -axis. Note that when α is smaller than or equal to α_{critical} , the subject cannot see the rim from under the ball in the ready position.

Fig. 3 displays the relevant parameters for the calculation of α and α_{critical} in the ready position. The eyes (a) were positioned approximately 1.5 cm under one of the markers on the goggles ($m1$). The horizontal and vertical positions of the center of the rim (d) relative the origin of the coordinate frame were 5 and 3.05 m, respectively. From the positions of a and d , α_{critical} could be calculated as $\alpha_{\text{critical}} = \tan(de/ae)$ (see Fig. 3). The position of the balls’ center (b) was approximated by translating the marker on the shooting hand ($m2$) over 8 cm at an angle (β) of 45° with the positive x -axis. Visual inspection of the video recordings

confirmed that this was a realistic approximation in all shooters. From the positions of a and b , α could be calculated as $\alpha = \arccos(ac/ab) - \arcsin(r/ab)$ (see Fig. 3).

The value of $\alpha - \alpha_{\text{critical}}$ determined whether a high or a low shooting style was used. A positive value indicates that the rim was not occluded by the ball in the ready position, and thus, that a high shooting style was used. A negative value indicates that the rim was occluded by the ball in the ready position and, consequently, that a low shooting style was used. Values of $\alpha - \alpha_{\text{critical}}$ are given in Table 1.

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