:: Visual perception for basketball shooting

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The work presented in this thesis is part of the research programme of the Institute for Fundamental and Clinical Human Movement Sciences, and was carried out at the Faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands.

To Rolf and Dinant

ISBN: 978-90-9022139-7
Author and date: R.F. de Oliveira, 2007
Design and layout: Rui Pedro Henrique : rui.henrique@gmail.com
Printer: Ipskamp, Amsterdam

VRIJE UNIVERSITEIT

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ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad Doctor aan
de Vrije Universiteit Amsterdam,
op gezag van de rector magnificus
prof.dr. L.M. Bouter,
in het openbaar te verdedigen
ten overstaan van de promotiecommissie
van de faculteit der Bewegingswetenschappen
op maandag 29 oktober 2007 om 10.45 uur
in de aula van de universiteit,
De Boelelaan 1105

door
Rita Manuela Ferraz de Oliveira
geboren te Torres Novas, Portugal

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Copromotor: dr. R.R.D. Oudejans

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01 : Prolegomenon

:: Introduction

Vision is one of the six sensory systems that we use to know and interact with our environment but has been singled out as the most important form of exteroception for motor control. The reason for this implicit upgrade is probably that many human actions are directed at objects or targets beyond our immediate physical contact. The only link between these objects and us is the pattern of light reflected from their surfaces, and yet we identify and act upon them with great ease. No doubt humans make significant strides in establishing appropriate relations between perceptions and actions at early stages of their development. When my nephew Rodrigo was three months old it took him considerable perseverance and a lot of jerky movements to finally grasp the toy my mother was patiently holding and rambling. But once the relations between perceptions and actions are better established, humans can be incredibly skilful at interacting with distant objects even when the constraints imposed on the interaction are severe and a high degree of precision is required. Like many other sportive tasks, basketball shooting is characterised by tight temporal constraints, limited spatial variation, and high accuracy demands. How basketball players manage to consistently throw a ball through the basket, even if severely challenged by their opponents, is a remarkable feat that has occupied scientists for years, and the present work is but another step in understanding the intricate relations between visual perception and action in such a context where few errors are allowed and few are made.

The research reported in the present thesis was conducted to uncover the visual basis of basketball shooting. Basketball shooting consists of throwing a ball on a parabolic flight that passes through a metal rim twice the size of the ball at three metres height. Common shooting types are the free throw and the jump shot. Free throws are taken in less than 10 s from the 4.6 m line without opposition. Jump shots can be taken from anywhere in the field, usually in the presence of opponents, and imply that the ball is released while the player is airborne. Conventional knowledge stipulates that players must see the basket before they shoot. Straightforward as this statement may seem, it can be incorrect in two ways. First, it is not granted that vision is required before the shot, as opposed to during the shot. While vision gathered before the movement may be useful, it may also be insufficient or unnecessary for accurate shooting. This temporal aspect is relevant because it gives insight into the timely interaction between visual perception and action. Second, it is not certain that the player must actually see the basket, as opposed to merely looking at it. The location of the target may be perceived through various information sources, not necessarily retinal ones. This spatial aspect is relevant because it gives insight into the optical basis of goal-directed movement. In what follows we describe in more detail what these temporal and spatial aspects of visual perception and action consist of, backed up with relevant literature. Next, we briefly review the available literature on the visual perception of basketball shooting and introduce six experiments in which the temporal and spatial aspects of basketball shooting are investigated.

:: Temporal aspects of visual perception and action

One of the most intensive debates in the study of the visual control of action is whether visual information is used primarily for the planning of goal-directed movements or for the online guidance of such movements. At the base of this controversy are important philosophical and methodological differences (Abernethy & Sparrow, 1992; Williams, Davids, & Williams, 1999). Nevertheless, the theoretical arguments and experimental results that are put forward in support of either view are often appropriate, even though they are sometimes applicable only to a subset of actions. We start by presenting the arguments for the offline use of visual information, followed by the arguments for the online use of visual information. Next we discuss the timing of visual information pick-up, or in other words, whether there is a moment relative to a given action when picking up visual information is preferred, sufficient, or optimal.

:. Offline use of visual information for the control of action

Several authors have argued that many movements are controlled on the basis of visual information gathered before movement initiation. Broadly speaking, three arguments have been advanced for the offline use of visual information in the control of action. The first argument is that visuomotor delays sometimes exceed the duration of the movement, which would render online corrections of the trajectory impossible. The visuomotor delay is the duration it takes for visual information to be used in motor control. Although it is a physiological latency period in the sense that stimulation must travel from the sensory system to the musculoskeletal system, it has mostly been measured in terms of changes to the movement kinematics in near aiming movements. Over time, improved techniques and accumulated research led to estimations of visuomotor delays as short as 80 ms, with the precise value depending on several factors including the type of task, the type of error correction, and the experience of the participant (Carlton, 1992). For example, a pointing movement involving an elbow extension that is executed at maximal velocity over 100° degrees on the horizontal plane, would last approximately 130 ms (Kistemaker, van Soest, & Bobbert, 2006). Supposedly, in fast movements such as this, visual feedback plays a minimal role, implying that the movement is largely guided by visual information gathered before its initiation. Recent theoretical developments that qualify this argument (Desmurget & Grafton, 2000) will be discussed in the Epilogue of this thesis.

The second argument is that in order to plan the parameters of movement execution, long fixations on the target would be required before movement initiation. This is a consistent finding in the literature. Longer target fixations are found in more complex tasks, and have been associated with higher levels of expertise and more accurate performance (Janelle et al., 2000; Vickers, 1996; Williams, Singer, & Frehlich, 2002), although badminton seems to be an exception (Abernethy & Russell, 1987). Invariably, these authors surmise that the amount of time spent in looking at an object or target reflects the duration and accuracy of movement parameterisation. If the movement is to be planned in part or in total before its initiation, then it seems crucial to have enough time available to pick up advance visual information.

The third argument is that movement production and performance are largely similar when full vision is available during execution compared to when vision is eliminated. A movement executed in total darkness will exhibit the same characteristic kinematic features as in good lighting conditions such that it can be identified as a kick, a punch, or a throw. Also, its endpoint will likely be in the vicinity of the target, thus in many tasks visual information pick-up during execution has been considered an advantage rather than a necessity (Williams et al., 1999). In this connection, authors have argued that through practice performers may become less dependent on the use of online visual information (but see Proteau, 1992), either because the need to make corrections during movement execution is reduced (Schmidt & Lee, 1988), or because reliance on other sources of sensory information is increased (Bennett & Davids, 1995; Davids, Palmer, & Savelsbergh, 1989; Fleishman & Rich, 1963).

:. Online use of visual information for the control of action

Another group of authors have argued that movements are controlled on the basis of visual feedback during movement execution. In general, four arguments have been used for the online use of visual information in the regulation of action. The first argument is that in the absence of vision performance always deteriorates to some extent. Visual occlusion during movement execution has been demonstrated to have detrimental effects in a broad variety of actions. One reason is that, under such circumstances, corrective adjustments to the ongoing trajectory cannot be effectuated on the basis of updated visual information about the target and the limb. The consequence is increased endpoint variability and error in both near and far aiming tasks (Khan et al., 2006; Oudejans, van de Langenberg, & Hutter, 2002; Westwood, Heath, & Roy, 2003). Another reason for the decline of performance due to the removal of online visual information is the resulting increase in sway reflecting worse postural control and balance (Blanchard et al., 2007; Robertson, Tremblay, Anson, & Elliott, 2002; Sullivan & Hooper, 2005).

The second argument is that movement itself generates information, which amounts to saying that perception and action are functionally coupled in the attainment of a particular goal. Constancies in the relation between movement and perception, for instance the fact that the eyes converge more when looking at a closer object, are reliable information sources that can guide movement (Gibson, 1979/1986). In learning to move in a particular setting, children engage in exploratory behaviour revealing persisting and changing characteristics of the environment and objects therein (Adolphe, 1995; Mark, Jiang, King, & Paasche, 1999). Later, performers may exploit the learned links between perception and action to successfully perform challenging tasks like crossing a street or running to catch a fly ball (Michaels & Oudejans, 1992; Oudejans, Michaels, Bakker, & Davids, 1999; Oudejans, Michaels, van Dort, & Frissen, 1996). In tasks where perception and action are functionally coupled in real time, online vision may be the only means to attain the goal because, in part, the relevant visual information is brought about through movement (e.g., Bootsma & van Wieringen, 1990; Lee, Lishman, & Thomson, 1982).

A related argument is that in more dynamic tasks and situations events occur in real time, thus relevant information appears on the fly. Also, the relations between performer and object may change unpredictably, implying that actions need to be constantly adjusted to comply with novel or more precise information. For instance in driving, or sailing, new and more detailed visual information is constantly appearing and needs to be acted upon, and the same holds for running over rough terrain or when negotiating obstacles while walking (Patla & Greig, 2006; Reynolds & Day, 2005). Likewise, in shooting a basketball while being airborne, updated visual information is necessary for the guidance of actions because the relative positions between performer and target are changing continuously (Oudejans et al., 2002).

The fourth argument is that better spatial and temporal accuracy is achieved towards the end of goal-directed actions (e.g., Lee et al., 1982; Lee, Young, & Rewt, 1992). As we will see next, this may have several reasons. Some information sources, for instance binocular disparity, become more precise as the target object and the observer approach each other (Cutting & Vishton, 1995). In addition, towards the end of the movement, performers may resort to different sources of visual information than those that are used in performing the initial portion of the movement (Caljouw, van der Kamp, & Savelsbergh, 2004). Thus later, rather than earlier, information sources may be more specific to the temporal and spatial demands of the task (Bootsma & Wieringen, 1990; Caljouw et al., 2004). Also, because information is conveyed over time it is likely that accuracy improves as the performer takes the time to perceive the event, aspects of the object or layout (Gibson, 1979/1986). For these reasons, visual information towards the end of the movement may have increased informational value for the accuracy of goal-directed actions, especially in a dynamic environment.

In conclusion, it seems that both offline and online visual information is used in the control of complex, goal-directed movements but their relative contribution may depend on characteristics of both task and performer. While visual information gathered before movement initiation can be used to direct actions with relative accuracy, online visual information permits corrections or adaptations in more dynamic environments with marked consequences for endpoint accuracy.

:. Timing of optical information pick-up

Many studies of the temporal aspects of visual information pick-up have focused on either of two aspects. The first is the duration of visuomotor delays that we referred to earlier. The second is the minimal duration of information pick-up, or in other words, the amount of time necessary for object and environmental features to be perceived. Results on these topics are variable because both durations depend on characteristics of the performer as well as the task, but visuomotor delays of 80 ms and minimal pick-up durations of 100 ms have been reported in literature (Carlton, 1992). A related temporal aspect of optical information pick-up that has received far less research attention is the timing during an action when visual information would be most useful. For instance in catching a ball, it appears that certain portions of the ball flight are more informative than others. Thus, if one would be allowed to view only 200 ms of its flight, catching performance would depend on its timing relative to the catch. Viewing the ball very early in the ball's flight would require the prediction of the remaining trajectory, whereas placing it at the very end of the flight would mean that part of that information could no longer be used for movement control because of the visuomotor delay. Previous research has shown that visual information about the ball picked up closer to the moment of catching results in improved accuracy (Sharp & Whiting, 1974; Whiting, Gill, & Stephenson, 1970). However, in this research, the timing and the amount of viewing time varied together making it impossible to draw conclusions regarding each in isolation.

In table tennis, Ripoll and Fleurance (1988) found that expert players stabilise head and eyes on an intermediate location between the point of bounce and the point of contact with the ball, that is, relatively late during the hitting movement. In cricket batting participants follow the ball after it bounces almost until the moment of contact, that is, well into the batting movement (Land & McLeod, 2000). A late timing of optical information pick-up also seems to be advantageous in the control of the lower limbs. For instance, seeing the final portion of the ball flight has been found to be useful in controlling a soccer ball (Williams & Weigelt, 2002), looking only two steps ahead is sufficient to land the feet on targets along the travel path (Patla & Vickers, 2003), and late optical information is used in regulating the footfalls to a given demarcation point such as the take-off board in the long jump (Lee et al., 1982). During the approach phase the variability of footfalls relative to the take-off board reduces drastically during the last four steps prior to actually hitting the board.

This well-established finding, which holds for jumpers of all skill levels, demonstrates that the visual control in goal-directed locomotion emerges late and continues until the end of the action (Berg, Wade, & Greer, 1994; Hay, 1988; Scott, Li, & Davids, 1997). An interesting discussion point raised by Lee et al. (1982) is what visual information guides the regulation of gait for a successful positioning of the jumping foot relative to the take-off board. The same type of question can be asked with respect to many other tasks because, evidently, different sources of visual information are used in the control of different actions.

:: Spatial aspects of visual perception and action

The question of what visual information sources underlie the control of actions has been strongly inspired by the work of Gibson (1979/1986). His radical theory of visual perception draws heavily on the notion that the requisite information is available in the ambient optic array, and is detailed enough to guide action (Gibson; Warren & Fajen, 2004). Several information sources have been identified pertaining to object properties, the layout of the environment, and observer characteristics.

To perceive the layout of the environment and the depth and size of objects therein, one can use sources of visual information like eye convergence, accommodation, binocular disparity, motion perspective, height in the visual field, relative size, relative density, and occlusion (Cutting & Vishton, 1995; Ono & Wade, 2005). Some of these sources of visual information vary together and are only useful within a limited range of distances. Observers use different sources of information for objects at different distances and may resort to alternative sources depending on the prevailing constraints. The richness of information and the flexibility in its use is a great asset for observers, as it allows them to obtain the required information to perform a particular perceptual or perceptuomotor task. However, for researchers of perception, it poses formidable methodological challenges because the wealth of information sources available for judging, perceiving and acting upon objects demands meticulous control of the sources available. Nevertheless, important strides have been made to examine the contribution of many sources.

In reviewing the role of binocular eye movements for depth perception, Collewijn and Erkelens (1990) concluded that eye vergence is informative only for objects within reach, while disparity, which controls vergence, can be used to perceive objects within 3 m. In testing the relative contribution of changing size and changing disparity in the perception of object motion in depth it was found that task characteristics influence their relative effectiveness. For example, slow objects viewed for brief periods of time seemed to be judged on the basis of their changing size, whereas for fast objects viewed for a longer duration stereopsis prevailed (Regan, Beverley, & Cynader, 1979). Also noteworthy is that these effects were accompanied by large interpersonal differences. The use of binocular parallax and motion parallax have been investigated in walking yielding poor results at distances between 1 and 5 m when another information variable, angular elevation, was available (Philbeck & Loomis, 1997). Generalisations over different tasks and observers need to be made with caution because the environment is so rich in information sources and because observers are so resourceful in using alternative ones.

When an observer looks at an approaching object in the optic flow field, the image of the object expands continuously until the moment of contact, thus the optical looming pattern can inform about the time it will take for contact to occur between the object and the observer. Time-to-contact has been defined as the inverse of the expansion rate of the retinal image (or a closed optical contour), and is known as the optical variable tau (Lee, 1976). Though tau has been investigated predominantly in the control of catching (Caljouw et al., 2004; Tresilian, 1993), variants thereof have been examined in the control of braking, the timing of landing a somersault, and the regulation of the approach for the long jump discussed earlier (Goodman & Liebermann, 1992; Lee, 1976; Lee et al., 1982, 1992). Time-to-contact is one of the few attempts to identify and formalise an optical variable that can be used in the control of action and perhaps therefore has triggered a wealth of research. Other optical variables and information sources have been identified, although their corresponding laws of control have not been identified, nor, for that matter, has their usage been systematically proven.

As an observer moves about the environment, the optic flow field, that is, the pattern of motion visible at the eye, can also inform about motion and immobility, direction of heading, and steering (Gibson, 1979/1986). Following Gibson, several researchers have tested the use of optic flow in the guidance of heading, steering, and walking, postural control and the perception of layout (Domini & Caudek, 2003; Wann & Land, 2000; Wann & Swapp, 2000; Warren, Kay, & Yilmaz, 1996; Warren, Kay, Zosh, Duchon,

& Sahuc, 2001; Wilkie & Wann, 2002, 2005; Wu, He, & Ooi, 2005). Another optical variable that has been brought to the fore is the optical acceleration of the tangent of a projectile's elevation angle. Variables related to the optical acceleration of a fly ball have been shown to guide timely locomotion to the place of interception (Chapman, 1968; McBeath, Shaffer, & Kaiser, 1995). Importantly, this source of information can be picked up through visual kinesthesis as well as proprioception as the observer directs his or her gaze and visually tracks the ball (Oudejans et al., 1999).

One premise that underlies the identification of viable information sources (as well as the corresponding laws of control) is the specificity of visual information in relation to perception and action. It maintains that a single optical variable exists that directly relates to the to-be-perceived property and the to-be-performed action (Michaels & Carello, 1981). As explained above, the optical variable tau specifies time-to-contact, optic flow the direction of motion, and optical acceleration the location of interception with a fly ball. However, the premise of a one-to-one mapping between informational variable and action has received much empirical opposition by authors proposing the use of more than one variable to guide a given action. It has been shown that when two information sources specify the same property, accuracy is not improved by the availability of both. However, when they are incongruent with each other perceptual accuracy diminishes in proportion to their incongruence (Kim & Grocki, 2006). Likewise, authors have suggested the use of information sources that do not specify the appropriate actions per se but instead require given constancies in the environment to be taken into account. An obvious environmental constancy is gravity which may be exploited in perceiving limb orientation (Cohen & Welch, 1992; van de Langenberg, Kingma, & Beek, 2007). Other environmental constancies can be taken into account in particular tasks. For instance, as the observer directs the line of sight to a target on the floor, the viewing angle informs about the direction of the target. It is the knowledge, or assumption, that the target lays on the floor that allows angular declination to be informative about distance (Ooi, Wu, & He, 2001; Philbeck & Loomis, 1997). Perceptions and actions are also calibrated to observer characteristics like body size or eye-height that inform about which actions are possible and which are not (Mark, 1987; Warren & Whang, 1987). In conclusion, the spatial aspects of the environment and objects can be perceived and acted upon through the use of adequate visual information sources. Such variables may be used independently, combined with other sources of information, or calibrated to stable properties of the environment and observer.

:: The visual control of basketball shooting

After having reviewed a selected part of the vast literature on the temporal and spatial aspects of visual perception and action, we now briefly review the available studies on the visual control of basketball shooting and introduce subsequent chapters.

:. **Review of the visual control in basketball shooting**

Previous research on the visual control of basketball shooting suggests that eye and head stabilisation relative to the target are crucial for successful performance in the free throw and jump shot alike (Ripoll, Bard, & Paillard, 1986). In addition, although visual acuity does not seem to be a necessary asset for performance (Applegate & Applegate, 1992), expert shooters fixate relatively long on the target before initiating the free throw (Vickers, 1996). This long fixation has been interpreted as evidence for movement programming, thus the free throw was considered to be mostly preprogrammed and subsequently executed in an open-loop fashion. However, critics charged that this interpretation would be invalid in more dynamic instances, namely in jump shooting or when the shooting kinematics allow vision of the target during movement execution (Oudejans et al., 2002). In support of this assertion, it was demonstrated that seeing the target only during the final shooting movements provided enough information for accurate jump shooting. [As an aside, the kinematics of the arms in basketball shooting determines whether or not the basket is visible during the last elbow extension. If the propulsion hand remains below the line of sight, the target is occluded by hands and ball during the last elbow extension. This is a low (hand) shooting style used by participants in the study of Vickers. If the propulsion hand rises above the line of sight, the target is visible during the last elbow extension. This is a high (hand) shooting style used by participants in the study of Oudejans et al.]. Although both the studies of Vickers and Oudejans et al. report interesting results, the authors offer divergent interpretations as to how the visual and motor systems would interact.

:. Preview of the visual control in basketball shooting

The goal of the work described in the present thesis is to deepen our insight into the visual basis of expert basketball shooting. This goal is pursued through detailed investigation of four pertinent topics. In Chapter 2 we examine the preferred timing of optical information pick-up taking into account differences in shooting kinematics. Participants with either a low or a high shooting style were asked to perform jump shots while wearing glasses that allow only intermittent viewing. Under this condition, we examined whether players couple the brief vision period with a particular moment of the shot, and whether this moment is similar for participants across shooting styles. In Chapter 3 we examine the consequences of introducing visual delays between viewing the target and shooting. Again, participants with either a low or a high shooting style were asked to take set shots while wearing glasses that either remain transparent or become opaque 0, 1, or 2 s before movement initiation. We examined the consequences of the visual delays in terms of kinematic adaptations (i.e., the coupling between adjacent joints of the shooting arm), and in terms of shooting performance (i.e., endpoint accuracy and variability). In Chapter 4 we examine the pattern of gaze behaviour during the preparation and execution phases of shooting. Once again, participants with either a low or a high shooting style were asked to take both free throws and jump shots while gaze excursions were measured, allowing a comparison of visual search patterns between the two shooting styles and the two shooting types.

In Chapter 5 we examine the optical basis of basketball shooting. At the outset, we define several information sources that in principle can specify the location of the target relative to the participant, namely, convergence, binocular parallax, motion parallax, and angular elevation. In the first experiment we tested whether the selected information sources are sufficient for successful basketball shooting, operationalised in terms of endpoint accuracy, by having participants take basketball shots under three conditions: full light, one glowing dot in an otherwise dark room (where only the selected information sources were available), and complete darkness. In the second experiment we tested the use of the binocular information sources, convergence and binocular parallax when motion parallax was reduced to a minimum. In the third experiment we tested the use of angular elevation by changing the basket's height unbeknownst to participants.

Throughout the next four chapters we seek to gain insight into how visual information influences basketball shooting by investigating its temporal and spatial aspects. Along the route we introduce different theoretical stands that broaden our perspective on the phenomena of interest. A wealth of research has been conducted and interpreted under either the information processing approach or the direct perception approach, both of which have made invaluable contributions to the understanding of the visual control of actions (e.g., Williams et al., 1999). Likewise, neuropsychological studies have made significant strides towards a more comprehensive understanding of the interaction between visual and motor systems. They stimulated bridges between the direct and indirect approaches to perception and action. Along the same route we will use sophisticated methodologies with original applications, and explore new methodologies to study the visual basis of basketball shooting. Intermittent viewing has been used before in juggling, but not in a discrete task such as basketball shooting. Gaze behaviour has been measured in several tasks including basketball shooting, but the timeline has not been kept. The analyses of ball-flight trajectories and endpoint accuracy have been developed and optimised for the purpose of a rigorous evaluation of performance. In Chapter 6 we discuss the theoretical implications of our results in view of the extant literature. We also discuss the merits and pitfalls of our methodologies, sketch some lines for future research, and provide more practical applications of the insights we gained into the visual control of basketball shooting.

02 :

Late information pick-up is preferred in basketball jump shooting

We investigated the timing of optical information pick-up in basketball jump shooting using an intermittent viewing technique. We expected shooters to prefer to look at the basket as late as possible under the shooting style used. Seven experts with a high and five with a low shooting style took 50 jump shots while wearing liquid-crystal glasses that alternately opened and closed at pre-set intervals. In principle, under this constraint, the participants could control when they saw the basket by actively modulating the timing of their movements. Analyses of the phasing of the movements relative to the events defined on the glasses revealed that low-style shooters prefer to see the basket just before the ball passed their line of sight, whereas high-style shooters tended to view the basket from underneath the ball after it passed their line of sight. Thus, most shooters preferred to pick-up optical information as late as possible given the adopted shooting style. We concluded that, in dynamic far aiming tasks such as basketball jump shooting, late pick-up of optical information is critical for the successful guidance of movements.

:: Introduction

In sports, there is an abundance of far aiming tasks, often with the purpose of scoring. Although it is evident that vision plays an important role in the control of far aiming tasks, this role is still poorly understood. In static far aiming tasks, like rifle shooting, shooting free throws in basketball, and playing billiards, the duration of the final fixation on the target prior to initiating the final movements correlates with expertise (e.g., Janelle et al., 2000; Vickers, 1996; Williams, Singer, & Frehlich, 2002). Compared to non-experts, experts fixate their gaze at the target for longer before taking the actual shot, a phenomenon called quiet eye (Vickers). A long target fixation has been associated with movement programming (Vickers; Williams et al., 2002). However, long target fixations have only been reported in static self-paced tasks where the positions of both performer and target are stationary. Note that physiological regulation in static tasks is often related to performance and a long fixation may enhance the state of readiness as proposed by Williams et al. (2002). In dynamic far aiming tasks, like shooting at goal in soccer or basketball jump shooting, there is often no time for long fixations and thus no time for elaborate movement programming. In such dynamic tasks, the timing of optical information pick-up may well be crucial because the opportunities for information pick-up are limited and the detected information has to be used in controlling an unfolding movement given certain neuromuscular delays.

Interestingly, using a visual occlusion technique, Oudejans, van de Langenberg, & Hutter (2002) found that, in basketball jump shooting, players relied almost exclusively on optical information picked up late during the unfolding movement, that is, just prior to ball release. This finding may be understood as standing in contrast to the finding of Vickers (1996) that free throw shooters fixate at the basket for an extended duration prior to movement initiation, but this understanding should be qualified in two ways. First, and importantly, the presence of long fixations in no way denies the possibility that a particular preferred timing of optical information pick-up exists if only limited time is available. Second, the finding of Oudejans et al. pertained to high-style shooters and that of Vickers to low-style shooters. As we will argue next, it might well be that the kinematic properties of low and high shooting styles place different constraints on the pick-up of optical information.

With the low shooting style (cf. Kreighbaum & Barthels, 1981), ball and hands remain below eye level before the final extension of the elbow, after which they move in front of the face (see Figure 2.1, left). An advantage of this shooting style is that the final extension of the elbow can be initiated as soon as sufficient information has been picked up. A potential disadvantage is that information pick-up has to occur before the final extension of the elbow because the target is obscured during the remainder of the movement (cf. Vickers, 1996). With the high style, the ball is first carried to a position above the head

:: Figure 2.1

Image of low-style and high-style shooting. On the left, the low hand as well as the ball occludes the target during the final elbow extension. On the right, the high hand brings the ball above the head leaving the target visible.

followed by an extension of the elbow until ball release (cf., Hay, 1973/1993). An advantage of the high style is that the shooter can look at the basket from underneath the ball when it is held overhead (Figure 2.1, right), allowing online visual control of the final shooting movements close to ball release, with the potential disadvantage that the time window for viewing the target becomes rather small.

Oudejans et al. (2002) concluded that high-style players take advantage of the possibility of late optical information pick-up but it is unclear whether this conclusion generalises to low-style shooters because, until now, they have not been investigated in this regard. It is important, however, to do so because the notion of quiet eye implies that optical information is being picked up from a relatively early time onwards, leaving the possibility open that also in low-style shooters late optical information is more critical in controlling the movement than early information. In low-style shooters the ball occludes the target for only the last 123 ms before ball release (Oudejans et al.), which is in the same order of magnitude as the visuomotor delays reported in literature (Caljouw, van der Kamp, & Savelsbergh, 2004; Carlton, 1992; Michaels, Zeinstra, & Oudejans, 2001). This implies that, in principle, low-style shooters could also control their movements until ball release on the basis of the information picked up just before the ball entered their field of vision.

One way to investigate whether both high-style and low-style shooters prefer to pick-up late rather than earlier optical information is by using an experimental setup in which participants themselves can control during which phase of the shooting movements they see the basket, thereby revealing their preferred timing of optical information pick-up. Such a strategy has been used successfully in examining the relationship between the phasing of hand movements and the pick-up of optical information in cascade juggling (van Santvoord & Beek, 1994) and one-handed catching and throwing (Amazeen, Amazeen, Post, & Beek, 1999). In both studies, the participants, who wore LC glasses that alternately opened and closed at pre-set intervals, coupled (i.e., phase locked) the throws and catches of the balls to the opening and closing frequency of the glasses. A subsequent study on one-handed catching and throwing with a gaze-tracker confirmed that the part of the ball flight that was visible during intermittent viewing was also the part at which the participants directed their gaze while performing the task with full vision (Amazeen, Amazeen, & Beek, 2001).

Using a similar occlusion technique, the present study was conducted to examine the preferred timing of optical information pick-up as a function of shooting style, and to test the hypothesis that both high-style and low-style shooters prefer to pick up late optical information. In particular, we expected high-style shooters to time the moment when the ball passed their line of sight (henceforth referred to as mLoS) with the opening of the glasses as this would allow them to view the basket until ball release. Conversely, we expected low-style shooters to time mLoS with the closing of the glasses as this would allow them to view the basket until it is obscured by ball and hands.

:: Method

:. Participants

Twelve expert right-handed basketball players participated in the study. Seven participants with a high shooting style (all men) and five with a low style (one man and four women) were selected. Shooting style was confirmed after the experiment, as will be reported in the Results. The age of the participants ranged from 18 to 39 years (M = 26.8, SD = 7.9 years), and their basketball experience from 6 to 27 years (M = 16.0, SD = 7.1 years). The two style groups did not differ significantly ($p > .05$) in age, $U_{N = 12} = 13.0$, nor in years of basketball experience, $t_{10} = 0.92$. All participants played either at the guard or forward position in the highest league in The Netherlands or the league just under this league, and were the best shooters of their respective teams. After a brief explanation of the experimental procedure, the participant gave his or her written informed consent. The experiment was approved by the ethics committee of the Faculty of Human Movement Sciences.

:. Task

The participants, who wore LC glasses, were asked to make a left-hand dribble, a step, a jump stop and a jump shot from a designated area on the floor. The dribble and step were included to guarantee that the shots were not taken from exactly the same position, thus ensuring that optical information about the relative location of the hoop had to be picked up each trial afresh. These preparatory movements also ensured that the shooter had enough time available to negotiate the constraints imposed by the intermittent viewing. A full-vision control condition was not run because these data were already available for all participants from previous studies (e.g., Oudejans et al., 2002; Oudejans, Koedijker, Bleijendaal, & Bakker, 2005).

:. Experimental setup

The experimental setup was identical to that used by Oudejans et al. (2002). It consisted of a standard basketball backboard and rim placed in a large gym-size laboratory. The initial position of the participant for each trial was about 6 m obliquely to the right of the basket. The shooting area, indicated by a 1 × 1 m square drawn on the floor, was about 5 m from the basket.

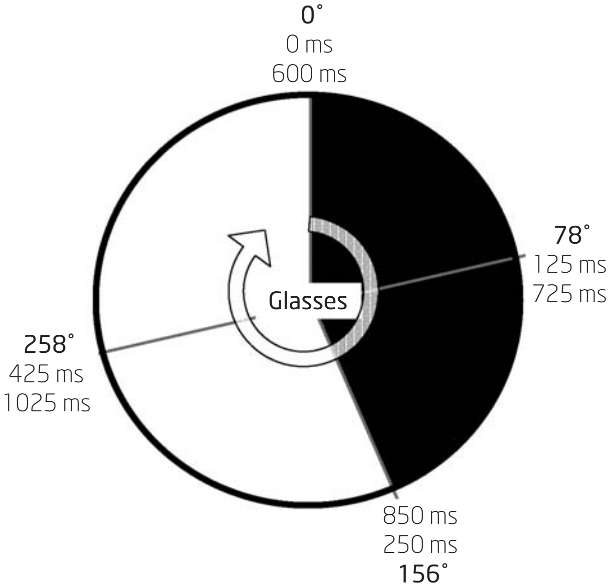
Participants wore Plato LC glasses (Translucent Technologies, Toronto, Canada), which opened and closed alternately at pre-set intervals. Hand and head movements were registered at 100 Hz (i.e., with a temporal precision of 10 ms) using a 3D motion measurement system with active infrared markers (Optotrak 3020, Northern Digital Inc., Waterloo, Canada). Data recording could be briefly interrupted if the reflective markers were occluded from the cameras' line of sight by the ball or parts of the shooters' body. Three markers in a triangular configuration were taped to the right leg of the glasses, with the two upper markers of the triangle defining the line of sight. One marker was attached to the right ring finger.

The configuration included a host PC, an Optotrak control unit connected to the host PC and a 3D sensor connected to the control unit. The position sensor was placed about 5 m obliquely behind the shooting area at a height of 2.65 m. A marker strober and a battery case for the glasses were strapped to the shooters' waist. Two cables connected to the Optotrak control unit and PC were led to the shooter's waistband via a pulley system, preventing the shooter from becoming entangled in the cables or be hindered otherwise in his or her performance.

A digital video camera was set up perpendicularly to the plane of shooting to detect the moment of ball release. In order to synchronise the video and Optotrak recordings, a box with two red light emitting diodes (LEDs) was placed in view of the video camera on the opposite side of the set up. One LED indicated the start and end of each trial and the other the opening and closing of the glasses. Official FIBA regulation size basketballs were used according to the participant's gender.

:. Procedure

The experimenters taped the Optotrak marker onto the ring finger of the participant and provided instructions about the task. Participants were instructed to execute the task at their own pace. They were allowed 15 warm-up shots, also with the purpose of becoming familiar with the experimental



:: Figure 2.2

Conversion of the events defined on the glasses, in milliseconds, to circular coordinates, in degrees. The black right side of the circle represents the window of the glasses that was closed for 250 ms, while the white left side represents the window that was open for 350 ms. A diagonal line across the diameter of the circle indicates the middle of both the open and closed windows. The intermittency is indicated by the central arrow.

environment. Each player then took 50 jump shots under intermittent viewing. Vision was manipulated by opening and closing the LC glasses at pre-set cycles. During each cycle the LC glasses were open for 350 ms and closed for 250 ms. These intervals were chosen based on previous results (Oudejans & Coolen, 2003; Oudejans et al., 2002), indicating that, for the high-style shooters, the final period duration (the period between the moment when hands and ball pass the line of sight until ball release) lasted on average about 350 ms while the mean duration from landing in the shooting area to the moment of ball release was about 600 ms.

At the beginning of each trial, one of the experimenters indicated when the shooter could start, while simultaneously triggering the Optotrak, the intermittent viewing, and the LEDs. After the ball was shot, the glasses were opened, upon which the player returned to the starting position, and the ball was returned to the shooter by the second experimenter. For each trial, the registration period was about 6 s. Within this time the task could be executed without additional time pressure other than shooting before landing (as demanded by the rules of basketball). The success of each shot (hit or miss) was registered.

:. Data reduction

Shooting style was checked by calculating the viewing angles using the method described by Oudejans et al. (2002). This method consisted of subtracting the angle formed by the line between the rim, the eye and the anteroposterior horizontal line from the angle formed by the tangent line to the ball through the eye and the anteroposterior horizontal line. Positive angles indicate that the shooter looked at the target from underneath the ball, and negative angles indicate that the ball occluded the target. In cases where the computation of the viewing angles was impossible due to loss of Optotrak data, shooting style was assessed by visual inspection of the video recordings of hand and head movements during shooting and by comparing the final period durations to those reported in the literature (Oudejans et al., 2002). In combination, these analyses allowed us to determine whether the shooters could look underneath the ball at the basket prior to and during the final extension of the elbow.

The moment hand and ball passed the line of sight (mLoS) was calculated offline on the basis of the Optotrak data by determining the sample number at which the hand marker was in line with the two markers defining the line of sight (Oudejans & Coolen, 2003). The moment of ball release was determined from video and defined as the first video image at which the hand had visibly lost contact with the ball.

In order to analyse the timing of mLoS relative to the events defined on the glasses, we needed to take into account the cyclical nature of these events. Note that if mLoS occurred at 250 ms, at 850 ms, or at 1450 ms after the first closing of the glasses this would be qualitatively the same because at each of these moments mLoS coincides with the opening of the glasses (Figure 2.2). In addition, the beginning and end of each cycle were qualitatively similar and this would not have been accounted for in a linear analysis. For this reason we related mLoS to the cyclical events defined on the glasses by converting mLoS to an angle on a circle, with 0° (= 360°) corresponding to the closing of the glasses (0 ms) and 150° corresponding to the opening of the glasses (250 ms). Using circular statistics (Batschelet, 1981; Fisher, 1993), we examined the phasing (distribution and angular direction) of mLoS in order to examine whether shooting-style dependent timing patterns were present.

:: Results and discussion

:. **Shooting style**

We first verified that the shooting styles used by the twelve participants were indeed as expected. As indicated in the Method section, this was done on the basis of an analysis of viewing angle and, if necessary, by a combined analysis of final period durations and video footage. The analysis of the viewing angles confirmed that five shooters had a high style and three a low style (H and L, respectively; see Table 2.1). For the remaining four participants (1H, 2H, 3L, 5L), the Optotrak signal from the hand was interrupted prior to the final propulsion movement, rendering it impossible to estimate the viewing angle. For participant 1H it was already confirmed in a previous study that he had a high shooting style (Oudejans et al., 2002). For the remaining three participants, the final period durations indicated that one (2H) had a high style and two (3L, 5L) a low style which confirmed the results derived from the video footage. Thus, all participants exhibited the expected shooting style.

On average, the high-style group had longer final period durations (M = 343, SD = 50 ms) than the low-style group (M = 134, SD = 80 ms), $t_{10} = 5.59$, $p < .01$. This finding is consistent with the results of Oudejans et al. (2002), who found an average final period duration of 357 ms for high-style basketball shooters performing an identical task under full vision, and a final period duration of 123 ms for the two low-style shooters that participated in their study.

:. Shooting performance

To check for learning effects over trials, we computed the number of hits for every 10 trials, resulting in five 10-trial blocks for each of the 12 participants. In view of the small number of hits in each block, we conducted a χ^2-test to analyse the effects of block and shooting style. The test revealed that the number of hits did not differ significantly between blocks for both the high- and low-style group, respectively $\chi^2_{4,\ 199} = 4.4$ and $\chi^2_{4,\ 154} = 0.68$, indicating that no learning effects had occurred across the 50 trials. These group results were reflected in the data of all individual participants.

To examine the effects of the imposed intermittent viewing on task outcome, we compared the percentage of hits achieved under intermittent viewing to those that were available from previous studies with the same participants for the full-vision condition (i.e., Oudejans et al., 2002, 2005). Since the shooting performances were distributed normally on a Shapiro-Wilk test, $W_{12} > 0.96$, ps > .05, we used a paired t-test for this comparison. On this test, no significant differences were found between the percentage of hits achieved under intermittent viewing in the present study ($M = 58.8\%$, $SD = 8.2$) and those realised under full-vision in previous studies ($M = 61.3\%$, $SD = 7.9$), $t_{11} = 1.0$. Hence, under intermittent viewing, sufficient optical information was picked up allowing the participants to shoot as accurately as with full vision. In addition, an independent t-test revealed no significant differences between the experimental percentage of hits of the high-style group ($M = 56.9\%$, $SD = 9.0$) and the low-style group ($M = 61.6\%$, $SD = 6.7$), $t_{10} = 0.99$, indicating that the percentage of hits of the two groups were similar.

:. Timing of optical information pick-up

: Active phasing of mLoS

To analyse whether expert shooters actively negotiated the intermittent viewing constraint, we tested the null hypothesis that mLoS was distributed uniformly along the cycle of opening and closing defined on the glasses. To this aim, we performed Rao's spacing test, which is based on the spacing between adjacent phase values. A mean distance (R) between adjacent phase values that deviates strongly from 360°/n implies a small probability of the data being uniformly distributed (see Batschelet, 1981, p. 66). According to Rao's spacing test, mLoS was neither randomly distributed in the low-style group, $R_{246} = 272.2$, $p < .01$ (Figure 2.3, upper left) nor in the

Participants	Viewing angles	Final durations	Video footage
	M ± *SD* (degrees)	*M* ± *SD* (ms)	Style
Low-style			
Total	-5.3 ± 2.4	134 ± 80	
3L	–	75 ± 10	Low
4L	-5.4 ± 1.7	130 ± 12	Low
5L	–	67 ± 11	Low
7L	-2.9 ± 3.0	267 ± 21	Low
11L	-21.3 ± 1.7	131 ± 14	Low
High-style			
Total	31.3 ± 6.1	343 ± 50	
1H	–	262 ± 28	High
2H	–	288 ± 14	High
6H	35.7 ± 0.1	383 ± 15	High
8H	31.5 ± 2.3	366 ± 14	High
9H	22.2 ± 0.6	335 ± 13	High
10H	37.9 ± 5.8	387 ± 11	High
12H	29.1 ± 3.5	382 ± 12	High

:: Table 2.1

Viewing angles, final period durations and results of video footage used to determine shooting style. Viewing angles were calculated as described in Oudejans et al. (2002). Positive angles indicate that the shooter looked at the target from underneath the ball, and negative angles indicate that the ball occluded the target. – Indicates that the variable in question could not be calculated.

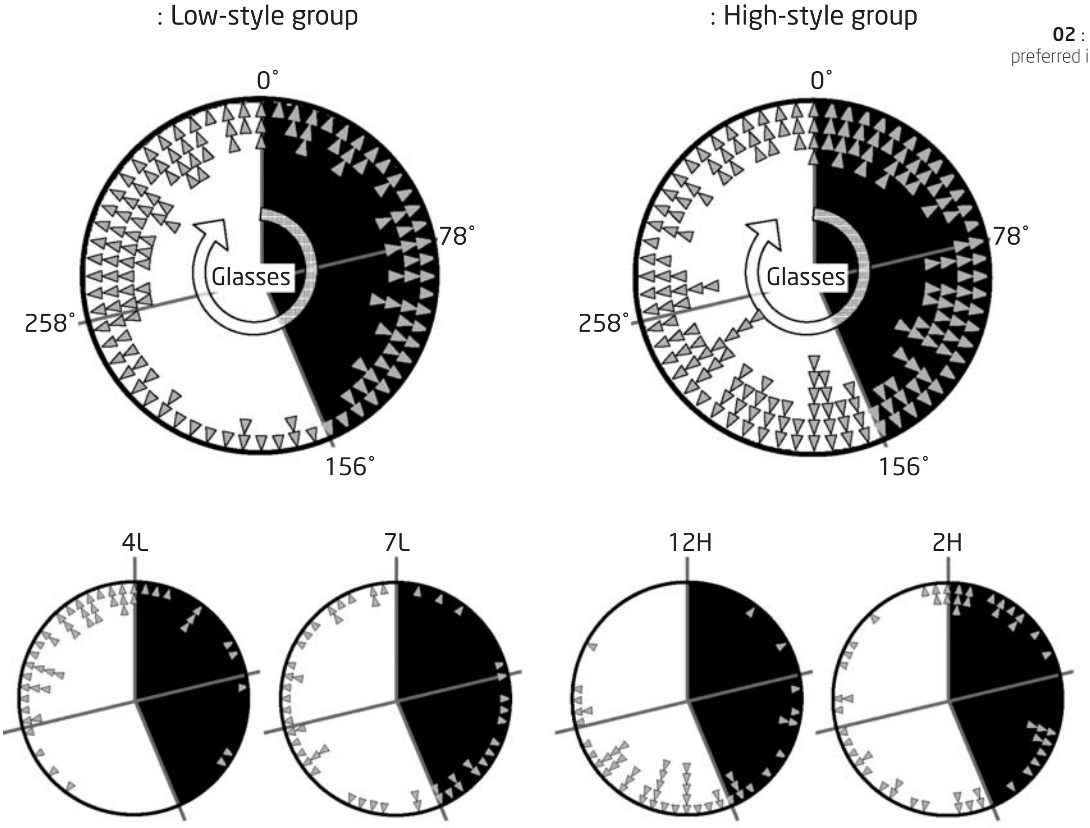
high-style group, R_{336} = 295.7, p < .01 (Figure 2.3, upper right), indicating that both groups actively negotiated the pattern of opening and closing of the glasses.

We also examined to what extent this group effect was present at the individual level by performing Rao's spacing test on the data of each participant. This test revealed that for five of the twelve shooters (4L, 5L, 8H, 10H, 12H) mLoS was not randomly distributed over the cycle defined on the glasses, all $R_{>47}$ > 158.4, *p*s < .05, implying that these shooters actively negotiated the intermittent viewing constraint, whereas two shooters (3L and 9H) showed a tendency in this direction, $R_{>49}$ > 151.2, *p*s < .10. Thus, five (or even seven) of the twelve shooters had a preference for timing mLoS within a particular location of the glasses' cycle.

: Average phasing of mLoS

After having established that, at the group level, the distribution of mLoS over the cycle of opening and closing of the glasses was not random, we examined the average phasing (i.e., central tendency) of mLoS within the cycle defined on the glasses to scrutinise whether the low-style and high-style groups indeed preferred to look at the basket as late as possible given their shooting style. In the low-style group mLoS occurred, on average, at 317.7° (*SD* = 106.2°), while, in the high-style group, mLoS occurred, on average, at 162.4° (*SD* = 131.3°). This difference was significant on a non-parametric circular test (Mardia-Watson-Wheeler) for examining whether two distributions are identical, W_{582} = 19.19, p < .01. Given that the glasses closed at 0° (= 360°) and opened at 150°, this means that in the low-style group mLoS occurred just before the closing of the glasses, permitting vision just before ball and hands occluded the target, whereas in the high-style group mLoS occurred just after the opening of the glasses, permitting vision after mLoS until ball release. Thus, the group data confirmed the expectation that shooters prefer to look at the basket as late as possible given their shooting style.

Again we examined to what extent the individual data reflected the group effects. This analysis revealed that the average phasing of mLoS was closer to the closing than to the opening of the glasses in three (3L, 4L, 5L) of the five low-style shooters and that the average phasing of mLoS was closer to the opening than to the closing of the glasses in three (9H, 10H, 12H) of the seven high-style shooters. As became evident in the previous analysis, these six shooters all actively negotiated the intermittent viewing (albeit with a tendency for 3L and 9H). Thus, only 8H actively negotiated the intermittent viewing without arriving at an average phasing of mLoS consistent with the expected preference for looking as late as possible.



:: Figure 2.3

Circular distribution of the moment when the ball passes the players' line of sight, mLoS, within the cycle of the glasses. The upper left panel represents the distribution of mLoS for the 246 trials of the low-style group and shows a larger concentration of mLoS at the end of the open window. The upper right panel represents the distribution of mLoS for the 336 trials of the high-style group and shows a larger concentration of mLoS at the beginning of the open window. The lower panels show the distribution of mLoS for individual participants for purposes of illustration. Low-style shooter 4L has a larger concentration of mLoS at the end of the open window while high-style shooter 12H has a larger concentration of mLoS at the beginning of the open window reflecting the group results. Both participants 7L and 2H have random distributions of mLoS, therefore it is useful to know which trials resulted in hits or misses.

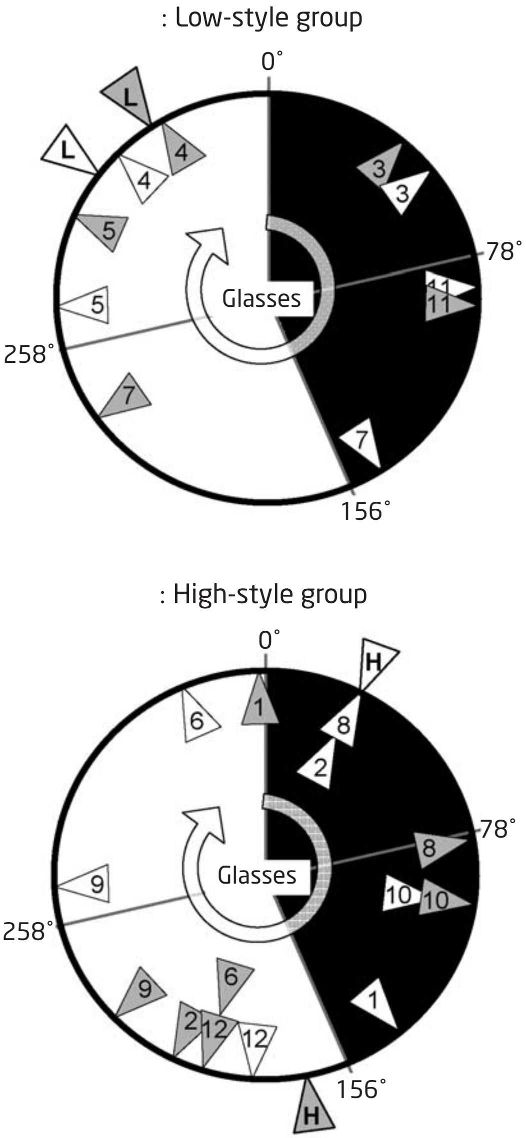
: Phasing of mLoS and shooting accuracy

Having established a preference for looking as late as possible in half of the participants, we examined whether shooting success depended on the phasing of mLoS relative to the opening and closing of the glasses in the participants who did not show a preference for looking late. In the two low-style shooters with random phasing of mLoS (7L and 11L) mLoS occurred on average closer to the opening than to the closing of the glasses in both hits and misses, implying that shooting accuracy was independent of the phasing of mLoS. In contrast, two of the three high-style shooters with random phasing of mLoS (2H and 6H) showed a significant difference between mLoS for hits and misses, $W_{>47} > 5.9$, $p < .05$, in that mLoS occurred closer to the opening of the glasses for the hits and closer to the closing of the glasses for the misses (Figure 2.4). Shooters 2H and 6H benefited from having mLoS closer to the opening than to the closing of the glasses, that is, the preferred phasing of mLoS of the shooters who actively negotiated the opening and closing of the glasses. Thus, besides the six participants who showed a preference for looking as late as possible given their shooting style, the shooting success of two participants benefited from being able to view the target as late as possible.

:: General discussion

Before turning to the main hypothesis, it is useful to stress that the occlusion technique that was used in the present study (i.e., intermittent viewing) did not affect the integrity of task performance. The percentages of hits realised under intermittent viewing were similar to those achieved under full vision, suggesting that participants were still able to pick up sufficient optical information about the target to successfully guide their shooting actions. Results from a previous study showed that having no vision during the entire shooting movement resulted in a deterioration of performance. In the no-vision condition of Oudejans et al. (2002), percentages of hits ranging from 0 to 32% were found, as opposed to an average of 61.5% in the full-vision condition. It should be noted that the intermittent viewing in the present study almost halved participants' normal viewing duration. Therefore, it is quite remarkable that expert shooters, regardless of the adopted shooting style, were still able to shoot accurately under the imposed visual constraints. The occlusion technique used was appropriate to examine the timing (or phasing) of optical information pick-up in expert basketball jump shooting, as was the purpose of the present study.

Our hypothesis was that players prefer to look at the basket as late as possible given their shooting style. The group analyses fully supported this hypothesis. On average, both groups exhibited an active



:: Figure 2.4

Circular average of mLoS across the cycle of the glasses for hits and misses of the low-style and high-style shooters. The letters in the outer triangles identify group averages for hits in white and misses in grey, while the numbers in the inner triangles identify the individual shooters to whom the averages correspond. Note that hits and misses of one shooter are close together when that shooter actively negotiated the phasing of the glasses.

negotiation of the visual constraint, resulting in a non-random, group-specific distribution of the phasing of mLoS, such that the high-style shooters could see the basket just before ball release, whereas the low-style shooters could see the basket just before ball and hand passed the line of sight. Further analyses revealed that these group effects were reflected in the data of three low-style shooters and three high-style shooters. Finally, task success was dependent on the phasing of mLoS in two high-style shooters in a manner that was consistent with the 'preference for looking late' hypothesis.

These results underscore the importance of the timing of optical information pick-up in dynamic far aiming tasks and qualify, or at least complement, the emphasis that is currently placed on the duration of gaze fixations in quiet eye research in the context of static far aiming tasks. In dynamic far aiming tasks like jump shooting the opportunities for information pick-up are severely restricted in time due to the unfolding action itself and inherent neuromuscular delays. As a result, actors are forced to pick up the requisite information at an appropriate time at which the information in question is perceptually available and can be used in guiding the action. In the present study it was found that basketball jump shooters prefer to pick up optical information about the basket as late as possible given the adopted shooting style, that is, just before the basket is occluded by ball and hands (low style) or just before ball release (high style). In this regard, the visual guidance of basketball jump shooting abides by a common principle – picking up optical information as late as possible – which is independent of the adopted shooting style. It is important to note that, in the present study, long fixations were impossible due to the intermittent opening and closing of the glasses. The fact that shooting performance was not affected by this manipulation compared to full vision suggests that long fixations are not critical for the performance of the current dynamic basketball shooting task.

The present results also have a number of broader theoretical implications beyond the visual guidance of basketball jump shooting as such. We mention four. First, the identified principle of late optical information pick-up might generalise to dynamic far aiming tasks other than basketball jump shooting. As it stands, evidence for the importance of late optical information pick-up has been found in the context of several tasks, including racket sports (Cauraugh & Janelle, 2002) and manual aiming (e.g., Elliott, Binsted, & Heath, 1999; Khan, Lawrence, Franks, & Buckolz, 2004), but may prove to be much more general if investigated in other task contexts. Second, the present results emphasise that goal-directed actions, like basketball jump shooting, are not only guided by perceptual information but are also modulated online to facilitate pick-up of the requisite perceptual information, as emphasised in Gibson's ecological approach (1979/1986) and the corresponding notion of a perception-action cycle (Kugler & Turvey, 1987). Third, the present findings illustrate the resilience of the perceptuomotor system when dealing with visual constraints. Although this was already demonstrated in studies of cyclical movements, which are predictable by virtue of their inherent periodicities (Amazeen et al., 1999; van Santvoord & Beek, 1994), it has not been demonstrated before for discrete tasks involving aiming at a far target. Finally, the present study revealed marked individual differences in dealing with the visual constraints imposed, thus underscoring Bernstein's (1896/1996) notion of resourcefulness as a hallmark property of expertise.

In closing, it is useful to briefly discuss the implications of the present results for the currently increasing interest in perceptual training in sports. Research has established that perceptuomotor expertise is a key element of excellence in sports, and investigations are now focusing on the outcome of on-court training programmes designed to optimise this feature of expert performance (e.g., Adolphe, Vickers, & Laplante, 1997; Harle & Vickers, 2001; Williams, Ward, Knowles, & Smeeton, 2002; for a review, see Williams & Ward, 2003). This development is important because training programmes in sports seldom pertain specifically to the pick-up of optical information. For basketball jump shooting, Oudejans et al. (2005) designed and implemented a visual training programme consisting of on-court and laboratory training which yielded positive results. They trained the pick-up of late optical information by letting high-style shooters shoot from behind a screen, thus forcing them to use only late optical information from the basket. A similar training exercise might be used for low-style shooters by letting them dribble passed the screen and then perform a jump shot, in a single fluid movement. This permits the same setting to be used for training the pick-up of relevant late optical information taking into account the shooting style of the players.

In this Chapter we investigated the preferred timing of optical information pick-up and our results suggest that optical information is picked up and used online, i.e., during movement execution. To examine this suggestion further we conducted the experiment reported in the next Chapter.

03 : Basketball jump shooting is controlled online by vision

An experiment was conducted to examine whether basketball jump shooting relies on online visual (i.e., dorsal stream-mediated) control rather than motor preprogramming. Seventeen expert basketball players (eight males and nine females) performed jump shots under normal vision and in three conditions in which movement initiation was delayed by zero, one or two seconds relative to viewing the basket. Shots were evaluated in terms of both outcome and execution measures. Even though most shots still landed near the basket in the absence of vision, endpoint accuracy was significantly better under normal visual conditions than under the delay conditions, where players tended to undershoot the basket. In addition, an overall decrease of inter-joint coordination strength and stability was found as a function of visual condition. Although these results do not exclude a role of motor preprogramming, they demonstrate that visual sensory information plays an important role in the continuous guidance of the basketball jump shot.

:: Introduction

How far-aiming movements like kicking or throwing a ball are organised and guided by visual information has become an important research theme of late. With regard to the question when visual information is used in motor control, an old dichotomy has recently surfaced in studies of basketball shooting. While some researchers have emphasised that aiming movements are preprogrammed before execution, other researchers have argued for their online control, dismissing the need for detailed motor programming. For instance, Vickers (1996) found that, when preparing a basketball free throw, players fixated their gaze on the target for a long time before initiating the shot, and that gaze fixation was terminated once they started the shot phase of the movement (i.e., final elbow extension). This author proposed that players needed visual information before the shot to preprogramme movement parameters, allowing the shot to be performed without sensory feedback. In contrast, Oudejans, van de Langenberg, and Hutter (2002) found that basketball players could accurately perform a jump shot when their vision was blocked up to the last 350 ms before ball release, whereas performance was hampered when vision was blocked during this period (which includes the final elbow extension). Oudejans et al. (2002) concluded that having only online visual information available during the shot is sufficient for accurate performance, rendering elaborate motor preprogramming superfluous.

These contrasting results and interpretations concerning the classic preprogramming-online control dichotomy may be understood in view of recent neurophysiological insights into the visual control of action. In this research, temporal aspects of motor control have been linked to the distinction between the dorsal and ventral streams of visual information processing (cf. Milner & Goodale, 1995; Rossetti & Pisella, 2002). According to this dichotomy, the dorsal stream uses visual information coded in motor coordinates for the continuous guidance of movement, whereas the ventral stream uses visual information for object identification (Milner & Goodale, 1995). Initial neurological evidence for the dorsal-ventral distinction came from studies on DF, a patient with visual form agnosia (i.e., damage of the ventral pathway), who could accurately reach and grasp objects while being unable to describe or identify such objects. In contrast, AT, a patient with optic ataxia (i.e., damage of the dorsal pathway) could describe objects, but showed poor performance when asked to point to objects, suggesting that she was unable to properly guide her movements online. Unlike healthy individuals, AT's pointing errors reduced when a delay was introduced between viewing the object and making the pointing movement (Milner et al., 2001; Milner, Paulignan, Dijkerman, Michel, & Jeannerod, 1999). These results have led to the insight that dorsal stream information is used for the online control of action (even if the processing of this information is compromised by brain damage), while ventral stream information may come into play when movement execution is delayed relative to the timing of visual information pick-up (Pisella et al., 2000; Rossetti & Pisella, 2002).

Delaying the movement relative to the pick-up of visual information thus constitutes a promising behavioural manipulation to study the visual guidance of basketball shooting (Rossetti & Pisella, 2002), which may cast light on the contrasting results that have been published so far on this topic. Since the dorsal system is devoted primarily to the online guidance of movements, this stream of visual information processing can be disrupted by introducing a visual delay. In contrast, the ventral system is dedicated to longer-term cognitive processes, and will thus remain functional after relatively long visual delays. It has been established that the briefest delay after which changes in motor control are observed is 500 ms and that a 2-s delay is long enough to produce observable changes in motor output (Rossetti & Pisella, 2002).

To examine whether basketball jump shooting relies on the online (i.e., dorsal stream-mediated) use of visual information, we had expert basketball players perform jump shots under normal visual conditions and conditions in which the shooting movement was delayed relative to the availability of vision by zero, one and two seconds. Motor performance was evaluated in terms of endpoint accuracy and the kinematics of the shooting arm (see Method). Players with low and high shooting styles were included in the experiment in view of Oudejans et al.'s (2002) suggestion that the visual control of basketball jump shooting depends on the adopted shooting style. This suggestion was based on the fact that the low shooting style involves simultaneous shoulder anteflexion and elbow extension, resulting in an upward and forward pushing movement that brings ball and hands into the shooter's field of view thereby occluding the basket just before ball release, whereas the high shooting style is characterised by a shoulder anteflexion that brings the ball above the head, followed by an elbow extension that propels the ball towards the basket, allowing vision of the basket throughout the movement. Oudejans et al. (2002) therefore conjectured that low-style shooters would preprogramme their movement before execution, whereas high-style shooters would rely solely on online control. According to this hypothesis, high-style shooters would be expected to show marked decrements in performance under the visual delay conditions, whereas low style shooters would be expected to be less susceptible to (externally) imposed visual delays, provided they are brief. After all, under the low style the shooting movement itself already introduces a visual delay by virtue of its kinematic characteristics, whereas under the high style the target is always visible. In short, if basketball players preprogramme their shooting actions, as might be the case under the low style, then a brief visual delay should not interfere with performance. Conversely, if online control is used, as might be the case under the high style, then brief visual delays should lead to marked decrements in performance. The experiment reported here was designed to examine these expectations.

:: Method

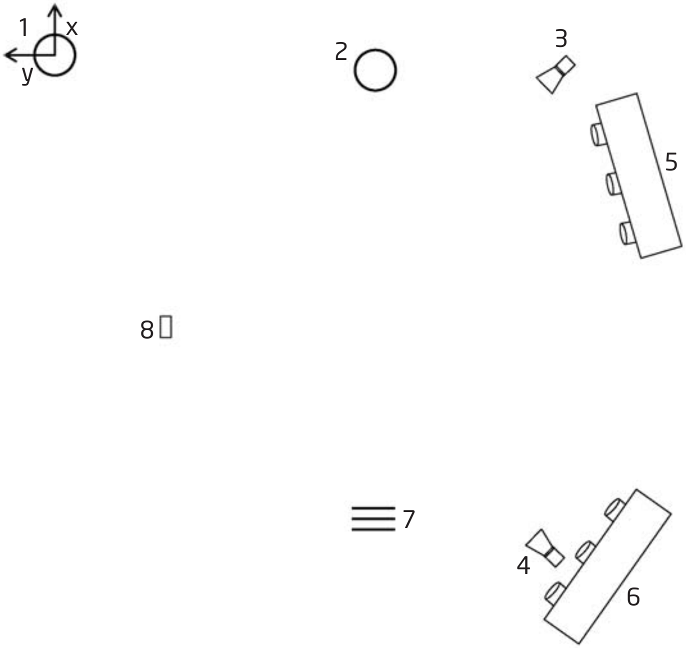
:. Participants

Seventeen experienced basketball players (age *M* = 23.9, *SD* = 5.8 years) participated in the study. All played either at the guard or forward position in the two highest leagues in The Netherlands for 10.4 years on average (*SD* = 6.0). Nine players had a high shooting style (eight men and one woman) and eight a low shooting style (all women), which was confirmed after the experiment through video-footage analysis using previously established criteria (Chapter 2; Oudejans et al., 2002). There were no significant ($p > .05$) group differences regarding age or experience, $t_{15} = 1.28$ and $t_{15} = 0.09$, respectively. The experiment was approved by the ethics committee of the Faculty of Human Movement Sciences.

:. Experimental setup

A standard basketball backboard and rim were set up in a large laboratory and a shooting area was defined about 4.6 m away from it (see Figure 3.1). To the right of the shooting area two Optotrak sensor units (Optotrak 3020, Northern Digital Inc., Waterloo, Canada; sampling rate 100 Hz) were placed to capture the shooters' movements. In addition, two digital video cameras were placed on both ends of the setup to record the entire ball's trajectory at 25 Hz. Light emitting diodes that indicated visual condition, start cue (delivered via an earphone to the shooter), and ball release (captured by a microswitch) were placed in view of the cameras.

Participants wore Plato LC glasses (Translucent Technologies, Toronto, Canada) that could switch from transparent to opaque, thus enabling and preventing vision. Nine Optotrak active infrared markers were recorded; six markers were attached to the participants' shooting arm (little finger, ring finger, metacarpal area, wrist, elbow, and shoulder), and three others were taped to the right leg of the glasses.



:: Figure 3.1

Experimental setup with (1) the coordinate system used; (2) basket with 450 mm of diameter; (3 and 4) digital video cameras to record ball trajectory; (5 and 6) Optotrak cameras for movement registration; (7) shooting positions; (8) light-emitting diodes to code for the visual conditions.

A microswitch was taped to the shooters' middle finger to detect the moment of ball release, which triggered a masking sound (white noise superimposed on a 100 Hz frequency) on an earphone with 0.5 s delay so as to prevent auditory feedback from the ball's landing position. The earphone also cued the start of each trial. Official regulation-sized, FIBA basketballs were used.

:. Design

The participants performed 12 blocks of 12 trials for a total of 144 jump shots. The shots were taken under four visual conditions, randomised over each 12-trial block: a full-vision condition in which the glasses remained open (V_f); a 0-s delay condition in which the glasses closed at the cue to shoot (V_0); a 1-s delay condition in which the cue to shoot was given 1 s after the glasses had closed (V_1); and a 2-s delay condition in which the cue to shoot was given 2 s after the glasses had closed (V_2). To ensure that players would not shoot each time from the same position, they were instructed to shoot randomly from three distances (4.3, 4.6 and 4.9 m) marked on the floor. In addition, the backboard was positioned alternately either parallel or orthogonal to the player's sagittal plane on each trial block.

:. Procedure

The participant gave his or her written informed consent after a brief explanation of the purpose of the experiment and the experimental procedure. The experimenters placed the Optotrak markers, glasses, microswitch and earphone. Participants took several shots to warm-up and get used to the experimental setup. They were instructed to look at the basket for 3 s on each trial, to initiate their movements immediately after the signal and to shoot at their own pace. During the initial 3 s players were free to stay still or bounce the ball. During each trial visual feedback from the ball trajectory was prevented by closing the glasses 0.05 s after ball release, while auditory feedback was eliminated by delivering the masking sound over the earphone 0.5 s after ball release. After each trial the result of the shot was registered as hit or miss, the glasses opened, and the ball was returned to the player.

:. Data processing

The coordinate system was defined with the x-axis increasing from the starting position to the basket, the y-axis increasing leftwards, and the z-axis increasing upwards, such that the centre of the rim was $x = 0$, $y = 0$, $z = 3050$ mm. We calculated the percentage of hits for each player and submitted this variable to a repeated measures ANOVA with within-subjects factor vision (4 levels) and between-subjects factor group (2 levels). To augment the discriminatory power of the performance measure, we also examined the landing positions of the ball relative to the centre of the rim along the *x*- and *y*-axis. This was accomplished by digitisation (using WinAnalyse, Mikromak) of the ball's flights in 3D, followed by a second order polynomial fitting procedure that allowed estimation of the ball's position when its centre (would have) crossed the horizontal plane of the rim. This procedure was necessary as the ball often hit the rim or backboard before the ball's centre crossed the plane of the rim. Because the 3D digitisation of the ball trajectories was laborious, this analysis was restricted to a random subsample of 10 participants. There were no significant (p > .05) differences between the five high-style and the five low-style shooters in this subsample with respect to age or experience, $t_{5.8}$ = 1.28 and t_8 = 0.25, respectively. From the estimated landing positions of the ball on the (horizontal) plane of the rim, we calculated the average absolute error along the *x*- and *y*-axis as well as the corresponding standard deviations (both measures in mm). To examine the effects of the visual conditions, we submitted both absolute errors and standard deviations to a repeated measures MANOVA on *x*- and *y*-axis, with within-subjects factor vision (4 levels) and between-subjects factor group (2 levels).

The raw kinematic data of 14 participants were filtered using a fourth-order, low-pass Butterworth filter with a cut-off frequency of 14 Hz and subsequently normalised to unit variance. Data from three participants were excluded from this analysis because they contained lacunae due to occlusion of the markers. No significant (p > .05) differences were found between the remaining six high-style and eight low-style shooters with respect to age or experience, t_{12} = 1.24 and t_{12} = 0.36, respectively. Next, we calculated the covariance function between the following joint pairs: shoulder-elbow, elbow-wrist, and wrist-finger in the *x*- and *z*-axis (as the shooting movement evolved primarily in the *xz*-plane), determined the time lags at which the covariance was maximal, and calculated the intra-individual means and standard deviations of the covariance coefficients at lag zero. The effect of the visual conditions on the strength and variability of inter-joint coordination, or coupling, was examined by submitting the means and standard deviations of the covariance coefficients in the *x*- and *z*-axis to repeated measures MANOVAs on the joint pairs shoulder-elbow, elbow-wrist, and wrist-finger, again with within-subjects factor vision (4 levels) and between-subjects factor group (2 levels). The exact statistics are reported for the multivariate tests using Wilk's Lambda. Where appropriate, the degrees of freedom were adjusted for violations of sphericity using the Huynh-Feldt correction. Significant main effects were examined further using pairwise comparisons with the Bonferroni correction procedure.

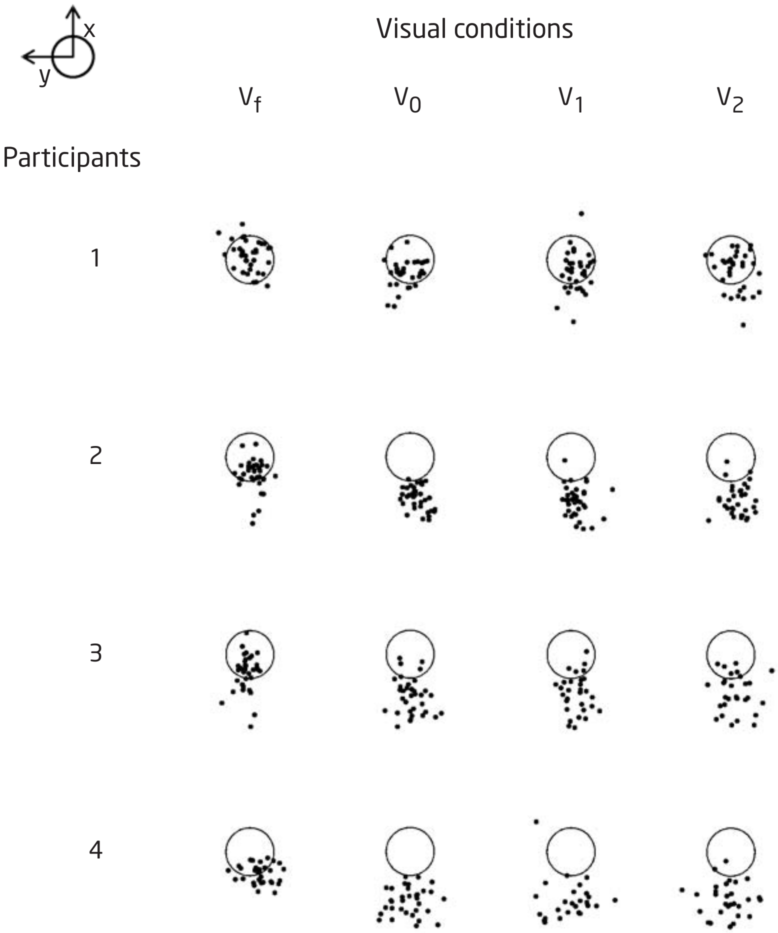
:: Results

:. **Shooting accuracy**

There was a significant effect of vision, $F_{3,\ 45} = 10.03$, $p < .001$, $\eta^2 = .40$, revealing that the percentage of hits was significantly larger in the full-vision condition (V_f: $M = 32.7\%$, $SE = 4.9$; all *p*s $< .05$) than in the visual delay conditions, which were not significantly different between each other (V_0: $M = 17.0\%$, $SE = 4.1$; V_1: $M = 15.9\%$, $SE = 3.9$; V_2: $M = 18.3\%$, $SE = 4.7$; all *p*s $> .05$). The absence of a significant Vision × Group interaction or a group effect indicated that shooting accuracy was independent of shooting style. These results were preserved when the ANOVA was restricted to the subsample of 10 participants selected for the analysis of the landing position, $F_{3,\ 24} = 11.01$, $p < .001$, $\eta^2 = .58$, as well as the subsample of 14 participants included in the kinematic analysis, $F_{3,\ 36} = 10.12$, $p < .001$, $\eta^2 = .46$.

Furthermore, there was a significant effect of vision, $F_{6,\ 46} = 4.17$, $p < .01$, $\eta^2 = .35$, on the absolute error of the ball's landing position along both the *x*-axis, $F_{1.4,\ 11.1} = 6.67$, $p < .05$, $\eta^2 = .46$, and the *y*-axis, $F_{2.2,\ 17.8} = 3.57$, $p < .05$, $\eta^2 = .31$. Along the *x*-axis, the absolute error was smaller under the full-vision (V_f: $M = 175$, $SE = 18$) than under the delay conditions (V_0: $M = 288$, $SE = 68$; V_1: $M = 306$, $SE = 64$; V_2: $M = 304$, $SE = 60$). The same effect occurred along the *y*-axis (V_f: $M = 97$, $SE = 10$ vs. V_0: $M = 116$, $SE = 15$; V_1: $M = 128$, $SE = 21$; V_2: $M = 122$, $SE = 17$). The distribution of the ball's landing positions revealed that shooting errors consisted predominantly of undershooting the centre of the rim (see Figure 3.2).

Finally, there was a significant effect of vision on the standard deviation of the error, $F_{6,\ 46} = 5.21$, $p < .001$, $\eta^2 = .40$, that was also present for both the *x*-axis, $F_{3,\ 24} = 3.34$, $p < .05$, $\eta^2 = .29$, and the *y*-axis, $F_{3,\ 24} = 9.13$, $p < .001$, $\eta^2 = .53$. Variability increased from the full-vision condition to the 2-s delay condition and was larger along the *x*-axis (V_f: $M = 163$, $SE = 14$ vs. V_0: $M = 161$, $SE = 13$; V_1: $M = 188$, $SE = 15$; V_2: $M = 205$, $SE = 14$, with V_f significantly smaller than V_2; $p < .05$) than along the *y*-axis (V_f: $M = 98$, $SE = 6$ vs. V_0: $M = 117$, $SE = 7$; V_1: $M = 123$, $SE = 8$; V_2: $M = 130$, $SE = 7$, with V_f and V_1 significantly smaller than V_2; $p < .05$).



:: Figure 3.2

Distribution of the balls' landing positions relative to the rim of the basket under full vision (V_f), 0-s delay (V_0), 1-s delay (V_1) and 2-s delay (V_2). Each dot represents the position of the centre of the ball when it crossed the horizontal plane of the rim. Circles represent the rim, which had a diameter of 450 mm. Data of two high-style shooters (1 and 3) and two low-style shooters (2 and 4) are plotted. The balls' flights evolved along the *x*-axis. Note the marked undershooting of the rim under the delay conditions.

In sum, the visual manipulation had a marked effect on shooting accuracy and its variability, in the absence of significant Vision × Group interactions or group effects ($p > .05$). The percentage of hits was substantially smaller under the visual delay conditions than under the full-vision condition. In fact, the distance between the balls' landing positions and the centre of the rim was larger under the visual delay conditions than under full vision. This effect was accompanied by larger variability under the three delay conditions along both the *x*- and *y*-axis. The error distribution revealed that players tended to undershoot the basket under the visual delay conditions.

:. **Inter-joint coordination**

The time lag for which the covariance coefficient was largest was close to zero for all joint pairs (i.e., the shoulder-elbow, elbow-wrist, and wrist-finger joint pairs) along both the *x*- and *z*-axis. The coefficients were, in general, positive, implying that the joints moved in the same direction along these axes. Because the time lags were only marginally different from zero (if at all), the covariance coefficient at zero time-lag was used in the statistical analyses. On average, coupling strengths along the *x*-axis were smaller in the shoulder-elbow ($M = .66$, $SD = .30$) and elbow-wrist joint pair ($M = .44$, $SD = .27$) than in the wrist-finger joint pair ($M = .82$, $SD = .15$), whereas average coupling strengths along the *z*-axis were larger than .93 in all joint pairs.

Along the *x*-axis, there was a significant overall effect of vision on the covariance coefficients, $F_{9,8\ 2.9} = 2.58$, $p < .05$, $\eta^2 = .18$, that occurred predominantly in the elbow-wrist coupling, $F_{3,\ 36} = 4.06$, $p < .05$, $\eta^2 = .25$. As the severity of the imposed visual constraints increased, the degree of elbow-wrist coupling decreased (V_f: $M = .22$, $SE = .14$ vs. V_0: $M = .18$, SE = .14; V_1: $M = .16$, $SE = .15$; V_2: $M = .14$, $SE = .14$). As regards the standard variations of these covariance coefficients, we found a significant effect of vision on the shoulder-elbow coupling, $F_{3,\ 36} = 3.30$, $p < .05$, $\eta^2 = .22$, where variability was largest under the 2-s delay condition (V_f: $M = .22$, $SE = .04$; V_0: $M = .20$, $SE = .04$; V_1: $M = .21$, $SE = .05$; V_2: $M = .26$, $SE = .05$). We found the same tendency for the elbow-wrist joint pair, $F_{3,\ 36} = 3.34$, $p = .09$, $\eta^2 = .16$, again with the largest variability under the 2-s delay (V_f: $M = .25$, $SE = .04$; V_0: $M = .22$, $SE = .02$; V_1: $M = .23$, $SE = .03$; V_2: $M = .28$, $SE = .03$). These results indicate that movement execution was least consistent in the 2-s delay condition. No significant Vision × Group interactions or group effects were found along the *x*-axis for average or standard deviation of the covariance coefficients.

Along the *z*-axis, there was a significant overall effect of vision, $F_{9,\ 90.2} = 2.64$, $p < .01$, $\eta^2 = .17$, that occurred predominantly in the shoulder-elbow coupling, $F_{2.0,\ 26.2} = 3.78$, $p < .05$, $\eta^2 = .23$, even though the degree of this coupling decreased only minimally with increasing severity of visual conditions (V_f: M = .920, SE = .02; V_0: M = .922, SE = .02; V_1: M = .919, SE = .02; V_2: M = .911, SE = .02). No significant effects of group were found, but there was a tendency towards a significant Vision × Group interaction for the elbow-wrist pair, $F_{2.5,\ 32.2}$ = 2.54, p = .08, η^2 = .16, in that coupling strength under the 0-s delay condition decreased in the high-style group and increased in the low-style group. As regards coordination variability, there was a significant overall effect of vision, $F_{9,\ 82.9}$ = 3.74, $p < .01$, η^2 = .24, that was most pronounced for the shoulder-elbow pair, $F_{1.7,\ 20.1}$ = 9.36, $p < .01$, η^2 = .44. Again, the variability of this joint linkage was largest under the 2-s delay condition (V_f: M = .028, SE = .01; V_0: M = .026, SE = .01; V_1: M = .024, SE = .01; V_2: M = .045, SE = .01). In addition, there was a marginal group effect for the elbow-wrist pair, $F_{1,\ 12}$ = 3.97, p = .07, η^2 = .25, because the overall variability of inter-joint coordination tended to be larger in the high-style group (M = .02, SE = .004) than in the low-style group (M = .01, SE = .003). No significant Vision × Group interaction was present.

In sum, these results showed that the severity of the imposed visual constraints was associated with a decrease in coupling strength between the arm joints, especially for the elbow-wrist pair along the *x*-axis and the shoulder-elbow pair along the *z*-axis. Increasing the severity of the imposed visual constraints further resulted in increased movement variability, particularly so for the shoulder-elbow pair.

:: Discussion

In the present study, we examined the nature of the visual control of basketball jump shooting in terms of the dichotomy between preprogramming and online control. Based on previous suggestions (Oudejans et al., 2002; Vickers, 1996), we hypothesised that players with a low style would preprogramme their movements, whereas players with a high style would control their movements online. Expert players of both styles performed jump shots with full vision and under visual delays of zero, one or two seconds. We expected high-style shooters to show large decrements in performance under the visual delay conditions, whereas low-style shooters were expected to be less susceptible to (externally) imposed visual delays of brief duration (i.e., under V_0 but not under V_1 and V_2).

We evaluated shooting accuracy in terms of the percentage of hits as well as the average and variability of the ball's landing position relative to the centre of the rim. In all three measures performance was significantly better in the full vision condition than in the three visual delay conditions (in the absence of significant differences among them). Contrary to our expectation, there was no significant Delay × Group interaction, indicating that the low-style shooters did not employ a different kind of control than the high-style shooters. Although low-style shooters indeed occluded their vision of the basket during the final elbow extension, the duration of this occlusion was only 123 ms in the two participants in Oudejans et al. (2002), which is well within the visuomotor delays reported in the literature. Thus, in principle, low-style shooters could control the shooting movement in the same way as high-style shooters (i.e., online control), implying that, in hindsight, the association of shooting style with type of motor control underlying our hypothesis might have been invalid.

The conclusion that low-style and high-style shooters in fact used the same kind of control is consistent with the results reported in Chapter 2, where we studied the preferred timing of optical information pick-up in shooters of both styles using an intermittent vision paradigm. In the experiment in question viewing windows of 350 ms duration were applied to eliminate the possibility of extensive preprogramming. In spite of this, both high-style and low-style shooters preserved their full-vision shooting accuracy. Furthermore, shooters with either style picked up optical information as late as possible as permitted by the adopted shooting style, that is, until the moment of ball release itself in the high-style shooters and until ball and hand started occluding the target in the low-style shooters (i.e., a fraction of a second before actual ball release). Thus, in combination with the present results, it seems that the accuracy of expert players with either style derives from an optimal use of information picked up during movement execution. This general conclusion, however, does not imply that motor programming played no role whatsoever in the organisation of the jump shot. Even in the conditions in which movement initiation was delayed for 1 or 2 s, all shots landed in the vicinity of the basket (< 1 m), indicating that in those conditions shooting was not random but that visual information gathered before movement execution was used. However, from the fact that shooting performance deteriorated with the delay in movement initiation, we might conclude that remembering the exact location of the basket in a somewhat far, extrinsic space is a rather demanding task. It may well be that this limitation in the working memory capacity for remembered target location forces expert basketball players to rely on visual information as long as it is available, allowing them to tune the action online to the basket. This interpretation is consistent with recent suggestions in the literature that actions are organised “effortlessly” so as to achieve perceptible goal states (Mechsner, 2004), but other interpretations are viable (see Chapter 5).

The distribution and variability of end point accuracy revealed undershooting errors in the anterior-posterior direction (x-axis) that were markedly larger under the three delay conditions than under full vision. This is in line with past research on near aiming showing that errors are typically observed in the movement direction, especially when vision is restricted (Khan, Lawrence, Franks, & Buckolz, 2004), as well as studies on reaching that have found undershooting effects under visual delay conditions (Westwood, Heath, & Roy, 2003). The undershooting observed in the present study may have been caused by players misperceiving the occluded basket as being closer to their shooting position. In studying eye movements to remembered visual targets, Gnadt, Bracewell, and Andersen (1991) found upward shifts in the end point of saccades to occluded targets as opposed to visible targets. If basketball players indeed misperceived the occluded basket as being higher in their visual field, then they may have perceived it as being closer (see Chapter 5; Oudejans, Koedijker, Bleijendaal, & Bakker, 2005). Given that people use gaze to guide goal-directed movements (Soechting, Engel, & Flanders, 2001; Vickers, 1996), shooting at a basket being misperceived as closer would cause undershooting it.

We also examined the consequences of imposing delays on movement coordination by investigating the strength and variability of the coupling between joints in the xz-plane. We found that all joint pairs were coupled strongly along the *z*-axis in all delay conditions and in both groups, indicating that all joint pairs were implicated in the movement. This result is manifest in view of the fact that the entire movement pattern was one of transporting the ball upward to its release point. Along the *x*-axis we found weaker couplings for the shoulder-elbow and elbow-wrist pairs. Furthermore, we found large coupling strengths at the wrist-finger joint pair along both the *x*- and *z*-axis in both groups under all conditions. This finding is readily understandable from the kinematics of the unfolding action in that the movements of the hand and fingers are severely constrained by carrying the ball, requiring a continued dorsal flexion of the hand. Hence, the strong couplings and small variability for the wrist-finger joint pair reflect a largely fixed relative position of wrist and finger that was unaffected by the visual conditions.

Importantly, there was a significant effect of the vision manipulation on the coupling strength as well as on its variability in the shoulder-elbow and elbow-wrist joint pairs along both the *x*- and *z*-axis. Overall, inter-joint coordination strength and stability decreased as a function of visual condition. This effect was especially pronounced in the 2-s delay condition, i.e., the most severe of all visual delays. This effect suggests that visual information played a role in the continuous guidance of the basketball jump shot, favouring interpretations of online control rather than motor preprogramming. Notwithstanding earlier suggestions that sensory information cannot be used in the online control of rapid (hand) movements (cf. Jeannerod, 1988), the view that fast aiming movements can be controlled on the basis of visual information gathered during movement execution is rapidly gaining ground, particularly in studies of forward models of motor control. Forward models propose a feedback system that uses sensory information about the visual target position as well as motor-related changes and motor output to estimate hand location. An error signal is generated by comparing the visual target position and the internal estimate of hand location that will be used to perform the necessary adjustments to the ongoing movement (see Desmurget et al., 1999). In the delay conditions of the present study visual target location information was not available, implying that the error signal for movement guidance may have been generated on the basis of an estimate of hand and arm position as well as gaze position (including its up-shift bias as discussed in the preceding). The consequence for the movement kinematics was a decrease in the reproducibility of actions along with weaker couplings for the shoulder-elbow and elbow-wrist joint pairs.

The brain area thought to be involved in the error signal generation (i.e., the instantaneous difference between hand and target position) is the posterior parietal cortex, which is part of the dorsal stream of visual information processing. Previous studies have shown that lesion or disruption of the posterior parietal cortex (by transcranial magnetic stimulation) prevent movement adjustments towards targets if their location was changed unbeknownst to participants after movement onset. Evidence from healthy participants (Desmurget et al., 1999) as well as patients with lesions in this brain area (Grea et al., 2002) underscores the role of this structure in the control of online adjustments during aiming movements. Desmurget et al. (1999) have shown that disruption to posterior parietal cortex activity prevents healthy participants from correcting their movements towards targets if these targets are moved but not if they remain stationary. Other authors have also shown that participants perform adjustments to their hand trajectory when targets are displaced unbeknownst to them (Prablanc & Martin, 1992).

The present results demonstrate that the online control of movement based on visual information about the target also prevails in dynamic perceptual-motor tasks like basketball jump shooting.

In the present study we provided evidence for the use of optical information picked up during movement execution. While it is in accordance with the results of Chapter 2 as well as previous studies (Oudejans et al., 2002), it appears in contrast with other results and interpretations (e.g., Vickers, 1996). To examine these contradictions we conducted theexperimentreported in the next Chapter.

04 : Gaze behaviour in basketball shooting

The visual control of basketball shooting has been examined in previous studies with mixed results and interpretations. Whereas a long duration of target fixation was found in experts taking free shots, purportedly to programme the shooting movements in advance of their execution (Vickers, 1996), experts were also found to pick up optical information as late as possible when taking jump shots, suggesting online visual control (Chapter 2; Oudejans et al., 2002). Three factors may have been responsible for these contrasting findings: the experimental method used (gaze recordings vs. occlusion methods), the shot type under investigation (free throw vs. jump shot), and participants' shooting style (low vs. high). The goal of the present study was to resolve the current ambiguity in the understanding of the visual control of basketball shooting by taking all three factors into account. Specifically, we examined the gaze behaviour of six expert basketball players, three with a high and three with a low shooting style, while they prepared and performed free throws and jump shots. The results corroborated previous findings and interpretations underscoring the online use of visual information in basketball shooting, with the specifics of the timing of the pick-up of optical information depending on both shot type and shooting style.

:: Introduction

The role of gaze behaviour has been examined extensively in the context of sports in order to identify visual search strategies, as well as differences therein between skilled and less skilled athletes (e.g., Williams, Davids, & Williams, 1999). An important finding in this line of research is that experts look longer than non-experts at relevant areas in the environment (e.g., Janelle et al., 2000; Vickers, 1996; Williams, Singer, & Frehlich, 2002). For example, Vickers recorded the gaze behaviour of expert and near expert shooters during the preparation phase of the free throw, using an eye-tracking system. The computation of target fixation durations showed that expert shooters look at the target area more than twice as long as near experts (972 versus 357 ms). Vickers interpreted this finding to imply that long durations of visual fixation are necessary to allow detailed parameterisation of the motor programme for the required shooting movements. This is in accordance with the view of other authors who deemed this period of fixation to be essential for the programming of the direction, force, and velocity of the movement, as well as the timing and coordination of limb movements (Williams et al., 2002). In addition, Vickers found that expert shooters suppress their vision of the target, either by blinking or looking away, as the final shooting movement of the free throw is initiated. In line with the notion that far aiming movements are controlled in open-loop fashion, she interpreted this finding as a strategy to reduce interference between the visual and the motor system.

However, subsequent research has challenged the notion that successful basketball shooting always involves, or should involve, extensive movement preprogramming. First, it became apparent that if the target remains visible until ball release, viewing it for only the last 397 ms is sufficient for successful jump shooting (Oudejans, van de Langenberg, & Hutter, 2002). Using an occlusion paradigm, these authors found that shooters performed well when only late viewing was allowed but performed poorly when only ample early viewing was allowed. In this context it is important to realise that the kinematics of the arms in basketball shooting determines whether or not the basket is visible during the last elbow extension. If the propulsion hand remains below the line of sight, the target becomes occluded by hands and ball as soon as the elbow starts the extension. This so-called low (hand) shooting style was used by the participants in the study of Vickers (1996). If the propulsion hand and ball rise above the line of sight before elbow extension, the target is visible during the entire elbow extension until ball release. This so-called high (hand) shooting style was used by participants in the Oudejans et al.'s (2002) study. Thus, whether or not the player can see the target after ball and hands enter their line of sight (mLoS which denotes moment of line of sight) determines their shooting style. So defined, the shooting style is an observable characteristic of each individual player which is preserved in the presence of opponents and in variations of shooting distance within (at least) the 3-point line (Elliott, 1992; Miller & Bartlett, 1993; Rojas, Cepero, Oña, & Gutierrez, 2000).

Second, using an intermittent viewing paradigm, we found (Chapter 2) that expert performance of the jump shot is characterised by a late pick up of visual information in low-style and high-style shooters alike. In this study, long fixations were denied by virtue of intermittent occlusions but gaze behaviour was not recorded. In a subsequent study, we found (Chapter 3) that performance of the basketball jump shot deteriorated when visual information was unavailable during movement execution. When vision was occluded just before the initiation of the shooting movement there were marked decrements in performance, as well as clear decreases in inter-joint coordination strength and stability. Collectively, these findings underscored the importance of the online use of visual information in basketball shooting. However, there are three important caveats of those studies vis-à-vis the study of Vickers (1996), which, as it stands, preclude regarding the aforementioned conclusion as final or general.

The first caveat concerns the methods used. While Vickers (1996) used an eye tracking system to study the duration and location of gaze behaviour, subsequent studies (Chapters 2 and 3; Oudejans et al., 2002) employed visual occlusion methods to study the timing of optical information pick up. Whereas gaze behaviour informs about locations of interest in the environment, it does not inform about the relevance of visual information at different moments of the movement. Conversely, whereas occlusion methods inform about the sufficient and necessary timing of visual information pick-up, they do not inform about what locations are actually fixated. Because previous conclusions pertain to different methodologies it is difficult to evaluate their relative merits and validity, especially with regard to high-style shooters because, to date, their gaze behaviour has not been examined.

The second caveat concerns the shot type under investigation, i.e., free throw vs. jump shot. The results of Vickers (1996) pertain to the free throw, a task in which the relative positions of target and performer remain unchanged in the course of the movement. Subsequent results pertain to the jump shot, a rather dynamic task involving a whole body movement in which the relative positions between player and target are changing continuously. Although it is unlikely that different shot types would require different patterns of visual control, this has never been verified before.

The third caveat is the possible influence of the kinematic pattern of high and low style shooters on the use of visual information in basketball shooting. The kinematics of high-style shooters allows the target to be visible until ball release permitting visual information to be picked up and used online, that is, during the shot. In contrast, low-style shooters occlude the target with their hands during the final elbow extension lending support to the interpretation of open-loop control according to which visual information is picked up only before movement initiation (Vickers, 1996; Oudejans et al., 2002).

The goal of the present study was to resolve the current ambiguity in the understanding of the visual control of basketball shooting by taking all three factors into account. Specifically, we examined the gaze behaviour of six expert basketball players, three with a high and three with a low shooting style, while they prepared and performed free throws and jump shots. Based on previous findings we hypothesised that low style shooters look at the target relatively long before their hands and ball occlude the target in the free throw, but look for a shorter duration in the jump shot. In addition, we hypothesised that high-style shooters look at the target during the final elbow extension both in the free throw and in the jump shot.

:: Method

:. Participants

Six experienced basketball players participated in the experiment (four men and two women, mean age = 27.7 years, *SD* = 7.9). All played in the two highest basketball leagues in The Netherlands for 11 years on average (*SD* = 6.4). Three participants exhibited a high shooting style (all men) and three a low shooting style (one man and two women). Shooting style was confirmed after the experiment through video footage (cf., Chapter 2). The experiment was approved by the ethics committee of the Faculty of Human Movement Sciences. Each participant gave their written informed consent before the experiment.

:. Apparatus

We placed a standard basketball backboard and rim in a large laboratory and marked a line on the floor at a horizontal distance 4.6 m away from the backboard, which is the official distance for taking free throws. Gaze behaviour was registered using an eye tracking system (Applied Science Laboratories 501, Bedford, MA) that consisted of a head-mounted scene camera (50 Hz) and a monocular corneal reflection system. In brief, the system recorded the field of view with a superimposed marker that corresponded to gaze direction. A digital video camera (50 Hz) was placed orthogonal to the plane of shooting to determine the moment of ball release (cf., Chapter 2). Two light emitting diodes (LEDs), one placed at the left and one in front of the participant, signaled the initiation of each trial. Official FIBA regulation size basketballs were used.

:. Procedure

After a brief explanation of the task participants took several warm-up shots, both before and after the eye tracking system was mounted, adjusted, and calibrated. Participants were instructed to look at the LED placed below the backboard and to start the trial when the LED switched on. This allowed the experimenter to verify the calibration of the eye tracking system on each trial. Participants then performed 10 free throws and 10 jump shots in blocked fashion. The order in which those blocks were executed was counterbalanced across participants. The free throw consisted of shooting from the 4.6 m line within the official 5 s. The jump shot consisted of taking a step and a dribble, then stopping and jump shooting from the 4.6 m line in a continuous self-paced movement. Finally, the eye-tracking system was removed and participants took another 10 free throws and 10 jump shots to establish their percentage of hits for undisturbed shooting. Each trial was registered as a hit or miss. This experiment lasted about 45 minutes.

:. Data reduction

Looking behaviour was coded for each frame starting when the LED was illuminated and ending when the ball was released. The scores ranged from 0 to 1 such that looking at the rim was 1, the basket's net or the small square on the backboard was .8, the remaining backboard was .6, other locations were .4, and no gaze behaviour was 0. We registered the moment when the ball entered the participants' field of view (further denoted mLoS, the moment of passing the line of sight) and the duration of this target occlusion. For each condition, we calculated the average duration of looking behaviour directed at the target (i.e., basket or backboard, scores ≥ .6) and submitted those average durations to a repeated measures 2×2×2 ANOVA with shot type (2 levels: free throw, jump shot) and period (2 levels: before, after mLoS) as within-subject factors and style group (2 levels: low, high style) as between-subjects factor. Five of the six participants started looking at the target less than 1.2 s before mLoS; therefore we depicted this period in Figures 4.1 and 4.2. In addition, we calculated the duration of target occlusion (i.e., the duration of mLoS) and the final period duration (i.e., from start of mLoS to ball release) and submitted those durations to repeated measures 2×2 ANOVAs with shot type as within-subjects factor and style group as between-subjects factor. The percentage of hits was submitted to (non-parametric) Wilcoxon Signed Ranks Tests. Significance level was set at $p < .05$.

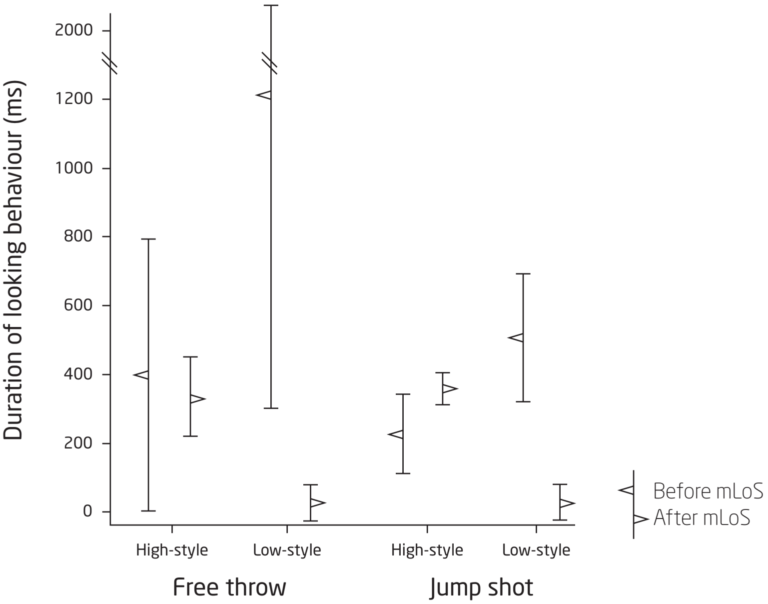
:: Results

:. Shooting style

To verify the shooting styles used by the six participants we analysed the side view images as well as the images from the head-mounted scene camera. Footage from the side view camera showed whether or not participants brought the ball above their head before the final elbow extension, meaning that they used a high or low shooting style respectively. Previously, this method has been used to assess shooting style and corroborated more elaborated methods (cf., Chapter 2). In addition, footage of the head-mounted camera showed that all low-style players occluded the target during the final elbow extension, whereas in all high-style players the target remained visible after the ball passed their line of sight until ball release. The procedure was repeated independently by two researchers with 100% agreement. This analysis thus confirmed that three participants had a low shooting style and three a high shooting style.

:. Looking behaviour

The total duration of looking behaviour was independent of shot type and style group. The significant effect of period, $F_{1,4} = 9.08$, $p = .039$, $\eta^2 = .69$, revealed that overall participants looked longer at the target before than after mLoS ($M = 587$, $SE = 132$



:: Figure 4.1

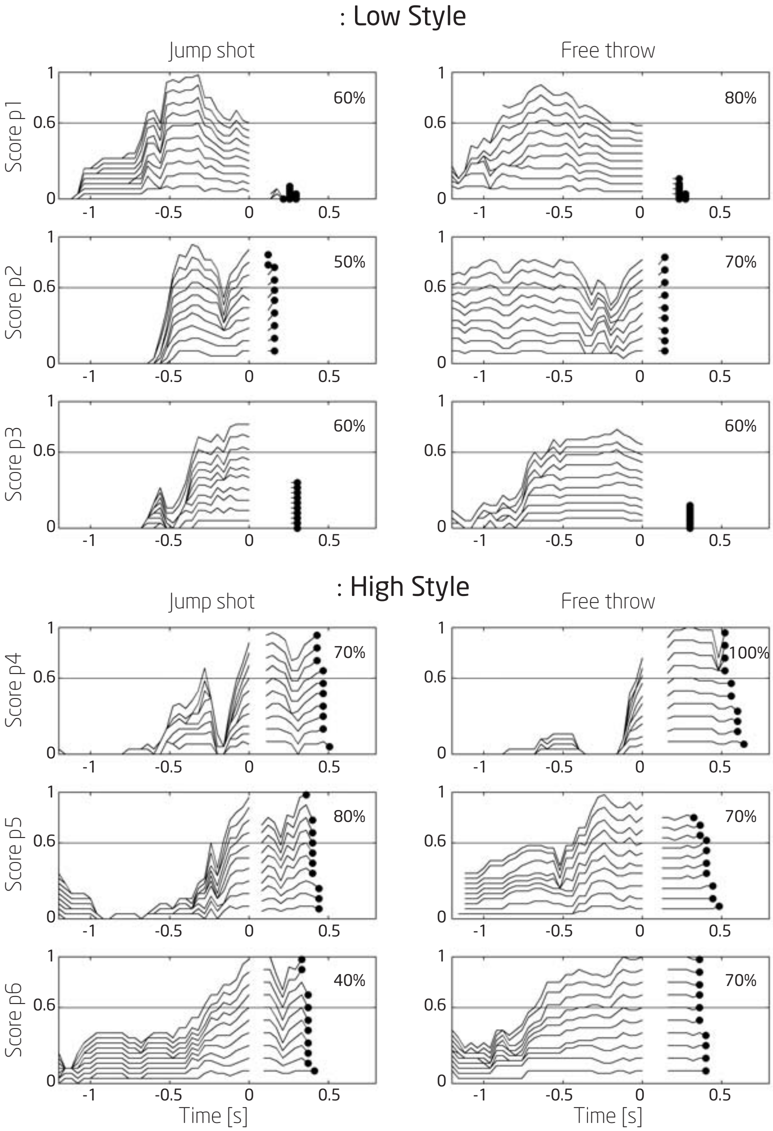
Average duration of looking behaviour directed at the target for each style group and shot type. Triangles pointing left indicate average durations of looking behaviour before the ball and hands passed the players' line of sight (mLoS) while triangles pointing right indicate durations after mLoS. Bars represent ± 2 *SE* of the mean. The third bar replicates the result found by Vickers (1996; *M* = 1213, *SE* = 351 ms) while the sixth bar replicates the result found by Oudejans et al. (2002; *M* = 360, *SE* = 25 ms).

vs. M = 187, SE = 24). Importantly, there was a significant Period × Style Group interaction, $F_{1,4}$ = 10.66, p = .031, η^2 = .73. This effect occurred because participants in the low-style group looked at the target significantly longer before than after mLoS, $T_{N=6}$ = 2.21, p = .03 (M = 860, SE = 186 vs. M = 27, SE = 34), whereas no such difference was present in the high-style group, $T_{N=6}$ = .27, p = .79 (M = 313, SE = 186 vs. M = 347, SE = 34). Complementary pairwise comparisons showed that looking before mLoS was significantly longer in the low-style than in the high-style group, $T_{N=12}$ = 2.09, p = .04, whereas, conversely, looking after mLoS was significantly longer in the high-style than in the low-style group, $T_{N=12}$ = 2.95, $p < .01$ (see Figure 4.1).

Figure 4.2 depicts the individual pattern of looking behaviour during each trial for each shot type. Each plot shows the accumulated scores over 10 trials, normalised to the score scale, thus accumulated values larger than .6 indicate gaze behaviour directed at the target area. As can be appreciated from the figure, the final period duration was longer in the high-style than in the low-style group, $F_{1,4}$ = 6.97, p = .058, η^2 = .64 (M = 417, SE = 49 vs. M = 234, SE = 49), independent of shot type. Furthermore, the duration of target occlusion immediately following mLoS (depicted as a gap in each plot) was independent of style, but significantly longer for the free throw than for the jump shot, $F_{1,4}$ = 9.90, $p < .05$, η^2 = .71 (M = 140, SE = 35 vs. M = 93, SE = 23). Finally, the percentage of hits (overall 68%, SD = 15) was independent of shooting style group, shot type, and the use of the eye-tracking system, all $T_{2\text{ or }4} < 2.24$, ps > .08. The percentages of hits for each participant and for each shot type are also reported in Figure 4.2.

:: Discussion

The aim of the present study was to help resolve conflicting findings and interpretations regarding the visual control of basketball shooting by examining the looking behaviour of six expert basketball players, three with a low shooting style and three with a high shooting style, executing both free throws and jump shots. As hypothesised, the expert low-style shooters look long at the target area when taking free throws, as was the case in previous research (Vickers, 1996). However, this does not necessarily imply that low-style shooters used this long fixation duration to preprogramme their movements. Although several authors assume that long visual fixations are necessary for preprogramming the various parameters of movement, like the direction, force, velocity, timing and limb coordination (cf., Williams et al., 2002), they say little about the nature and details of this preprogramming. Nevertheless, it has been argued that long target fixations may enhance performance because this time would be used for psychological as well as physiological regulation (Williams et al., 2002). Moreover, contrary to what was reported by Vickers, none of the participants blinked or looked away from



:: Figure 4.2

Contribution of each trial to the pattern of looking behaviour for each participant and shot type (jump shot and free throw). Accumulated scores larger than .6 indicate that on average the participant was looking at the target area. A gap indicates the average duration of mLoS for each participant and condition. For representational purposes, mLoS was defined as 0 s. Filled circles indicate the moment of ball release for each trial. Corresponding shooting percentages are indicated in the upper right corner of each panel.

the target at movement initiation. Instead, the participants continued fixating the target either until the hands and ball occluded the target or until ball release, depending on their shooting style (Figure 4.2). As regards the more dynamic shot task, i.e., the jump shot, we found that low-style shooters looked at the target only half as long (1 vs. 0.5 s) as in the free shot without any consequence for their shooting performance. This finding is consistent with previously found evidence for the informative value of the last moments before mLoS (Chapter 2), as well as with the finding that viewing the target for 3 s prior to movement initiation was insufficient for accurate performance if no vision was allowed during the movement (Chapter 3). It should be noted in this context that the argument that low-style shooters must preprogramme their movements because, under this style, the target is occluded following mLoS is invalid. Since the duration of mLoS is shorter than the visuomotor delays reported in the literature, low-style shooters may have used updated optical information at the moment of ball release.

Again as hypothesised, high-style shooters looked at the target during the final shooting movements. This hypothesis was based on the finding in previous occlusion studies that having the target visible after mLoS was sufficient as well as necessary for accurate jump shooting using a high style (Chapter 2; Oudejans et al., 2002). The present results extend this previous finding by demonstrating that players are actually gazing at the target while airborne, and that the employed pattern of looking behaviour is similar to that seen in the free throw. Participant 4 was the best illustration in this regard because his excellent performance was associated with about 400 ms of vision after mLoS and practically no vision before mLoS (Figure 4.2).

In combination with previous results (Chapters 2 and 3; Oudejans et al., 2002), the present findings corroborate the view that basketball shooting is largely controlled online by vision, in the sense that visual information is picked up and used during movement execution. The specifics of the timing of optical information pick-up depend on both the prevailing shot type and shooting style. These findings derive their relevance from the failure in previous studies to account for the confounding influence of shooting style, which resulted in ill-grounded conclusions.

In spite of the improved understanding of the visual control of basketball shooting achieved here, it remains unknown what information is used by expert players as they organise and deliver a basketball shot. To date, research has focused predominantly on retinal sources of information by investigating either gaze behaviour or consequences of visual occlusion. A notable exception is the study of head and eye stabilisation in basketball shooting by Ripoll, Bard, and Paillard (1986), which showed that head stabilisation serves as a reference for subsequent movement. In other tasks, kinesthetic information about the orientation and movements of head and eyes has also been found to play a prominent role (e.g., Ooi, Wu, & He, 2001; Oudejans, Michaels, Bakker, & Davids, 1999). Besides these variables it has been suggested that relatively invariant factors such as eye level or the official height of the basket may be used as well in basketball shooting (Oudejans, Koedijker, Bleijendaal, & Bakker, 2005). Investigating the informational basis of basketball shooting remains an exciting and rich avenue for future research on the coupling between perception and action in far aiming tasks and is therefore the topic under investigation in the next Chapter of this thesis.

05 : Experts use angle of elevation information in basketball shooting

For successful basketball shooting, players must use information about the location of the basket relative to themselves. In this study, we examined to what extent shooting performance depends on the absolute distance to the basket (d) and the angle of elevation (α). In Experiment 1, expert players took jump shots under different visual conditions (light, one dot glowing on the rim in a dark room, and dark).
Task performance was satisfactory under the one-dot condition, suggesting that m and α provided sufficient information during movement execution. In Experiment 2, expert wheelchair basketball players performed shots binocularly and monocularly, under one-dot and light conditions. Performance under the one-dot condition was similar binocularly and monocularly, suggesting that distance information was not crucial for online control. In Experiment 3, expert basketball players took jump shots under light, one-dot and dark conditions while the basket's height was varied between trials unbeknownst to the participants. Players relied on α in combination with the official basket's height to guide their shooting actions.
In conclusion, basketball shooting appeared to be based predominantly on angle of elevation information.

:: Introduction

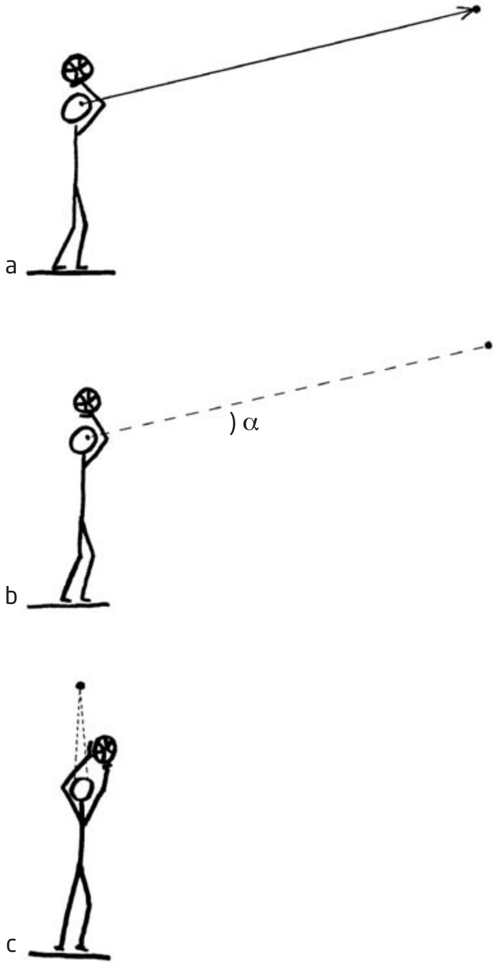
Much research has been done to identify the information sources used in goal-directed movement. For example, the relative rate of optic expansion of an approaching object has been found to guide successful catching (e.g., Tresilian, 1993), while the zeroing out of optic acceleration has been identified as the perceptual basis of the interception of fly balls (Chapman, 1968; Dannemiller, Babler, & Babler, 1996; Michaels & Oudejans, 1992). Optic flow information has also been found to play a role in the control of both steering and walking (Wann & Swapp, 2000; Warren, Kay, Zosh, Duchon, & Sahuc, 2001). Within the context of these investigations, it has become apparent that the optic variables that are relevant to the control of goal-directed action may be picked up through both retinal and extra-retinal processes. For instance, information from the neck muscles may help to detect optic acceleration in catching fly balls (Oudejans, Michaels, Bakker, & Davids, 1999), while the orientation and movements of head and eye appear important in the control of heading (Loomis, 2001; Ooi, Wu, & He, 2001; Royden, Crowell, & Banks, 1994; Warren, 1998). Identification of the sources of information that are exploited by humans performing goal-directed actions is not only important from a theoretical point of view, but may also have implications for a broad range of practical applications, including virtual environments (e.g., Tarr & Warren, 2002) and robotics (e.g., Kurazume & Hirose, 2000; Rushton & Wann, 1999). Against this background, it seems especially useful to examine optimal performance in tasks with high accuracy demands, such as sport actions performed by expert athletes. The reason is that, in the course of many years of practice, expert performers are likely to have become attuned to the variables that are most useful for the control of specific actions.

In the present study we examined what information sources are used by expert basketball players as they organise and deliver a basketball shot. Like most daily activities, basketball shooting occurs in a rich environment where multiple information sources are available that may be used to guide the shooting action. In addressing the topic of interest, we proceed by identifying the information sources that, in principle, could be sufficient for successful basketball shooting. This initial step was constrained by findings of previous research indicating that players typically look at the basket just before and during the shooting movements (Chapter 2; Vickers, 1996), suggesting that sources of information essential for the localisation of the target may be available to the player by directing their gaze at the basket (Oudejans, Koedijker, Bleijendaal, & Bakker, 2005). Based on this observation we assumed that the determination of the relative position of the basket would not be critically dependent on information sources that require looking away from the basket, such as the horizontal distance to the basket. Moreover, research on the temporal aspects of basketball shooting has revealed that even though shots still landed in the vicinity of the target when vision was prevented during movement execution, accuracy was significantly better with vision (Chapter 3). These findings indicated that, although visual information gathered before the shot can contribute to spatial accuracy, basketball shooting strongly depends on visual information that is picked up during movement execution, particularly towards ball release (Chapter 2). From this it follows that the information sources under scrutiny should be continuously available during movement execution.

In three-dimensional space, the location of a target relative to an observer must be perceived both in the right-left direction (*y*-axis) and in depth (*x*-axis). It has been shown that players orient to the basket in the *y*-direction relatively early before initiating the shooting movement (Ripoll, Bard, & Paillard, 1986). To align the midline of the body with the basket, the player can use kinesthetic information (Wu, He, & Ooi, 2005), neck proprioception and vestibular information (e.g., Karnath, Reich, Rorden, Fetter, & Driver, 2002; Karnath, Sievering, & Fetter, 1994). However, we were primarily interested in the contribution of information sources that could be used to locate the target along the sagittal plane through player and basket, rather than the vertical plane parallel to the backboard. The reason is that errors along the *x*-axis are always larger than those along the *y*-axis under a variety of visual conditions (Chapter 3), probably because the shooting movement evolves mainly along the player's sagittal plane.

The exact location of the basket in depth relative to the player's position can be defined by a vector **v** running from the eye to the target (Figure 5.1a). Like any vector, **v** is defined by its direction α and magnitude d. The direction α, which has also been called the angle of elevation (e.g., McLeod, Reed, & Dienes, 2003, 2006; cf. Ooi et al., 2001), indicates that the basket is positioned somewhere along the player's line of sight when he or she is looking at the basket (Figure 5.1b). In principle, information related to α can be picked up kinesthetically, i.e., through sensory information about the body's configuration as provided by muscle spindles, Golgi tendon organs and the vestibular apparatus (e.g., Karnath, et al., 1994). The magnitude d reflects the absolute distance between the player's eyes and the basket. In a well-lit environment, there are plenty of information sources pertaining to distance (e.g., convergence and accommodation, occlusion, height in the visual field, binocular disparity, motion parallax, relative size, familiar size). When the target is reduced to a single dot in a darkened environment the only remaining information sources are convergence and accommodation, binocular disparity, and motion parallax. Convergence (in association with lens accommodation) is the angle between the optical axes of the two eyes. As the eyes fixate at a target, oculomotor information about the eyes' convergence movements relate to distance because they will converge less as the physical distance increases, albeit that its effective range is limited to objects within 3 m (Leibowitz, Shina, & Hennessy, 1972). Binocular disparity can inform about distance through dissimilarities in the relative position of the object projected on the eyes' retinas (Figure 5.1c). Although its effectiveness diminishes with increased distance, it is thought to be useful up to 10 m (Cutting & Vishton, 1995). Absolute motion parallax is the apparent motion of a target due to a change in the player's position (Philbeck & Loomis, 1997); thus, for a given movement of the player, the apparent motion of the target will be larger when the player is closer to it. Motion parallax is thought to be informative about the distance of an object within 5 m (Cutting & Vishton). Besides these information sources, the official height of the basket (3.05 m) is a relevant rule-based constraint in basketball shooting, which might be exploited in determining the relative position of the basket. During years of extensive practice, players may have calibrated their actions and perceptions to the height of the basket (Withagen, 2004). Thus, the height of the basket may prove important in basketball shooting because, in principle, it may be combined with any one of the information sources discussed in the preceding to disambiguate the location of the basket. Although these information sources are available when the player looks at the basket and may be used to determine the location of the basket relative to the player, it is unknown to what extent they contribute to successful shooting.

In the present study, we investigated the visual information that is used in the online control of basketball shooting. To this aim, we created an experimental condition in which there was only one dot of light attached to the rim in an otherwise dark room (one-dot condition), which, in principle, could only provide information about d and α. We hypothesised that these two information sources would be sufficient for successful basketball shooting, in combination with (knowledge about) the official height of the basket. To evaluate whether players accurately perceived the location of the target, we repositioned the basket between each trial and measured the landing position of the ball in the plane of the rim. We performed three experiments to test whether the information sources available under the one-dot condition are indeed sufficient for basketball shooting, and to assess the relative contributions of d, α, and (knowledge about) the official height of the basket to shooting performance. In Experiment 1 we



:: Figure 5.1

Vector **v** runs from the player's eye to the basket, which is represented by the filled circle (a; side view). When the player is looking at the basket, the angle of elevation α indicates that the basket is positioned anywhere along the player's line of sight (b; side view). As the player looks at the basket, convergence and binocular disparity can inform about the distance between player and basket (c; back view).

investigated whether having information available about d and α only, given the height of the basket, would be sufficient for successful performance. In Experiment 2 we controlled the availability of eye convergence and binocular disparity while reducing absolute motion parallax to a negligible minimum in order to evaluate the relative contribution of d. Finally, in Experiment 3 we changed the basket's height, thereby undermining any reliance on knowledge regarding this rule-based informational constant, and examined the resulting pattern of errors to evaluate the contribution of α information.

:: Experiment 1

The goal of the first experiment was to determine how well expert basketball players shoot baskets, set at official height, when they only have information available related to d and α. We asked expert players to execute jump shots under three visual conditions (light, one-dot and dark) while changing the horizontal position of the basket on each trial. We evaluated shooting performance in terms of percentage of hits and endpoint errors (i.e., the distance between the centre of the ball and the centre of the basket in the horizontal plane defined by the rim of the basket). If players were still able to successfully perform jump shots this would imply that information was available during movement execution with regard to the location of the basket and that the basketball players organised the jump shots on the basis of this information.

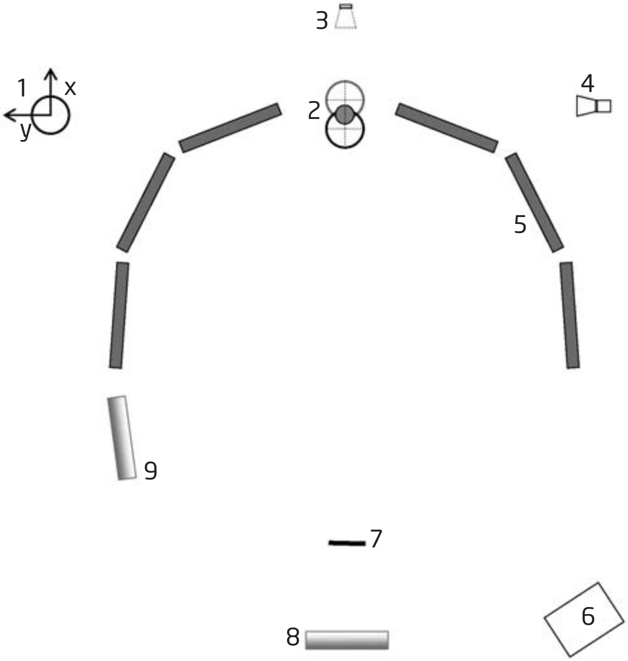
:. Method

: Participants

Ten expert basketball players (all men, mean age 26.4 years, *SD* = 5.3) participated in the experiment. All played either at the guard or forward position in the two highest stand-up basketball leagues in The Netherlands for 8.3 years on average (*SD* = 4.3), and were the best shooters of their respective teams. The experiment was approved by the local ethics committee of the Faculty of Human Movement Sciences.

: Setup

We set up a standard basketball backboard and rim in a large laboratory and placed two digital video (dv) cameras to record the rim under a top and side view angle, respectively, as well as the area around the basket at 25 Hz (see Figure 5.2). Both cameras were set to manual focus and were activated during the entire experiment. They were connected to dv recorders that time-coded the images enabling later synchronisation. The starting position of the participants was marked on the floor. Two light sources (4 × 40 W each, Kino Flo BAL-410, California), were placed behind the starting position and on the



:: Figure 5.2

Experimental setup with (1) the coordinate system used; (2) basket with 450 mm of diameter in the near and far positions (350 mm apart), and a 225-mm diameter ball superimposed in the overlap area that is 100 mm at its widest; (3) top view camera 3 m above the baskets; (4) side view camera 3 m to the side of the setup; (5) six screens that enclosed the experimental space; (6) digital video recorders and light switch operator; (7) starting position for the participant; (8 and 9) light sources.

side of the setup. These lights could be switched on and off simultaneously by operating a single power supply, darkening or lightening the environment completely within 40 ms. The location of the basket could be identified by a small electroluminescent white sheet (2 V, Pacel Electronics, UK) taped to the front of the rim. Because its size could, in principle, provide distance information to the participants, we used a 1-cm^2 patch of this material (one-dot). When lit in an otherwise dark room, this patch of white sheet was visible up to 10 m as a single dot of light without the rim and the backboard being visible. Assuming a focal length of 17 mm, the dot's retinal image at distances of 3.60 m and 5.13 m (minimal and maximal distances across the three experiments) was 0.045 mm and 0.033 mm, respectively, and changes of 350 mm in those distances (as induced by the experimental manipulation, see below) corresponded to changes in the dot's retinal image of 0.004 mm or 0.003 mm, respectively, which were deemed too small to be used as information for distance. For one of the analyses (see Data reduction) four calibration points were marked equidistantly on top of the rim, at the front, back, right and left. For another analysis we used a cube (40 cm^3) with 24 calibration points, which was placed on the basket and recorded on video before each session. An official regulation-sized, FIBA basketball (Spalding) was used.

: Design

The shots were taken under three visual conditions, the order of which was randomised across participants: a light condition (L) in which the environment remained fully lit during the entire trial, a one-dot condition (O) in which the environment was darkened at the initiation of the trial except that one dot was lit on the front of the rim, and a dark condition (D) in which the environment was fully darkened at the initiation of the trial. There were also two position conditions, between which the basket was randomly repositioned before each trial. These positions were located at 4.78 and 5.13 m from the starting position of the participant. Participants were ignorant of those positions, although they were informed that the basket could be repositioned between trials. We chose to manipulate the participant-basket distance by changing the position of the basket rather than that of the participant in order to prevent the participant from becoming aware of the change in distance.

: Procedure

After a brief explanation of the task the participants gave their written informed consent. Participants took several warm-up shots that also served the purpose of getting used to the experimental environment. After 5 familiarisation trials, in which the basket was randomly repositioned, participants performed 26 shots under each visual condition for a total of 78 trials in the entire experiment. Before each trial the participant was instructed to dribble the ball in place, facing one of the light sources, while the basket was positioned. At a cue signal, the participant turned around and took a jump shot in one continuous self-paced movement. Under the dark and one-dot condition the lights were turned off at the cue signal and turned back on when the participant landed on his feet enabling video recordings of the ball's trajectory (thus allowing visual feedback from the shot). This moment was identified visually by a glow-in-dark star that was taped for this purpose to the participant's shoe at heel level. The lights were off for about 1.6 s during which the player turned around and performed the jump shot (i.e., launched the ball on its flight trajectory). Once the environment was illuminated it took no longer than 100 ms for the ball to appear in the video images while travelling downward. The visible part of the trajectory lasted for about 450 ms. After each trial the result of the shot was registered as hit or miss, and the ball was returned to the participant. The experiment lasted about one hour.

: **Data reduction**

We examined the landing positions of the ball in a coordinate system defined around the centre of the rim in the near position (i.e., $x = 0$, $y = 0$, $z = 3050$ mm), with $x < 0$ representing values between the centre of the rim and the participant, and $x > 0$ representing overshoots (see Figure 5.2 for the orientation of the axes). Landing positions were determined for each trial using two different 3D digitisation procedures (available in WinAnalyse, Mikromak), depending on whether or not the ball's trajectory was interrupted before intersecting the horizontal plane of the rim. For uninterrupted trajectories we first used the video footage of the side view image to determine the image frame at which the ball intersected the plane of the rim (i.e., at $z = 3050$ mm) to then digitise the four calibration points and centre of the ball on the corresponding image frame on the video footage on the top view image. For trajectories that were interrupted by the backboard we used conventional 3D digitisation followed by a second-order polynomial fitting procedure to estimate the ball's position at the time it would have touched the plane of the rim if unobstructed in its travel. On both methods a ball whose centre intersected the plane of the rim was measured as an undershot of the rim's centre by about half the radius of the ball, i.e., 112.5 mm (see Figure 5.3). Therefore, this value was added to all *x*-data (Chapter 3). Note that this procedure had no consequences for the data analyses because we were only interested in the relative error between conditions.

: Statistical analyses

We submitted the average percentage of hits to a repeated measures ANOVA with within-subject factors visual condition (3 levels: light, one-dot, dark) and position (2 levels: near, far). We also submitted the errors along the *x*-axis and the *y*-axis to repeated measures ANOVAs with within-subject factors visual condition (3 levels: light, one-dot, dark) and position (2 levels: near, far) and between-subjects factor participants. To examine relevant interaction effects we performed additional repeated measures ANOVAs and one-way ANOVAs as described in the Results section. Significance level was set at $p < .05$. Where appropriate, degrees of freedom were adjusted for violations of sphericity using the Huynh-Feldt correction. Significant main effects were examined further using pairwise comparisons with the Bonferroni correction procedure.

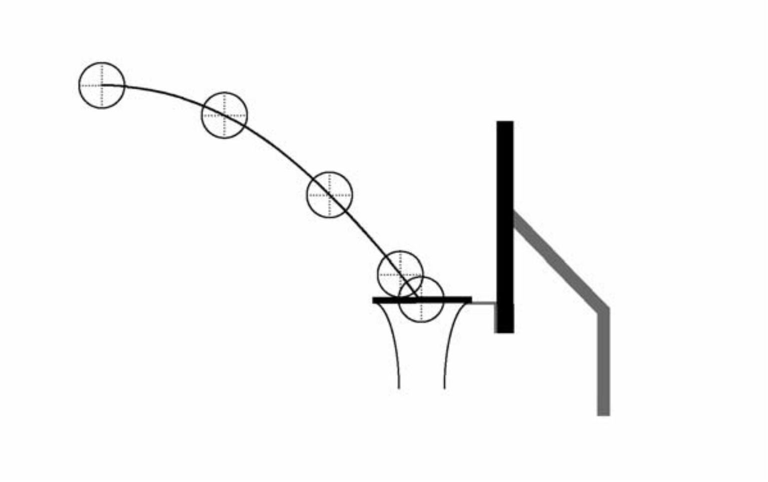
:. Results

: Percentage of hits

The percentage of hits differed significantly, $F_{2,\,18} = 59.98$, $p < .001$, $\eta^2 = .87$, across and between each of the three visual conditions (L: $M = 67.7\%$, $SE = 3.5$; O: $M = 42.7\%$, $SE = 3.9$; D: $M = 16.5\%$, $SE = 2.2$, all ps < .01), in the absence of significant effects of the basket's position and the visual condition by position interaction. No significant differences were found between the first and the last 13 trials of each condition, all $t_9 < .517$, all ps > .62, indicating that no learning had occurred in those conditions.

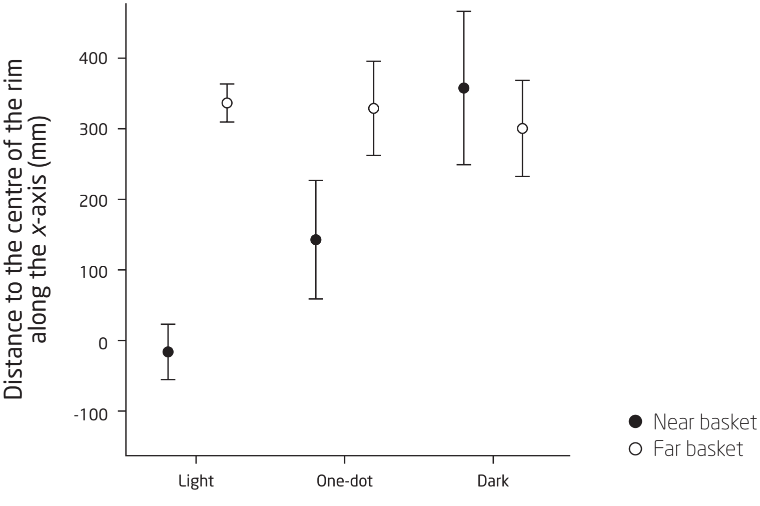
: Average error

Shooting errors along the *x*-axis differed significantly, $F_{1.6,\,196} = 34.86$, $p < .001$, $\eta^2 = .23$, between the three visual conditions (L: $M = 158$, $SE = 7$; O: $M = 234$, $SE = 12$; D: $M = 327$, $SE = 19$, all ps < .01), in the presence of a significant effect of participant, $F_{9,\,120} = 6.22$, $p < .001$, $\eta^2 = .32$. In addition, a significant effect of position was found, $F_{1,\,120} = 170$, $p < .001$, $\eta^2 = .59$, indicating that landing positions differed between basket positions (near: $M = 159$, $SE = 10$; far: $M = 319$, $SE = 8$). A significant Visual Condition × Position interaction, $F_{2,\,240} = 71.1$, $p < .001$, $\eta^2 = .37$, revealed that error patterns depended on visual condition (see Figure 5.4). Finally, a significant Visual Condition × Participant interaction, $F_{14.7} = 3.35$, $p < .001$,



:: Figure 5.3

Side view of the basket and the ball trajectory when it touches the plane of the rim and when its centre passes through the centre of the rim.



:: Figure 5.4

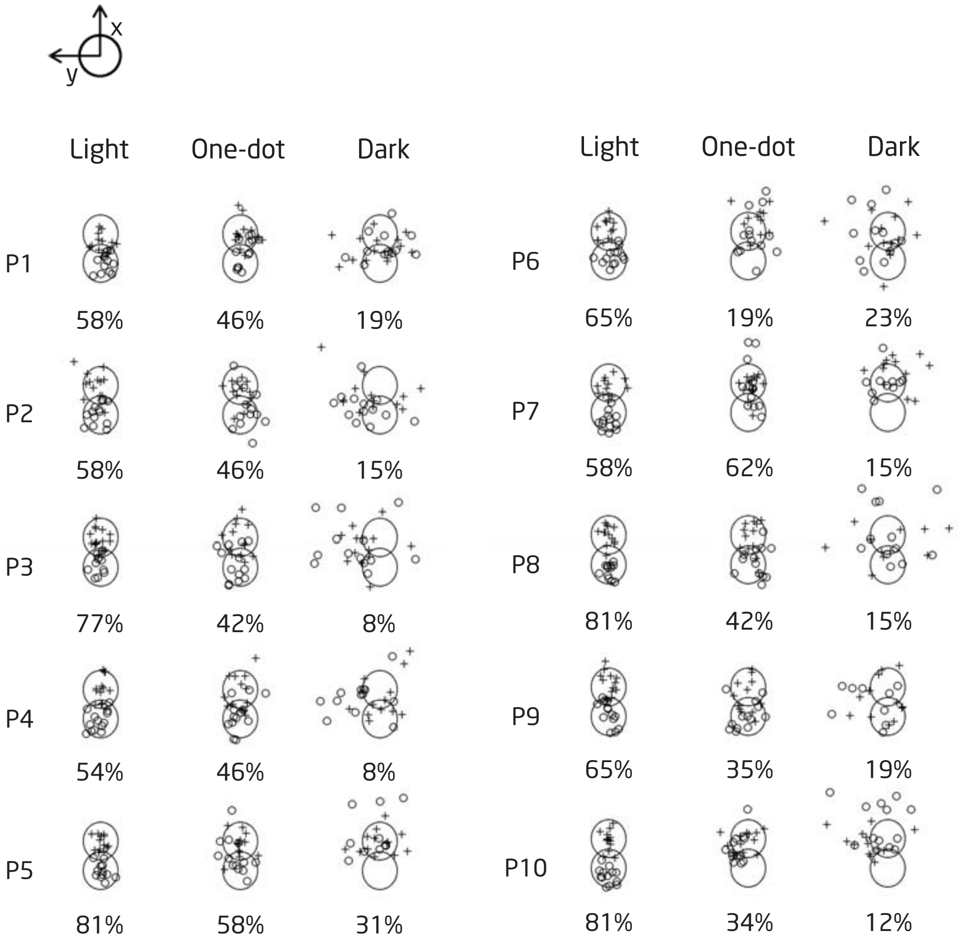
Average landing positions of the ball relative to the two positions of the rim under the three visual conditions, light, one-dot and dark. Bars represent the 95% confidence interval of the mean. Filled circles represent averages for the near position of the basket while open circles represent averages for the far position of the basket. The ball travelled from negative to positive values.

$\eta^2 = .20$, and a significant Visual Condition × Position × Participant interaction, $F_{18} = 1.66$, $p < .05$, $\eta^2 = .11$, revealed that the error patterns of the participants differed across experimental conditions.

To further examine the Visual Condition × Position interaction, we performed two 2 × 2 ANOVAs with within-subject factors visual condition (one-dot vs. light in the first ANOVA and one-dot vs. dark in the second ANOVA) and position (near vs. far). Both ANOVAs revealed significant effects of visual condition, $F_{1,\,9} = 5.24$, $p < .05$, $\eta^2 = .37$; $F_{1,\,9} = 6.39$, $p < .05$, $\eta^2 = .42$, and position, $F_{1,\,9} = 352.85$, $p < .001$, $\eta^2 = .98$; $F_{1,\,9} = 5.76$, $p < .05$, $\eta^2 = .39$, as well as a significant Visual Condition × Position interaction, $F_{1,\,9} = 16.41$, $p < .01$, $\eta^2 = .65$; $F_{1,\,9} = 26.43$, $p < .01$, $\eta^2 = .75$. These results indicated that the error pattern under the one-dot condition was significantly different from both the light and dark conditions (Light: near *M* = -17, *SE* = 18, far *M* = 333, *SE* = 12; One-dot: near *M* = 141, *SE* = 37, far *M* = 326, *SE* = 29; Dark: near *M* = 356, *SE* = 48, far *M* = 298, *SE* = 29).

To further examine the Visual Condition × Position × Participant interaction, we performed one-way ANOVAs on the shooting errors under each visual condition with basket position (near vs. far) as the only within-subjects factor. Under the light condition, all participants showed significant differences between the errors for the two basket positions, $F_{1,\,24} > 32.97$, *p*s < .001. The difference between errors for the near and far positions was 353 mm (*SD* = 55), i.e., similar to the actual displacement of the basket, suggesting that they accurately perceived the (changed) location of the basket and delivered the shots accordingly (Figure 5.5). Under the one-dot condition, 7 out of 10 participants showed significant differences between the errors for the two basket positions, $F_{1,\,24} > 5.22$, *p*s < .05, as they shot shorter at the near target and longer at the far target, resulting in an average difference in shot locations of 237 mm (*SD* = 36, *n* = 7), i.e., somewhat less than the actual displacement of the basket. In the dark condition, only 2 out of 10 participants showed significant differences between the errors for the two basket positions, $F_{1,\,24} > 5.12$, *p*s < .05, but in this case they shot shorter at the far target and longer at the near target. Hence, in the dark condition all participants showed the expected inability to distinguish between the basket positions (*M* = -58 mm, *SD* = 127, *n* = 10). In combination, these results suggested that sufficient information was available under the light and one-dot conditions that could be used online for successful shooting, whereas in the dark condition no information about the target could be used online.

Also for the shooting errors along the *y*-axis a significant effect of visual condition was found, $F_{1.4,\,164} = 23.60$, $p < .001$, $\eta^2 = .16$, with pairwise comparisons revealing significant differences between the dark and the two other visual conditions (L: *M* = -1, *SE* = 5; O: *M* = 9, *SE* = 7; D: *M* = -87, *SE* = 17, ps < .001). Also the effect of participant was



:: Figure 5.5

Individual landing positions of the ball in the plane of the rim under the three visual conditions, light, one-dot and dark. Landing positions when the basket was in the near position are represented by (o) and when the basket was in the far position by (+). Percentage of hits is shown for each participant and visual condition.

significant, $F_{9, 120} = 6.28$, $p < .001$, $\eta^2 = .32$, as was the effect of position, $F_{1, 120} = 12.83$, $p < .001$, $\eta^2 = .10$, as shooting errors were smaller for shots to the far target (near: $M = -51$, $SE = 9$; far: $M = -1$, $SE = 10$). A significant Visual Condition × Participant interaction, $F_{12.3} = 2.24$, $p < .05$, $\eta^2 = .14$, revealed that shooting errors along the *y*-axis under the three visual conditions differed across participants (see Figure 5.5). There was also a significant Visual Condition × Position interaction, $F_{1.4, 166} = 4.94$, $p < .05$, $\eta^2 = .04$, in the absence of a significant Visual Condition × Position × Participant interaction.

To further examine the Visual Condition × Position interaction along the *y*-axis, we executed two 2 × 2 ANOVAs with within-subject factors visual condition (one-dot vs. light in the first ANOVA and one-dot vs. dark in the second ANOVA) and position (near vs. far). The first ANOVA yielded only a significant effect of position, $F_{1, 129} = 4.29$, $p < .05$, $\eta^2 = .03$, which revealed that shots fell to the right of the near basket and to the left of the far basket ($M = -7$, $SE = 9$; $M = 15$, $SE = 6$, respectively). The second ANOVA revealed significant effects of visual condition, $F_{1, 129} = 26.07$, $p < .001$, $\eta^2 = .17$, position, $F_{1, 129} = 10.13$, $p < .01$, $\eta^2 = .07$, as well as a significant Visual Condition × Position interaction, $F_{1, 129} = 3.9$, $p = .05$, $\eta^2 = .03$. Further analyses of these effects disclosed that under the dark condition errors were relatively large to the right of the basket in both positions (near: $M = -141$, $SE = 27$; far: $M = -33$, $SE = 27$), whereas under the one-dot condition there were small rightward errors to the near basket and leftward errors to the far basket ($M = -6$, $SE = 12$; $M = 25$, $SE = 11$, respectively).

:. Discussion

The goal of this first experiment was to examine how well expert basketball players performed the jump shot when only information related to d and α was available during the shot. In terms of the percentage of hits, the results under the full light condition (68%) reflected a good level of performance that is characteristic of top level basketball players taking jump shots under unrestricted laboratory conditions (for comparison, the percentage of hits in the light conditions of the studies in Chapter 2, and Oudejans, van de Langenberg, & Hutter, 2002, were 61.3% and 61.5%, respectively). Although there were important decrements in performance under the one-dot condition (in the order of 25%), participants were still successful in 43% of the trials when only a single dot of light was visible in an otherwise dark room. As the percentage of hits in the one-dot condition (43%) was markedly higher than in the dark condition (17%), participants must have used information that was available in the one-dot condition during movement execution. As no visual information was available during movement execution in the dark condition, the percentage of hits achieved in this condition should be attributed to the use of visual information that was obtained before the trials, as well as behavioural strategies specific to this condition. For instance, participants reported that they deliberately placed their feet at exactly the same starting position in order to reproduce their pivot turn as consistently as possible. Furthermore, they jumped lower than in the one-dot and light conditions. These behavioural adaptations to the absence of visual information during movement execution are effective in that they facilitate the reproduction of similar shots on consecutive trials. If players were to randomly shoot at an area of 1.1 m diameter that includes the basket, already 17% will result in hits regardless of changes in the basket's position (i.e., without taking into account the use of the backboard, spin, or angle of entry, all of which can increase the chances of success and thus the calculated diameter). Hence, to better understand the performance under the three conditions, we examined the pattern of landing positions as the position to the basket was varied randomly between the near and far position.

It appeared that in the light and one-dot conditions participants could distinguish between the two positions of the basket while they could not in the dark. Under the light condition, the difference in errors along the *x*-axis to the two basket positions was similar to the actual displacement of the basket, which was reflected in the data of all participants (i.e., 353 vs. 350 mm). This suggests that under the light condition participants perceived the correct location of the basket and performed the shot accordingly. Under the one-dot condition, 7 out of 10 participants still showed a significant difference between errors to the two basket positions, albeit smaller (237 mm) than in the light condition. In contrast, shooting errors did not differ significantly between the two basket positions in the dark condition, reflecting the absence of online visual guidance under this condition. As stated earlier, in this condition participants appeared to have reverted to a strategy aimed at reproducing the same shooting movements based on visual information gathered before the trial.

Some methodological aspects of this experiment are noteworthy and of consequence for subsequent experiments. First, although the percentages of hits were in accordance with the shooting errors (e.g., both differed across the three visual conditions), only the latter measure provides insight into the use of visual information in preparing and performing the shooting action. Second, the shift in the position of the basket had to be large enough for differences in errors to be detectable, but not so conspicuous that participants recognised that there was a near and far basket position; therefore, basket positions were manipulated by only 350 mm. This manipulation was successful in both regards because differences in errors could be detected under the light and one-dot condition, whereas no indications were found that participants learned the basket positions in the course of the experiment. Third, our results showed that errors were more pronounced along the *x*-axis than along the *y*-axis, perhaps because the position of the basket was manipulated only along the *x*-axis. The errors along the *y*-axis were largest in the dark condition, but even in this condition errors along the *x*-axis were more pronounced than along the *y*-axis. As the present study is focused on how expert basketball players perceived the location of the basket in depth, errors in the *y*-axis will not be reported in the subsequent experiments.

In principle, in basketball shooting the basket can be located in depth by detecting the upward direction of the basket and its distance away from the player (α and d), possibly in combination with (knowledge about) the basket's official height. To further examine the relative contributions of these information sources, we conducted two additional experiments.

:: Experiment 2

The purpose of the second experiment was to evaluate the contribution of information sources that could be picked up during movement execution and that related to distance (d). Under normal visual conditions information about the distance of the basket may be gleaned from several sources, including ground surface information and the familiar size of the backboard and basket (Fitzpatrick, Pasnak, & Tyer, 1982). As discussed, these information sources can be used offline but at the expense of accuracy. The information sources related to d that can be used during movement execution in the one-dot condition are convergence (and accommodation, both to a limited extent), binocular disparity, and absolute motion parallax (Cutting & Vishton, 1995). To asses the contribution of distance information to the online control of basketball shooting, we had to compare shooting performance when d was available with when d was not available, implying that for the one-dot condition we needed to control for the use of convergence, binocular disparity and motion parallax.

Both convergence and binocular disparity are binocular information sources, which can be manipulated by covering one eye. Under monocular vision only one eye is directed at the target and thus information about the inward direction of both eyes is disallowed. Also the disparity between the projections of the dot on the retinas cannot be used in this case. Motion parallax can be controlled by having the head stationary before and during the movement, but this may have undesired effects. A pilot measurement showed that stand-up basketball players were unable to shoot properly if required to keep their head still, either because they failed to comply with the instruction or because their shooting accuracy suffered greatly. Since our experimental paradigm relied on the evaluation of performance differences between basket positions, it was essential that the participants would still be able to shoot accurately when their head motion was restricted. In view of those considerations, we invited expert wheelchair basketball players to participate in the experiment because they can shoot accurately with little head motion (for example when taking free throws), and explicitly instructed them to keep their head and trunk as still as possible before shooting. To the extent that motion parallax information was indeed eliminated (or greatly reduced) in this manner, the one-dot monocular condition afforded no information related to d during shooting, whereas the one-dot binocular condition afforded obtaining information related to d by means of eye convergence and especially binocular disparity (the distance to the target was kept within 4 m). Thus, compared to the one-dot binocular condition, marked decrements in performance under the one-dot monocular condition would imply that information about d is used online in basketball shooting.

:. Method

: Participants

Thirteen expert wheelchair basketball players (all men, mean age 31.2 years, *SD* = 8.3 years) participated in the experiment. All played either at the guard or forward position in the two highest leagues in The Netherlands for 14.9 years on average (*SD* =8.4), and were among the best players of their respective teams. Their average functional classification was 3.4 (*SD* = 1.1), ranging from severely disabled to not disabled (1 and 4.5, respectively).

: Setup

The same setup as in Experiment 1 was used.

: Design

The shots were taken under the light (L) and one-dot (O) condition as described for Experiment 1 and under binocular (Bi) and monocular (Mo) vision. The order of the resulting four conditions was randomised across participants with the constraint that ocular conditions were allowed to change only once. There were also two position conditions nested within the four main conditions as the basket was positioned randomly on each trial at either 3.60 or 3.95 m away from the starting position. As in Experiment 1, the participant did not know the basket's positions, although participants were informed that the basket could be repositioned between trials. Participants used their own competition wheelchair and were instructed to remain seated as still as possible, especially immediately before shooting.

: Procedure

After a brief explanation of the task the participants gave their written informed consent. The dominant eye was determined with the "hole-in-the-card" test (Brod & Hamilton, 1971). In the monocular conditions the participants wore an eye-patch over the non-dominant eye. Participants took several warm-up shots that also served the purpose of getting used to the experimental environment. After 5 familiarisation trials, in which the basket was randomly repositioned, participants executed 24 shots under each visual condition, for a total of 96 trials. Before each trial the participant was instructed to hold the ball while facing a light-reflecting umbrella that occluded the basket. During this time the basket was (re)positioned. At a cue signal, the umbrella was rapidly removed, prompting the participant to shoot in a continuous self-paced movement. Participants received visual feedback from the shot. Under the one-dot condition the lights were turned off at the cue signal and turned on again when the movement of the participant's arm was completed, which could be observed by a glow-in-dark star that was taped for this purpose to the participant's shirt at shoulder level. Once the environment was illuminated it took less than 100 ms for the ball to enter the view of the cameras and remained in free flight for about 450 ms. After each trial the result of the shot was recorded as hit or miss, and the ball was returned to the participant. The experiment lasted about one hour.

: Data reduction

Data reduction was the same as in Experiment 1.

: Statistical analyses

We submitted the average percentage of hits to a repeated measures ANOVA with within-subject factors visual condition (2 levels: light, one-dot), and ocular condition (2 levels: binocular, monocular) and the errors along the *x*-axis to a repeated measures ANOVA with within-subject factors visual condition (2 levels: light, one-dot), ocular condition (2 levels: binocular, monocular), and position (2 levels: near, far). Significant interactions between ocular condition and position under the one-dot condition were analysed further by submitting the data to a repeated measures ANOVA with within-subject factors ocular condition (2 levels: binocular, monocular), and position (2 levels: near, far). The Huynh-Feldt correction was applied in case of violations of sphericity. The significance level was set at $p < .05$.

:. Results

: Percentage of hits

The percentage of hits was significantly larger, $F_{1,12} = 9.67$, $p < .01$, $\eta^2 = .45$, in the light condition than in the one-dot condition (L: $M = 46.8\%$, $SE = 4.4$; O: $M = 35.0\%$, se = 2.4). It was also significantly larger, $F_{1,12} = 6.30$, $p < .05$, $\eta^2 = .34$, in the binocular condition than in the monocular condition (Bi: $M = 45.0\%$, $SE = 3.7$; Mo: $M = 36.7\%$, $SE = 3.0$). Importantly, there was no significant interaction between visual and ocular conditions. Although the percentage of hits was about 8% lower in the monocular than in the binocular condition, this reduction was present in both the light and the one-dot condition (L Bi: 51%, $SE = 19$; L Mo: 42%, $SE = 16$; O Bi: 39%, $SE = 11$; O Mo: 31%, $SE = 10$). No significant differences were found between the first and the last 12 trials of each visual-ocular condition, all $t_{12} < .646$, all *p*s > .53, indicating that no learning had occurred in those conditions.

: Shooting error

Visual condition, ocular condition, and basket position all had significant (main) effects on shooting error (see Figure 5.6). The significant effect of visual condition, $F_{1,12} = 8.14$, $p < .05$, $\eta^2 = .40$, occurred because the basket was overshot more in the one-dot condition than in the light condition (L: $M = 99$, $SE = 17$; O: $M = 194$, $SE = 36$).

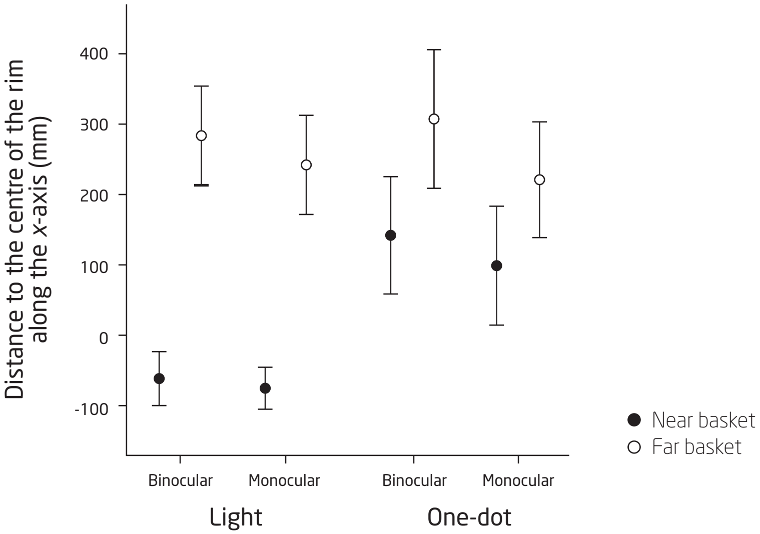
The significant effect of ocular condition, $F_{1,12} = 5.30$, $p < .05$, $\eta^2 = .31$, occurred because participants overshot the basket more under the binocular condition than under the monocular condition (Bi: $M = 169$, $SE = 24$; Mo: $M = 124$, $SE = 25$), while that of position, $F_{1,12} = 197$, $p < .001$, $\eta^2 = .94$, occurred because on average the shots to the far basket landed further along the *x*-axis than shots to the near basket (near: $M = 28$, $SE = 20$; far: $M = 265$, $SE = 27$ mm). In addition, there was a significant Visual Condition × Position interaction, $F_{1,12} = 42.89$, $p < .001$, $\eta^2 = .78$, which occurred because errors to the two basket positions were more position dependent under the light condition (near: $M = -66$, $SE = 10$; far: $M = 264$, $SE = 28$) than under the one-dot condition (near: $M = 122$, $SE = 36$; far: $M = 265$, $SE = 38$). The Visual Condition × Ocular Condition and Visual Condition × Position × Ocular interactions were not significant.

In a subsequent analysis, we found a significant effect of ocular condition under the one-dot condition, $F_{1,12} = 5.67$, $p < .05$, $\eta^2 = .32$, because the basket was overshot more under binocular than under monocular viewing (Bi: $M = 226$, $SE = 39$; Mo: $M = 161$, $SE = 37$ mm). In addition, a significant effect of position, $F_{1,12} = 65.47$, $p < .001$, $\eta^2 = .85$, was found, because shots to the far basket landed further along the *x*-axis than shots to the near basket (far: $M = 265$, $SE = 38$; near: $M = 122$, $SE = 36$). Importantly, the Position × Ocular condition interaction was not significant, implying that the perceptual distinction of the two basket positions was as difficult under the binocular as under the monocular condition.

:. Discussion

The purpose of this second experiment was to examine to what extent information related to the absolute distance to the basket, d, is used in basketball shooting during movement execution. Wheelchair basketball players were invited to perform shots to baskets placed at two different positions, either binocularly or monocularly, under two visual conditions (light and one-dot). They were instructed to sit as still as possible and to minimise head and trunk movements in an attempt to eliminate motion parallax. Hence, under the one-dot condition, information about d could only be obtained online through eye convergence and binocular disparity, that is, under binocular but not under monocular viewing conditions.

First, although the percentage of hits was smaller under the monocular than under the binocular conditions, these decrements were similar under the light and the one-dot condition. While under the light condition several other information sources related to d were available besides eye convergence and binocular disparity, no such information was available under the one-dot monocular condition during movement execution. Therefore, the results concerning the percentage of hits suggested that



:: Figure 5.6

Average landing positions of the ball relative to the two positions of the rim under the two visual conditions, light and one-dot, and two ocular conditions, binocular and monocular. Bars represent the 95% confidence interval of the mean. Filled circles represent averages for the near position of the basket while open circles represent averages for the far position of the basket. The ball travelled from negative to positive values.

participants did not rely on the online use of d in basketball shooting.

Second, the effects of visual condition and basket position on the shooting errors were similar to those found in Experiment 1 as it appears that participants could use the available information, albeit less so under the one-dot than under the light condition. As regards ocularity, the basket was undershot when viewed monocularly instead of binocularly. Undershooting under monocular viewing has also been found in reaching (e.g., Bingham & Pagano, 1998), where it has been argued that monocular viewing yields a "compression of distance" causing the observed undershooting. However, Loftus and colleagues (Loftus, Servos, Goodale, Mendarozqueta, & Mon-Williams, 2004) investigated this effect and argued that monocular viewing does not necessarily entail a systematic underestimation of distance, but rather augments perceptual uncertainty causing longer movement durations that may in turn result in the observed undershooting. This suggestion applies to the kinematics of prehension and whether a similar adaptation to uncertainty causes basketball undershooting is difficult to establish. In principle, however, if perceptual uncertainty caused the undershooting observed under the one-dot monocular condition, this would be likely to appear in the variability of the shooting errors. We therefore calculated the standard deviations of the shooting errors for each participant for each condition and submitted them to two ANOVAs (one under the light and one under the one-dot condition). Under the one-dot condition, a significant effect of ocular condition occurred, $F_{1,\,12} = 6.00$, $p < .05$, $\eta^2 = .33$, because the standard deviations were larger when viewing monocularly than binocularly. Under the light condition, no such significant difference was found. These results are in agreement with the perceptual uncertainty hypothesis as forwarded by Loftus et al. (2004).

Most importantly, the present results indicated that, under the one-dot condition, distinguishing between the two basket positions was equally difficult under binocular as under monocular viewing. Under the light condition participants may have relied on monocular information sources related to d (e.g., perspective from the lines on the backboard, size familiarity), thereby eliminating differences between binocular and monocular conditions. In contrast, under the one-dot condition, d could only be picked up during movement execution by means of eye convergence and binocular parallax (i.e., binocularly). The absence of an interaction effect between ocular condition and basket position under the one-dot condition suggests that the online use of d is not crucial for basketball shooting. It can be argued that discovering little or no change in performance following removal of binocular viewing does not necessarily mean that d is unimportant. Rather, what is evident is that participants were able to cope without the online use of that information. However, given the fairly good performance that was achieved under the information-poor one-dot condition, we conclude that d may not be used to guide basketball shooting. If so, participants must have used α to unambiguously determine the location of the basket, which implies the concomitant use of information about the basket height (either because information about basket's height was gathered before each trial or because the perception of α is calibrated to this height through extensive practice). Based on these considerations we conducted a third and last experiment to examine the contribution of α in the online guidance of basketball shooting.

:: Experiment 3

Although the results of Experiments 1 and 2 suggested that the angle of elevation α plays a role in the online control of basketball shooting, α was not explicitly manipulated in those experiments (although it varied each time the basket was repositioned). Therefore, an additional experiment was conducted to examine the contribution of α to the visual guidance of basketball shooting. Angle of elevation was manipulated by changing both the position and the height of the basket such that α would increase or decrease in a controlled fashion. The use of angle of elevation information has been reported for walking (Ooi et al., 2001; Philbeck & Loomis, 1997) and for catching baseballs (McLeod et al., 2003, 2006). The rationale for its usefulness derives from the fact that the angle of elevation (or declination) is an optical variable that is related directly to the direction of an observed object or target in the visual field. It can be picked-up by both kinesthetic and vestibular systems and is therefore, in part, made available through movement. Manipulating the basket's height is important because α is only uniquely related to the location of the basket if the basket's height is invariant and either known or perceived on each trial. Given the massive amounts of practice by expert players and the constancy of the height at which the basket is set, it is likely that perceptions and actions are calibrated to a specific height (Withagen, 2004). By changing the basket's height, that is, by heightening or lowering the basket relative to its standard official height, it is possible to break the unique relation between α and the location of the basket and thus to test the use of α information. If basketball shooting indeed depends on such information, then, in the one-dot condition, a heightened basket will be perceived as closer to the participant and therefore be undershot, whereas a lowered basket will be perceived as further from the participant and therefore be overshot (see Figure 5.7).

:. Method

: Participants

Twelve experienced basketball players (all men, mean age 26.2 years, *SD* = 4.2 years) participated in the experiment. All played either at the guard or forward position in the two highest stand up basketball leagues in The Netherlands for 10.3 years on average (*SD* = 4.2), and were the best shooters of their respective teams. Their average eye-height was 1.86 m (*SD* = 0.1).

: Setup

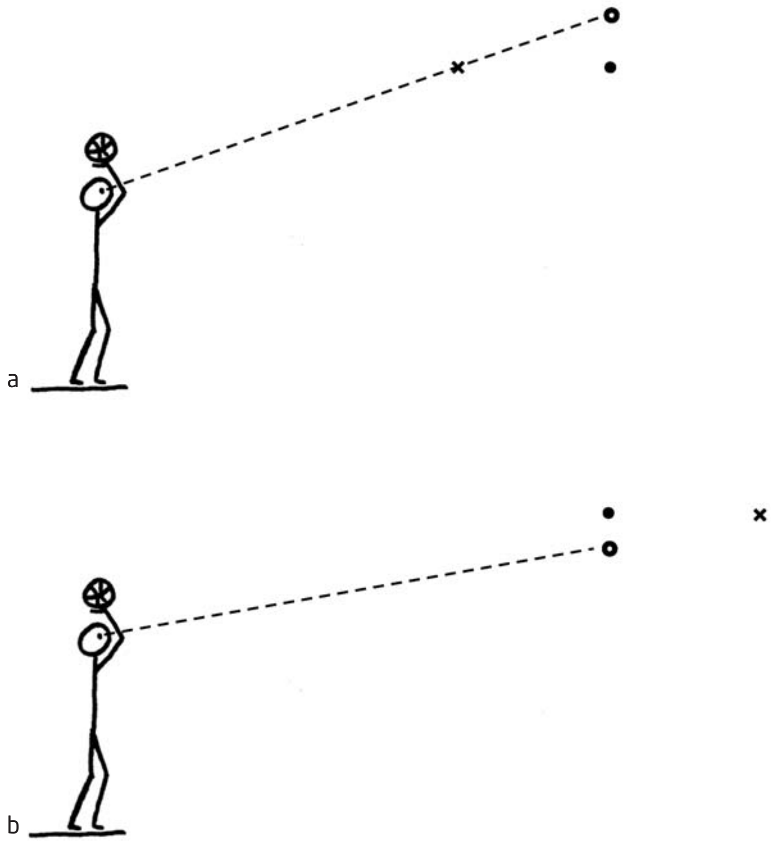
We used the same setup as in the previous experiments. However, in this experiment participants wore Plato Liquid Crystal glasses (Translucent Technologies, Toronto, Canada).

: Design

Shots were taken under the light (L), one-dot (O), and dark (D), as described for Experiment 1. In addition, there were two position conditions, as the basket was (re)positioned randomly on each trial at either 4.43 or 4.78 m away from the participant, and three basket height conditions, i.e., heightened, standard, and lowered. For the heightened and lowered conditions, the basket's height was changed such that the expected error in the *x*-axis would either be 350 mm before the centre of the rim (heightened condition) or behind the centre rim (lowered condition). We based the calculation of the different basket heights on each participant's eye-height (measured before the experiment) and the two position conditions. For example, for a participant with an eye-height of 1.85 m the rim was set at 3.17, 3.05, and 2.95 m for the near basket position, while it was set at 3.16, 3.05, and 2.96 m for the far basket position. As a result of this procedure, minimal and maximal heights of the basket across all participants were 2.94 and 3.18 m, respectively. Basket position and height conditions were randomised within each visual condition and the order of visual conditions was randomised across participants.

: Procedure

After a brief explanation of the task (which contained no information about the manipulation of the basket's height) the participants gave their written informed



:: Figure 5.7

Perceived target location if players use α in combination with the official height of the basket. A filled circle represents the basket set at the official height, an open circle represents the visible target (one-dot), and a cross represents the perceived location of the basket. If participants look at a heightened target α increases and therefore they perceive the target to be closer (a); conversely, participants perceive a lowered target to be further away (b).

consent. Participants took several warm-up shots that also served the purpose of getting used to the experimental environment. After 5 familiarisation trials, in which the basket was randomly repositioned, participants performed 30 shots under each visual condition, for a total of 90 trials. Each participant was instructed to dribble the ball in place, facing one of the light sources, while the basket was repositioned (both in height and position). At a cue signal, the participant turned around and took a jump shot in a continuous self-paced movement. After ball release, the experimenter turned on the liquid crystal glasses that participants were wearing to prevent vision from the basket. Participants were told that this was to prevent visual feedback from the shot, but in reality it served to obscure the manipulation of the basket's height. The experimenter provided verbal knowledge of results after each shot. Under the dark and one-dot conditions the lights were turned off at the cue signal and turned on after ball release when the participant landed on his feet. This moment was identified by a glow-in-dark star that was taped for this purpose to the participant's shoe at heel level. Once the environment was illuminated it took less than 100 ms for the ball to enter the view of the cameras from where it remained in free flight for about 450 ms. After each trial the result of the shot was registered as hit or miss, the participant turned his back to the basket, the glasses were opened and the ball was returned to the participant. The experiment lasted about one hour. Participants were informed about the purpose of the experiment and the manipulation of the basket's height after the experiment.

: Data reduction

The same method for estimating the landing positions of the ball was used as in Experiments 1 and 2. Landing positions were determined relative to the standard basket's height (3.05 m). Due to a technical problem we could not use the video recordings from one participant; hence, the landing positions were estimated for 11 participants.

: Statistical analyses

The percentage of hits and the errors along the x-axis (in mm) were submitted to a repeated measures ANOVA with within-subject factors visual condition (3 levels: light, one-dot, dark), position (2 levels: near, far), and basket's height (3 levels: heightened, standard, lowered). To examine the dependency of the pattern of errors on the height manipulation under each of the visual conditions we further performed three ANOVAs with within-subject factors position (2 levels: near, far) and basket height (3 levels: heightened, standard, lowered). The Huynh-Feldt correction was applied in case of violations of sphericity, and the Bonferroni correction procedure was used in pairwise comparisons. The significance level was set at $p < .05$.

:. Results

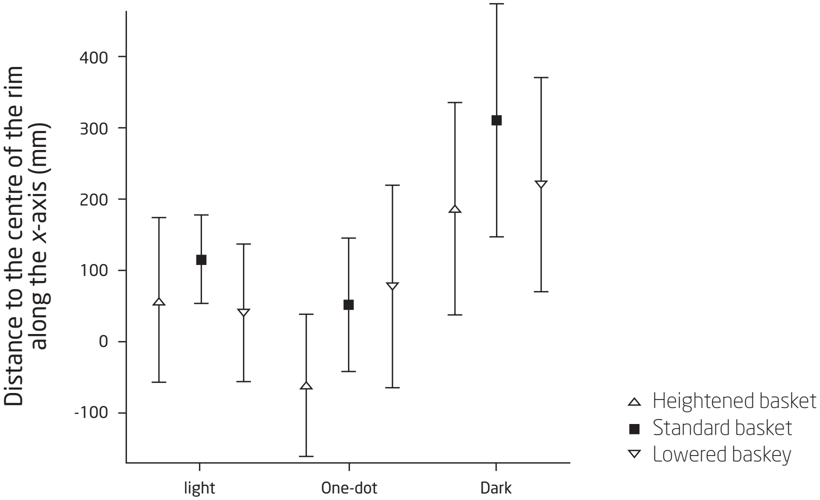
: Percentage of hits

The percentage of hits differed significantly, $F_{1.5, 22} = 27.74$, $p < .001$, $\eta^2 = .72$, across and between the three visual conditions (L: $M = 46.9\%$, $SE = 5.1$; O: $M = 22.8\%$, $SE = 3.5$; D: $M = 9.4\%$, $SE = 2.6$; all ps < .01), as well as across the three height conditions, $F_{2, 22} = 6.84$, $p < .01$, $\eta^2 = .38$. Pairwise comparisons of the latter effect revealed that the percentage of hits was smaller when the basket was heightened ($M = 19.2\%$, $SE = 2.5$) than when it was set at standard height ($M = 28.3\%$, $SE = 3.3$; $p < .03$) or lowered ($M = 31.7\%$, $SE = 3.7$; p = .06). The effect of basket position was not significant, but there was a significant Vision × Position interaction, $F_{2, 22} = 4.86$, $p < .05$, $\eta^2 = .31$. This effect occurred because under the light condition the percentage of hits was larger for the far than for the near basket, whereas under the one-dot condition the converse was true (L near: 42.2%, $SE = 5.3$, L far: 51.7%, $SE = 6.0$; O near: 28.3%, $SE = 4.8$, O far: 17.2%, $SE = 3.6$; D near: 10.6%, $SE = 2.2$, D far: 8.3%, $SE = 3.6$). No significant differences were found between the first and the last 15 trials of each visual condition, all $t_{11} < 1.023$, ps > .33, indicating that no learning had occurred in those conditions. To compare results across experiments, we performed three additional one-way ANOVAs on the percentage of hits in similar conditions (i.e., light, light binocular, light standard; one-dot, one-dot binocular, one-dot standard; dark, dark standard) with experiment (i.e., Experiment 1, 2 and 3) as the only between-subjects factor. For the light and dark conditions, there were no significant differences between experiments, $F_{2, 32} = 1.97$, $p = .16$, $F_{1, 20} = 3.63$, $p = .07$, respectively. For the one-dot condition, the percentage of hits differed significantly across experiments, $F_{2, 32} = 9.37$, $p < .001$, with the percentage of hits being smaller for Experiment 3 than for Experiments 1 and 2 (both ps < .01).

: Average error

Average error varied significantly across visual conditions, $F_{2, 20} = 8.66$, $p < .01$, $\eta^2 = .46$. Pairwise comparisons showed that the errors in the dark condition differed significantly from those in the light and one-dot condition (both p < .05), in the absence of a significant difference between the latter two conditions (L: *M* = 71, *SE* = 39; O: *M* = 21, *SE* = 46; D: *M* = 239, *SE* = 60). Average error also depended significantly on the basket's position, $F_{1, 10} = 328.74$, $p < .001$, $\eta^2 = .97$, as shots to the far basket landed further along the *x*-axis than shots to the near basket (near: *M* = 20, *SE* = 40; far: *M* = 201, *SE* = 36). A significant effect of height, $F_{2, 20} = 5.96$, $p < .01$, $\eta^2 = .37$, revealed that, compared to the errors for the standard height condition, participants overshot more in both the heightened ($p < .01$) and the lowered basket condition (heightened: *M* = 61, *SE* = 43; standard: *M* = 159, *SE* = 30; lowered: *M* = 113, *SE* = 48). Furthermore, a significant Visual Condition × Position interaction occurred, $F_{2, 20} = 43.26$, $p < .001$, $\eta^2 = .81$, which revealed that as visual information diminished the difference in shooting errors between the two basket positions became smaller. Finally, there was a significant Position × Height interaction, $F_{2, 20} = 4.32$, $p < .05$, $\eta^2 = .30$, which occurred because on average participants undershot both the heightened and lowered conditions when the basket was further away (far heightened: *M* = 144, *SE* = 45; far standard: *M* = 271, *SE* = 30; far lowered: *M* = 189, *SE* = 47), whereas this effect was less pronounced when the basket was closer (near heightened: *M* = -23, *SE* = 42; near standard: *M* = 47, *SE* = 33; near lowered: *M* = 36, *SE* = 50).

The subsequent analyses, which focused on the performance in each of the visual conditions separately, were more illuminating than the omnibus analysis with regard to the research question of interest (see Figure 5.8). Under the light condition as well as under the one-dot condition, the shooting errors were affected significantly by the basket's position, $F_{1, 10} = 573.23$, $p < .001$, $\eta^2 = .98$, and $F_{1, 10} = 41.24$, $p < .001$, $\eta^2 = .81$, respectively. Under both conditions shots to the far basket landed further along the *x*-axis than shots to the near basket (L near: *M* = -98, *SE* = 40; L far: *M* = 241, *SE* = 39; O near: *M* = -65, *SE* = 46; O far: *M* = 108, *SE* = 50). Also a significant effect of the basket's height was found under both the light, $F_{2, 20} = 3.68$, $p < .05$, $\eta^2 = .27$, and the one-dot condition, $F_{2, 20} = 6.87$, $p < .01$, $\eta^2 = .41$. Under the light condition the effect of the basket's height was caused by participants undershooting both when the basket was heightened and lowered compared to the standard height (heightened: *M* = 58, *SE* = 52; standard: *M* = 116, *SE* = 28; lowered: *M* = 40, *SE* = 44, $p < .05$). In contrast, under the one-dot condition the significant effect of height occurred because compared to the standard height (*M* = 50, *SE* = 42) participants undershot the heightened basket (*M* = -62, *SE* = 45; $p < .05$) and overshot the lowered basket (*M* = 77, *SE* = 64), in accordance with our hypothesis. Finally, under the dark condition no significant effects were found for position, basket's height and their interaction (near heightened: *M* = 180, *SE* = 72; near standard: *M* = 247, *SE* = 62; near lowered: *M* = 244, se = 73; far heightened: *M* = 194,



:: Figure 5.8

Average landing positions of the ball relative to the centre of the near rim under the three visual conditions, light, one-dot and dark. Bars represent the 95% confidence interval of the mean. Upward triangles represent averages for the heightened basket conditions, squares for baskets set at standard height, and downward triangles for lowered baskets. The ball travelled from negative to positive values.

SE = 67; far standard: *M* = 374, *SE* = 95; far lowered: *M* = 197, *SE* = 68).

:. Discussion

The goal of the third experiment was to examine whether, in basketball shooting, players rely on the online use of angle of elevation (α) information. As argued in the introduction to the experiment, α is uniquely related to the location of the basket if its height is invariant and known, and perceptions and actions are calibrated to the basket's official height (Withagen, 2004). To examine the use of basket-height calibrated α information we introduced deviations from the official basket's height and evaluated the resulting pattern of shooting errors. The main manipulation consisted of heightening and lowering the basket such that the expected error would be 350 mm before the centre of the rim when the basket was heightened and 350 mm behind the centre of the rim when the basket was lowered (as illustrated in Figure 5.7).

The percentage of hits under the light condition and a basket of standard height was 54%, as compared to 68% under the light condition of Experiment 1. The decrement in the light and especially in the one-dot conditions may have been caused by the lack of visual feedback from the shots and the resulting degree of uncertainty as well as from the manipulation of the basket's position and height. In terms of the percentage of hits, shooting performance was considerably worse for the heightened basket than for the lowered basket. This is readily understood from the fact that the same ball trajectory will bounce off a heightened basket after hitting the front of the rim, whereas it will bounce into the lowered basket after hitting the back of the rim (also due to the backspin imparted on the ball; e.g., Brancazio, 1981).

Compared to the percentage of hits, the landing positions provided more insight into the errors caused by the different manipulations because this measure was expressed relative to the standard basket's height. As in Experiments 1 and 2, a significant Visual Condition × Position interaction was found, which revealed that the difference between shooting errors to the two basket positions were almost as large as the actual distance between the two basket positions under the light condition (339 mm), smaller under the one-dot condition (173 mm), and negligible under the dark condition (31 mm).

Besides the effects of vision and position, we were particularly interested in the effect of the manipulation of the basket's height. We expected that participants would undershoot the basket when it was heightened and overshoot it when it was lowered, especially under the one-dot condition. The results were in accordance with this expectation and confirmed our hypothesis that basket-height calibrated α information is used in basketball shooting.

It might be argued that the effect of the manipulation of the basket's height was abridged since the undershooting and overshooting errors were smaller than the expected 350 mm. This is an important observation as it reminds us that d was available in this experiment through eye convergence, binocular parallax, and motion parallax. Although the results of Experiment 2 showed that these sources of information played a limited role in the online control of basketball shooting, binocular parallax and motion parallax could have played a considerable role as participants were taking jump shots and thus induced considerable vertical motion. A possible contribution of d to determining the location of the basket would result in an error pattern opposite to the effect expected from the basket's height manipulation. In fact, under the light condition there are many information sources for d which conflict with information about the angle of elevation. This is because a heightened basket is at a larger distance and thus can be perceived as further through d, but it is simultaneously at a larger angle and thus can be perceived as closer through α. An implication of the conflict between α and d is that their use may depend on their relative salience under different conditions. Along those lines, we can understand why under the light condition, larger angles entail α-related errors, whereas smaller angles entail d-related errors. Supposedly, this effect is replicated under the one-dot condition where larger angles entail α-related errors and smaller angles were more influenced by d-related errors (hence the smaller effect of α found for lowered baskets). The present findings suggest that accurate localisation of the basket is achieved by calibrating relevant optical information to the basket's official height. Although recalibration to a new basket's height is likely to occur relatively fast, such recalibration was prevented in the present experiment by eliminating visual feedback. Crucially, the errors that were found when only d and α were available during movement execution were in accordance with our hypothesis that the detection of (basket-height calibrated) α information represents an important information source in the online guidance of basketball shooting.

:: General discussion

In the present study we investigated the information sources and representational constraints (i.e., the official height of the basket) that are relevant to the online guidance of basketball shooting. We started out by analysing the information sources that, in principle, could be sufficient for successful basketball shooting. We identified the distance from the shooter to the basket (d) and the angle of elevation (α) as information sources that conjointly determine the exact location of the basket. Alternatively, each of these information sources alone may be combined with the official height of the basket to determine its exact location.

The results of Experiment 1 indicated that participants could accurately perceive the location of the basket when d and α were the only information sources available during movement execution, i.e., under the one-dot condition. Participants could distinguish between the two basket positions under the one-dot condition, consistent with the theoretical expectation that having only information about d and α during movement execution would be sufficient for successful basketball shooting.

Experiment 2 was designed to examine the use of information in the control of basketball shooting. Participants were experienced wheelchair basketball players who were instructed to sit as still as possible and to minimise head and trunk movements in order to reduce motion parallax. As a consequence, binocular parallax and eye convergence were the only viable sources of information that related to d that were available during movement execution in the one-dot condition, which rendered the comparison between binocular and monocular viewing of paramount importance. The results indicated that, under the one-dot condition, participants had difficulty distinguishing the two basket positions (as had also been observed in Experiment 1), and that this difficulty was similar for binocular and monocular viewing. We therefore concluded that participants were able to perceive the location of the basket without relying on d as provided by binocular parallax and convergence.

In view of the latter result we conducted a third experiment to further pinpoint and test the contribution of α. We hypothesised that the perception of α would be calibrated to the official height of the basket, so that α could be used online as a viable source of information about the location of the basket. We could test this hypothesis by altering the height of the basket unbeknownst to participants, because it predicts that a heightened basket is perceived as being closer to the participant, and that a lowered basket is perceived as being further away from the participant. As expected, the results showed that under the one-dot condition, where d and α were the only information sources that were available online, players undershot the basket when it was heightened and overshot it when it was lowered.

The results of all experiments combined thus strongly suggested that players use basket height-calibrated α information in the online guidance of basketball shooting. This is an important finding for several reasons. First of all, it shows that a complex action like basketball shooting may rely on rather minimal geometric information (as illustrated in Figure 5.1) available during movement execution, which explains why performance is so robust in the face of temporal constraints (e.g., time pressure, opponents) and under poor illumination of the environment. Second, it underscores that the information for action is often scaled to relevant properties in the environment, in this case the official height of the basket. This demonstrates that perceivers may exploit different kinds of information (i.e., perceptual and representational) in the performance and acquisition of perceptuomotor skills (Withagen, 2004). Third, from a motor control point of view, the use of basket height-calibrated angular elevation information implies that essentially geometric information is sufficient to generate the appropriate torques and forces to launch the ball over the required distance, which implies that another kind of calibration is operative as well, namely one from perception to action.

Having established that basketball shooting relies on angle of elevation information, the next issue to be discussed is the reference frame used in perceiving this information. To examine what reference frame is used in locating a target on the ground, Ooi et al. (2001) conducted a set of prism adaptation experiments in which they manipulated perceived eye level. They concluded that the angle of declination was detected in relation to the perceived eye level both in dark and well-lit environments. Although we did not study the role of perceived eye level in the use of α, there is no reason to assume that such a reference frame would be used in walking and throwing beanbags (Ooi et al.) but not in basketball shooting, although, admittedly, the latter task involves a whole body movement with a range of perceived eye levels. In tasks like sitting and stair climbing it has been shown that eye level is used to evaluate possibilities for action (Mark, 1987). In Mark's experiments, wearing 10 cm high blocks caused participants to underestimate the possibility to sit and overestimate the possibility to climb on surfaces, but this effect vanished after a few trials because eye level re-scaled in compliance with the visual environment.

This plasticity in the scaling of eye level (Mark; Ooi et al.) allows the visuomotor system to adapt to different environments and re-scaling of eye level will seldom fool the observer. However, when eye level is misperceived (e.g., because of contextual features like inclines or false horizons) interesting phenomena might occur, like the 'magnetic hill' illusion where cars put in neutral are perceived to move uphill (Bressan, Garlaschelli, & Barracano, 2003). Apart from sporadic illusions eye level seems to be a reliable reference frame for using optical information in the guidance of movement.

In closing, it is useful to link the finding that basket height-calibrated α information is used in basketball shooting to evidence supporting the use of angular information in other perceptuomotor skills. We mention two examples. First, Philbeck and Loomis (1997) investigated how observers perceive distance to a target on the floor. They found that neither binocular parallax nor motion parallax influenced distance perception (as measured by having participants walk to the target and by verbal reports). In a subsequent experiment they investigated the contribution of angular declination. They reasoned that angular declination could only be uniquely related to the target's location if participants knew that the target was positioned on the floor. In contrast, angular elevation would not be sufficient to determine the position of targets located at eye level. As expected, they found that targets on the floor were accurately located, both binocularly and monocularly, regardless of whether the environment was illuminated or dark, whereas participants were inaccurate in determining the location of targets located at eye level. As in the present study, these results underscore the importance of a calibrated use of angular elevation information in determining the location of a target. A second example of the use of angular elevation information comes from research on baseball, where fielders running to catch an approaching ball were found to run in such a manner that their angle of elevation to the ball increases at a decreasing rate while their horizontal angle to the ball increases at a constant rate (McLeod et al., 2003, 2006). Given the evidence for the use of angular information in a broad variety of skills, it appears that the current findings are not restricted to the domain of basketball shooting but rather reflect an important signature of the perceptual foundation of skilled action.

06 : Epilogue

:: Synopsis of main findings

In the preceding chapters we reported various experimental results and insights pertaining to temporal and spatial aspects of the visual perception for basketball shooting. The temporal aspects we examined were the preferred timing of optical information pick-up in Chapter 2, the issue of online versus offline control in Chapter 3, and gaze behaviour during shooting preparation and execution in Chapter 4. Together, the results in those studies underscored the importance of late visual information picked-up for the online control of basketball shooting. In Chapter 5 we investigated the information sources that players use to determine the spatial location of the basket. In this study, the angle of elevation subtended by the line of sight as the player looks at the basket was singled out as the primary information source for perceiving the distance between player and basket. These results have important implications for the interpretation of previous studies, as well as theoretical implications that provide guidelines for future research. Because the task studied in this thesis is a perceptuomotor skill taught and practiced around the world, we also discuss some of the implications of the research findings for professional practice. However, before discussing those implications, it is useful to first address some methodological issues that are relevant to a proper evaluation of the present results and those obtained in other studies.

:: Methodological considerations

In the experimental work reported in this thesis we made several choices with regard to participants, experimental paradigms, and performance measures that warrant more justification and discussion than provided in the previous chapters. The participants in all six experiments were experienced top-level basketball players as well as the best shooters of their respective teams. Expertise in sports results from thousands of hours of practice involving countless repetitions of specific actions such as taking free throws or jump shooting. Expertise is mostly defined on the basis of experience and level of competition as well as non-trivial performance measures like the percentage of hits. The prevailing assumption in studies of expertise is that, through practice, the links between perceptual and motor systems become well attuned making performance more efficient. The performer becomes sensitive to the most useful information sources, and the information used is better integrated into motor control. Under this assumption, changes in expert performance in experimental settings are attributable to experimental manipulation and not to random motor fluctuations or other factors. This is one reason why expert performance offers a privileged setting for examining the visual basis of complex perceptuomotor skills.

Besides the benefits of studying expert performance, the task we studied is also advantageous for three other reasons. First, it can be recreated in the laboratory (i.e., provided the laboratory is large) permitting the use of equipment such as movement registration systems in a controlled environment. Second, the goal of the task is maintained, namely that of scoring a point by having the ball pass through the rim (without making use of the backboard). Third, the task we studied is part of the training routines of the participants. Basketball shooting is also a complex perceptuomotor skill that involves a whole body movement, and thus the present findings are likely to have parallels in other relevant activities and actions such as walking, aiming, and catching.

In most studies we used a visual occlusion paradigm to probe the visual basis of basketball shooting. This technique is particularly useful in investigating the pick-up and use of visual information. Temporal occlusion can inform about the contribution of picking up visual information in a particular period of the movement. For instance, if visual occlusion during elbow extension deteriorates performance, then this period of vision is probably necessary to performance. Spatial occlusion can inform about the relative importance of information sources for performing the task at hand. For instance, if visual occlusion of the ground has no effects on performance, its contribution is probably minimal. In one study we examined the gaze behaviour in basketball shooting, which allowed us to verify our assumption that if players can look at the basket during shooting they will. Gaze tracking is probably the most used technique in investigating vision in sports because it allows the experimenter to assess what the participant is looking at with minimal performance disruption. However, great caution should be exerted in interpreting fixation location and duration as indicating, respectively, an area of interest and the amount of information processed (Williams & Ericsson, 2005). Also, gaze tracking does not disclose whether such aspects of behaviour are necessary or contiguous to performance. However, as illustrated in Chapter 4, a detailed, time-continuous analysis of gaze behaviour may reveal systematic differences between experimental conditions that can be given a meaningful interpretation in combination with other findings.

Clearly, the most direct performance measure in basketball shooting is the percentage of hits. However, because the actual distance as well as the direction of the error can inform about the quality of the visual information available, it was necessary to device a means to assess shooting errors with greater discriminative power. To this effect we used two synchronised cameras that permitted the recovery of the three-dimensional trajectory of the ball and consequent estimation of its landing position on the plane of the rim. Besides providing a very accurate estimation of ball position along both axes on the plane of the rim, this procedure permits precise estimations when the ball trajectory is interrupted by the backboard or rim. This is an innovative technique that can be used in other settings, for instance in recovering the trajectory of a fly ball or a frisbee. Overall, it is important to consider that these methods provide insight into the visual basis of action on a strictly behavioural level. An inherent limitation of this type of research is that internal processes cannot be uncovered but only inferred from the results of controlled manipulations.

:: Implications for previous studies

The present results call for a reinterpretation of previous studies on the visual guidance of basketball shooting. Only two studies have directly addressed the issue of online versus offline use of visual information during basketball shooting and their interpretations were contradictory. Vickers (1996), who recorded gaze behaviour of low-style expert shooters, found that they looked at the target for about 1 s before movement initiation and claimed that they needed this time to preprogramme their movement. Oudejans, van de Langenberg, and Hutter (2002), who occluded the vision of high-style expert shooters in selected moments of the shot, found that they required vision of the target only during the last 350 ms before ball release and claimed that they used visual information online to control their movements. Overall, the findings in Chapters 2, 3, and 4 are in accordance with previous results, though not with previous interpretations. The results of Chapters 2 and 3 are in agreement with the conclusion of Oudejans et al. (2002) that basketball players use visual information online to control movement execution, with the proviso that, contrary to their conjecture, the conclusion was extended to low-style shooters as well. The results of Chapter 4 replicate the finding of Vickers (1996) that low-style shooters look at the target for 1 s, and provide evidence for the suggestion of Oudejans et al. (2002) that high-style shooters look at the target while airborne, but extend those findings by mapping the gaze behaviour to different shooting styles and different shooting types. The results of Chapter 5 indicate that expert basketball players use the angle of elevation to guide their movements. This is a particularly interesting finding in itself, but also in relation to previous findings which it may help explain in retrospect. In 1986, Ripoll, Bard, and Paillard (1986) found that stabilisation of both head and eyes on the target is a determinant of success and a mark of expertise. They speculated that such stabilisation served a postural function in correctly orientating the trunk towards the basket but, in light of the present results, it seems that anchoring head and eyes on the target also plays an instrumental role in picking up angle of elevation information. This interpretation is also consistent with the finding that visual acuity is not crucial for accurate performance (Applegate & Applegate, 1992; Mann, Ho, de Souza, Watson, & Taylor, 2007). Even under the blurriest condition in their study participants still shot accurately. In that condition, so the authors contended, the rim and backboard could still be discerned and so the players could still fixate a point on the target. Finally, the visual fixation of the basket, as found by Vickers (1996), may be necessary for accurate shooting because it establishes a solid link between the player and the target which allows the player to reliably pick-up the elevation angle continuously as the movement unfolds.

:: Theoretical implications

:. **Online use of visual information**

Building on the studies of Oudejans et al. (2002) and Vickers (1996), the present findings make a rather complete case for the use of online visual information. In Chapter 2 we found that players prefer to look at the target, for some time, as late as possible given their shooting style, in Chapter 3 we showed decrements in performance when movement was delayed even briefly relative to visual information pick-up, and in Chapter 4 we found a pattern of looking behaviour of expert players consistent with the notion of online use of visual information. The case for online control is strengthened further by similar findings for a variety of tasks (Bootsma & van Wieringen, 1990; Caljouw, van der Kamp, & Savelsbergh, 2006; Khan et al., 2006; Oudejans et al., 1999; Westwood, Heath, & Roy, 2003), albeit that also those findings are limited to behavioural observations only.

Further insight into the mechanisms underlying the generation of muscle stimulation and its interplay with visual information can be gained from other approaches. For instance, the modelling of near aiming movements may shed light on the type of movement control. Whereas feedforward models have received much research attention of late, especially in terms of the integration of fast corrective adjustments to the prevailing motor plan using sensory information (e.g., Chapter 3; Desmurget & Grafton, 2000), the feasibility of equilibrium point control, which excludes the necessity to parameterise the required forces, has recently been established in the context of single-joint movements (Kistemaker, van Soest, & Bobbert, 2006). The neuropsychological approach has also yielded many interesting results. Previous studies have documented the perceptual and visuomotor capabilities of patients with quite localised brain damage, provided new insights into the neural pathways of visual information, and stimulated research and discussion (Glover, 2004; Goodale, 2000; Milner & Goodale, 1995; Revol et al., 2003). In general, there seems to be a visual pathway dedicated to the online control of movements, the dorsal pathway discussed in Chapter 4, though recent findings suggest that this pathway may be dedicated to the use of visual information for both perception and action under an observer-based perspective (Schenk, 2006). A valid methodology to examine the effects of online and offline use of visual information may be transcranial magnetic stimulation. It has been used to momentarily disrupt neural areas thought to be involved in online control resulting in the lack of proper kinematic adjustments to changed target positions (Desmurget et al., 1999; Schenk, Ellison, Rice, & Milner, 2005).

Though the use of visual information during movement execution has received empirical support from different areas, much remains unknown about the mechanisms of control and the neural underpinnings of complex perceptuomotor skills. Perhaps the current degree of ignorance is illustrated best by the clumsiness of very advanced robots in integrating perception and action when negotiating their environment.

:. **Angular information**

When an object is sought and brought to focus in the retina the body configuration can inform about the direction along which the object lies but also about what movement will be necessary to interact with that object. By body configuration we refer to the position of the eyes relative to the head, as well as the position of the head relative to the trunk and the gravitational field (Gibson, 1979/1986). These relative positions are picked up kinaesthetically through both proprioception and the vestibular system (Karnath, Sievering, & Fetter, 1994) and there is ample evidence for this in various tasks. Angular information, which can thus be picked up kinaesthetically, has been found to be used in walking to a target, in determining whether a flying object will land in front or behind a human or canine observer, and now in basketball shooting (Ooi, Wu, & He, 2001; Oudejans, Michaels, Bakker, & Davids, 1999; Philbeck & Loomis, 1997; Shaffer, Krauchunas, Eddy, & McBeath, 2004). It is no coincidence that all these tasks involve whole body movements and an interaction with objects outside the personal space. On the one hand, large body movements facilitate the pick-up of kinaesthetic information. On the other hand, other sources of information may be privileged in the interaction with nearby objects. However, even in the latter case angular information, especially visual direction, plays a relevant role in orienting eyes and head to the object. It has been shown to be used in simulated environments for walking, steering, and judging the motion of targets (Harris & Drga, 2005; Wann & Land, 2000; Warren, Kay, Zosh, Duchon, & Sahuc, 2001).

:. Calibration

Angle of elevation informs about the direction of objects relative to the observer, but as we mentioned earlier it can also be informative about distance as long as perceptions and actions are calibrated to a particular constant (e.g., basket height in basketball shooting). In general, calibration refers to the adequate scaling of information to either perception, or action, or both. Changes to basket height render the scaling of information inadequate which results in consistent undershooting or overshooting of the basket. Under such circumstances the performance of an expert player resembles that of a novice in that the basket is consistently missed. However, if the change in height is not too large (e.g., within a metre), we expect that an expert will be able to quickly recalibrate to the new basket height. After all, the expert is already familiar with a large range of elevation angles and shooting actions that will be specific to the new basket height. In other words, the required movements are already part of the repertoire thus all that is needed is to re-establish a working link between perception and action. In this sense, expert performance is robust to small changes in basket height even though the adequacy of the exploited information critically depends on basket height being constant. If the change in height is considerable, for example if the basket is placed on the floor, recalibration may be hampered because only a small range of elevation angles and shooting actions are common to such a basket height, or because the task requirements change so dramatically that an entirely different information source must be exploited.

Although recalibration is facilitated in expert performers, it is important to note that small changes in environmental constants (e.g., basket height) may have disastrous consequences, if calibration is prohibited. The reason is that in normal situations the observer does not pick up information relative to that environmental property (the height of the basket). For an illustration we are reminded of an incident that occurred in the Olympic Games of Sydney in 2000, when the gymnastics horse vault was set inadvertently 5 cm below official height. This small change caused the spectacular and dangerous falls of several potential gold medallists. Clearly, the affected gymnasts picked up visual information that was scaled to the official height of the horse vault and thus the movements that followed were not appropriate for the new height.

:. Future research

The previous chapters underscore the importance of using online visual information during movement execution. However, when visual information is reduced or occluded during movement execution, along with all sources of visual information, expert shooters still manage to land the ball in the target vicinity. This suggests that visual information gathered before movement initiation is in use and that the errors observed are a consequence of the deterioration of that previously gathered visual information. However, there is another possibility that can explain this result. In the absence of visual information the player may still exploit online kinesthetic information about body configuration and perform accordingly. In other words, it is possible that the visual information gathered before the trial is used primarily to orient the player to the target, to obtain an estimated anchoring point, and that kinesthetic information is still used to guide the movements online given that anchor point. In this light it would be interesting to train players to perform in the absence of vision during movement execution and evaluate the accuracy of their spatial representations as well as their reliance on kinesthetic information. These are interesting topics for further research as they could have important implications for the understanding of whether and how perceptual and representational information sources are used in the guidance of complex motor skills.

At this point it is unclear whether it is necessary to visually fixate one particular location in the environment in order to perform a shooting action accurately. Clearly, players do look at the target (Chapter 4; Vickers, 1996) and we think this is instrumental for picking up the angle of elevation, but our results do not rule out the use of other information sources that are available to the player. For example, the horizontal distance to the basket, which relates geometrically to the location of the basket, is a candidate variable and its contribution could be tested by having a single dot glowing at eye level underneath the basket. The disadvantage of this candidate information source is that if the player looks at the dot during the actual shooting action it is likely that inaccuracies result from the changes in kinematics; after all, looking at the basket is part and parcel of shooting. If the participant would be free to move head and eyes about, we would expect the participant to direct them to the estimated position of the basket and to shoot in accordance with that guessed position. This would imply that participants still make use of angular information but can use an estimated anchoring point on the basket based on other information sources.

Other candidate information sources are perspective information and familiar size, especially the apparent configuration of the backboard and rim change considerably with both the approach and the angle of approach, and could thus constitute relevant information. Another is ground surface information that can inform about the distance between player and basket, and the marked lines on the court could be useful in this respect. While it is likely that expert players exploit several information sources to their advantage, the relative contribution of most sources remains to be studied. In this connection it would be interesting to examine how the context of play co-determines the selection of the most useful information source as seems to be the case in the context of catching and hitting (Caljouw, van der Kamp, & Savelsbergh, 2006). In view of the number of information sources available it is necessary to control the availability of variables, thus appropriate methodologies include occlusion techniques, virtual reality environments, or proprioception stimulation where information sources can be deleted or perturbed and their contribution evaluated.

Some personal and task characteristics may influence the usefulness of different information sources. The height of the observation point, or eye level, is one of them. The angular elevation or declination is geometrically dependent on the eye level of the observer, and therefore its discriminative power is delimited by this characteristic. For instance, if the basket is at eye level of a player, angular information is useless simply because there is little or no angle to be detected. As the difference between eye level and height of the basket becomes larger, the discriminative power of angular information increases accordingly. Conversely, the discrimination between targets placed on the floor is also dependent on eye level. At greater distances, target discrimination is facilitated with increased eye level. Beyond basketball shooting and walking to targets further research on the use of angular elevation in other tasks could prove interesting. For instance, when driving vehicles with great inertia, like trucks and buses, it is of paramount importance to perceive and react timely to objects on the road for which a heightened position of the driver is functional if the driver uses angular information. Differences in the type of traffic, obstacles, and manoeuvres should all be taken into account when designing vehicles not only to guarantee the best performance of the car, but also the optimisation of the perceptuomotor responses of the driver. Through systematic research into exciting topics like these, more insight can be gained into the visual basis of complex perceptuomotor skills.

:: Practical implications

In a thesis about the visual perception for basketball shooting it would be peculiar to leave the practical implications of our results unaddressed. Here we establish some links to basketball shooting from a practical point of view for the perusal and benefit of interested trainers and players. The shooting style is a kinematic feature exhibited by expert basketball players, and unsystematic observation reveals that most top level players nowadays bring the ball high above their head before making the final elbow extension, characteristic of a high style, while some push the ball upwards from a resting position at chest level, characteristic of a low style. Pertinent questions are what shooting style is more advantageous, and how shooting should be taught and trained.

To address the topic of what shooting style is more advantageous we should consider what is known about it. There is no determining relation between shooting style and the use of visual information, the type of information source used, and performance accuracy, since all players seem to use visual information online and one of the information variables in use, angular elevation, is independent of style. Although there is no advantage in style from a perceptuomotor perspective, there is in terms of biomechanics. The low style permits more control over the timing of the shot, and probably a more stable and forceful delivery of the ball (Liu & Burton, 1999; Miller & Bartlett, 1993, 1996), whereas the high style permits a higher release point and a better guarded position of the ball (Brancazio, 1981; Rojas, Cepero, Oña, & Gutierrez, 2000).

Since ball possession and a higher release point are critical for performance in competitive and time restricted games the high style is advantageous for game play and should therefore be taught. Because younger players may need to develop muscular force before they are able to deliver a jump shot using a high style, it is advisable to use lowered baskets and lighter balls at early stages of learning (Chase, Ewing, Lirgg, & George, 1994). In this way the player can learn to exploit and establish the right links between the perceptual and motor systems through valid feedback about the task. Later, changes in basket height and ball weight should be invoked at separate instances such that the player can rescale perceptions and actions to the appropriate values.

There has been a growing interest in training methodologies designed to optimise perceptuomotor skills in sports, that is, to guide the exploitation of information variables and the optimisation of their use in the context of play. Most training methodologies still focus on the development of the technical and tactical components of individual performance and game play but entirely ignore the development of perceptuomotor expertise. However, the systematic training of this component is thought to improve performance and should thus be integrated in training (Williams & Ward, 2003). Harle and Vickers (2001) designed and implemented an on-court training programme for the basketball free throw where (low-style) participants were instructed to develop a routine, fixate the target and then take the free throw. This training procedure improved the performance of these players, thus increasing the interest for perceptuomotor training, but without elucidating the underlying mechanisms (Gayton, Cielinski, Francis-Keniston, & Hearns, 1989; Southard & Amos, 1996).

Recently, Oudejans, Koedijker, Bleijendaal, and Bakker (2005) developed and tested another perceptuomotor training procedure. Based on the finding that high-style shooters require late visual information about the target, they implemented a training drill that consisted of shooting from behind a screen such that players could see the basket only after the start of the jump. Besides this on-court training exercise, there were laboratory trainings where participants wore liquid crystal glasses that could occlude their vision in selected moments during the jump shot. Using both procedures, these authors found significant improvements in percentage of hits after eight weeks of training sessions.

Finally, the results in Chapter 5 highlight the importance of angular elevation information for basketball shooting. Because this information variable can be picked up kinesthetically, provided there is a visual anchoring point on the target, shooting under blurred vision could be effective in prompting players to rely on sensory information other than visual. Another training drill could consist of having players receive a pass with their back to the basket and take a jump shot while orienting towards the basket. Under this condition the player would have to rely on the fast use of the kinesthetical information that can be picked up while orienting towards the basket.

:: General conclusion

In sum, in the present thesis we have studied fundamental temporal and spatial aspects of visual perception in the context of a complex perceptuomotor skill. Using expert basketball shooting as our experimental task of choice we found that visual information gathered during movement execution is used for the online control of action. Moreover, we found that angular information is critical and that both perception and action are scaled to relevant environmental properties. These findings have broader theoretical and practical implications for future research in this area of enquiry.

07 : Miscellaneous

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:: Summaries

:. **Summary in English** :: Rita

The general aim of the research presented in this thesis was to elucidate the visual basis of basketball shooting. Chapter 1 provides an overview of the pertinent literature. Previous studies on the topic focused on temporal aspects of vision and identified the rapidity of orienting and stabilising head and eyes on the target (Ripoll et al., 1986) and long target fixations (Ripoll et al.; Vickers, 1996) as necessary ingredients for successful performance and distinguishing marks of expertise. In apparent contrast to the long target fixations, a more recent study highlighted the benefits of looking at the target late (Oudejans et al., 2002). To help resolve this issue we examined the preferred timing of optical information pick-up in Chapter 2, the effects of online and offline visual control in Chapter 3, and the gaze behaviour during the preparation and execution of the shooting movements in Chapter 4. In addition to the temporal aspects of vision, we investigated the information sources that are used to guide basketball shooting in three experiments, which are reported in Chapter 5. The contents of these chapters may be summarised in greater detail as follows.

In Chapter 2 we investigated the preferred timing of optical information pick-up and how this depended on the shooting style used. Our hypothesis was that expert basketball players prefer to look at the target as late as permitted by their shooting style. The employed shooting style determines whether or not a player can see the basket following the moment when ball and hands pass the line of sight (mLoS). Players with a low shooting style can only see the basket before mLoS, whereas players with a high shooting style can see the basket after mLoS until ball release. To investigate when players with either type of shooting style prefer to view the basket, we used an intermittent viewing technique and a 3D movement registration system. We used liquid crystal glasses that intermittently turned transparent and opaque (for 350 and 250 ms, respectively). The 3D movement registration system Optotrak was used to determine mLoS. Twelve expert basketball players, five with a low style and seven with a high style, participated in the experiment. Their percentage of hits under intermittent viewing was not significantly different from that under full vision, and was independent of shooting style. In a subsequent analysis, we mapped mLoS onto the events defined on the glasses, and used circular statistics to determine whether shooting-style dependent timing patterns were present. The results showed that in the low-style group mLoS occurred when the glasses became opaque, implying that the players could see the basket just before mLoS. In the high-style group, mLoS occurred near the moment when the glasses became transparent, implying that the players could see the basket just after mLoS until ball release. In other words, both groups viewed the basket as late as their shooting kinematics allowed. In addition to confirming our hypothesis, these results support the view that basketball shooting is controlled online by vision.

This view was examined further in Chapter 3, which reports an experiment that we conducted to determine whether basketball shooting relies primarily on online or offline visual control. Our hypothesis was that basketball players use online visual information to execute the shooting movements, in order to insure that performance is accurate. To test this hypothesis, we employed a visual delay paradigm. We used liquid crystal glasses that either remained transparent throughout movement execution, or became opaque zero, one, or two seconds before movement initiation. A movement registration system (Optotrak) was used to register the movements of the shooting arm (ring and little fingers, metacarpal area, wrist, elbow, shoulder) in 3D. Ball trajectories were recorded to estimate the landing position of the ball on the plane of the rim. Seventeen expert basketball players, eight with a low style and nine with a high style, participated in the experiment. Both the percentage of hits and the landing positions revealed marked decrements in performance with increasing delays. Furthermore, the analysis of covariance coefficients on the kinematic data revealed that the severity of visual conditions was associated with decreased coupling strength and increased variability between the arm joints. Even though most shots still landed in the vicinity of the basket in the absence of vision, accuracy was significantly better under normal viewing. Although this study does not rule out the use of offline visual information, it underscores the online use of visual information in basketball shooting.

In Chapter 4 we investigated whether the gaze behaviour of expert basketball players was dependent on their shooting style and the type of basketball shot performed. Based on previous findings, we expected that low-style players would look long at the basket in the free throw but less long in the jump shot, and that high-style players would look at the basket after mLoS until ball release both in the free throw and the jump shot. We invited six expert basketball players, three with a low style and three with a high style, to take ten jump shots and ten free throws while wearing an eye tracking system to register their looking behaviour. Looking behaviour was coded for each frame, such that looking at the rim was 1, the basket's net or small square on the backboard was .8, the remaining backboard was .6, other locations were .4 and no gaze behaviour was 0. Next, we analysed the gaze behaviour directed at the basket or backboard before and after mLoS. The results were in accordance with our expectations. The low-style shooters looked at the target only before mLoS and for about 1 s in the free throw but half that duration in the jump shot, without any repercussions for shooting accuracy. The high-style shooters, in contrast, looked consistently at the target after mLoS both in the free throw and in the jump shot for about 400 ms.

In Chapter 5 we investigated the optical basis of basketball shooting in a series of three experiments. From a theoretical analysis it appeared that the absolute distance between player and basket (d) and the angle of elevation subtended by the line of gaze to the basket (α) could be used conjointly to determine the exact location of the basket. Alternatively, the location of the basket could be determined by using either d or α in combination with the height of the basket, which was always set at the same official height. In the first experiment it appeared that expert basketball shooters preserved good shooting accuracy when d and α were the only information sources available during movement execution. In the second experiment, accuracy was maintained upon removal of information sources related to d, indicating that those information sources were less relevant for successful shooting. Finally, we tested the use of α by manipulating the height of the basket unbeknownst to participants. Consistent with the use of angle of elevation, participants misperceived heightened baskets as being closer and lowered baskets as being further away. We therefore concluded that angle of elevation information, calibrated to the official basket's height, was used for successful shooting.

In sum, the experiments presented in the present thesis provided clear insights into the visual basis of basketball shooting. They highlight the importance of the online use of visual information during movement execution and of using the latest and most updated visual information available. A likely variable that may be picked up and used to guide the shooting movements is the angle of elevation, which is informative about the distance from the player to the target provided that both perception and shooting action are calibrated to the official height of the basket. These insights have broad theoretical implications, as well as several possible applications, that are discussed in the sixth and final chapter of this thesis.

:. Summary in Dutch :: Peter

Visuele waarneming voor het basketbalschot

Het algemene doel van het in dit proefschrift gepresenteerde onderzoek was de visuele basis van basketbalschieten op te helderen. Hoofdstuk 1 verschaft een overzicht van de relevante literatuur. Eerdere studies naar het onderwerp waren gericht op temporele aspecten van de visuele waarneming en identificeerden de snelheid van het oriënteren en stabiliseren van het hoofd en de ogen op het doel (Ripoll et al., 1986), alsmede lange doelfixaties (Ripoll et al.; Vickers, 1996), als noodzakelijke ingrediënten voor een succesvolle taakuitvoering en als kenmerken van expertise. Ogenschijnlijk in tegenspraak met het belang van lange doelfixaties werd in een meer recente studie evidentie gevonden dat juist het laat zien van het doel belangrijk is voor een succesvolle taakuitvoering (Oudejans et al., 2002). Om deze kwestie te helpen oplossen onderzochten we de geprefereerde timing van het oppikken van optische informatie in Hoofdstuk 2, de effecten van het online en offline gebruik van visuele informatie in Hoofdstuk 3, en het kijkgedrag tijdens het plannen en uitvoeren van de schietbeweging in Hoofdstuk 4. Naast deze temporele aspecten van de visuele waarneming onderzochten we in drie experimenten, die beschreven zijn in Hoofdstuk 5, de informatiebronnen die gebruikt worden in het basketbalschieten. De inhoud van deze hoofdstukken laat zich in meer detail als volgt samenvatten.

In Hoofdstuk 2 onderzochten we de geprefereerde timing van het oppikken van optische informatie in samenhang met de gehanteerde schietttechniek. Onze hypothese was dat elite basketspelers bij voorkeur zo laat mogelijk naar het doel kijken. De gebruikte schiettechniek bepaalt of een speler al dan niet de basket kan zien vanaf het moment dat de bal en de handen de bliklijn passeren ("moment of Line of Sight", mLoS). Spelers met een "lage" schiettechniek kunnen de basket alleen zien voorafgaand aan mLoS, terwijl spelers met een "hoge" schiettechniek de basket na mLoS kunnen zien tot het moment dat de bal de handen verlaat. Om te onderzoeken wanneer spelers met beide technieken bij voorkeur de basket zien, maakten we gebruik van een "liquid-crystal"-bril waarvan de glazen afwisselend transparant en ondoorzichtig waren (voor respectievelijk 350 en 250 ms) en een bewegingsregistratiesysteem (Optotrak) om mLoS te bepalen. Twaalf elite basketspelers, vijf met een lage schiettechniek en zeven met een hoge schiettechniek, namen deel aan het experiment. Het percentage rake schoten onder intermittent zicht was niet significant verschillend van dat onder volledig zicht, en was onafhankelijk van de gebruikte schiettechniek. Vervolgens analyseerden we de fasering tussen mLoS en en het open en dicht gaan van de bril en gebruikten we circulaire statistiek om de onder de beide schiettechnieken aangetroffen timingspatronen te vergelijken. De resultaten lieten zien dat mLoS in de groep met de lage schiettechniek samenviel met het moment waarop de bril ondoorzichtig werd, hetgeen inhoudt dat de spelers de basket konden zien tot vlak voor mLoS. In de groep met de hoge schiettechniek viel mLoS ongeveer samen met het moment waarop de bril transparant werd, hetgeen impliceert dat de spelers de basket konden zien vanaf mLoS tot aan het loslaten van de bal. Met andere woorden, beide groepen spelers gaven er kennelijk de voorkeur aan de basket zo laat mogelijk te zien als toegestaan door de gehanteerde schiettechniek. Behalve de onderzoekshypothese ondersteunden de gevonden resultaten ook de visie dat basketbalschieten online gestuurd wordt door visuele informatie.

Deze visie werd nader onderzocht in Hoofdstuk 3, waarin een experiment wordt beschreven dat we uitvoerden om te bepalen of basketbalschieten primair steunt op online danwel op offline visuele sturing. Onze hypothese was dat basketbalspelers online gebruik maken van visuele informatie tijdens het uitvoeren van de schietbeweging, ten einde een zo nauwkeurig mogelijk schotprestatie te realiseren. Om deze hypothese te toetsen manipuleerden we de tijd tussen het beschikbaar zijn van visuele informatie en het daadwerkelijk uitvoeren van de worp. Hiertoe maakten we gebruik van een "liquid-crystal"-bril die ofwel transparent bleef tijdens de bewegingsuitvoering, ofwel 0, 1 of 2 s voor bewegingsinitiatie ondoorzichtig werd. De bewegingen van de schietarm (ringvinger, kleine vinger, metacarpeaal gebied, pols, elleboog, schouder) werden met Optotrak in 3D geregistreerd. Tevens werden de baltrajecten geregistreerd om de landingspositie van de bal in het vlak van de ring te bepalen. Zeventien elite basketbalspelers, acht met een lage schiettechniek en negen met een hoge schiettechniek, namen deel aan het experiment. Zowel het percentage rake schoten als de landingsposities lieten een duidelijke verslechtering van de prestatie zien met toenemende visuele vertraging. Analyses van de covariantiecoëfficiënten van de kinematische data toonden bovendien aan dat een toename in de visuele vertraging gepaard ging met een afname in koppelingssterkte en een toename in variabiliteit tussen de armgewrichten onderling. Hoewel de meeste schoten in de buurt van de basket landden wanneer geen visuele informatie beschikbaar was tijdens de worp, was de schotnauwkeurigheid significant beter onder normale visuele omstandigheden. Ofschoon deze resultaten het offline gebruik van visuele informatie niet uitsluiten, benadrukken zij het belang van online visuele sturing voor succesvol basketbalschieten.

In Hoofdstuk 4 onderzochten we of het kijkgedrag van elite basketbalspelers afhankelijk was van hun schiettechniek en het type basketbalschot (vrije worp versus sprongschot). Op basis van eerdere bevindingen verwachtten we dat spelers met een lage schiettechniek relatief lang naar de basket zouden kijken tijdens het nemen van een vrije worp en minder lang tijdens een sprongschot, en dat spelers met een hoge schiettechniek naar de basket zouden kijken vanaf mLoS tot het loslaten van de bal tijdens beide typen schoten. Om deze verwachtingen te onderzoeken vroegen we zes elite basketbalspelers, drie met een lage schiettechniek en drie met een hoge schiettechniek, tien sprongschoten en tien vrije worpen uit te voeren terwijl hun kijkgedrag werd gemeten met een video-gebaseerd systeem voor het meten van de blikrichting (een zogenoemde "eye tracker"). Kijkgedrag werd gecodeerd voor elk videobeeld afzonderlijk: kijken naar de ring van de basket werd gecodeerd met een 1, naar het net of de kleine rechthoek op het bord van de basket met een .8, naar de rest van het bord met een .6, naar andere locaties met een .4 en geen kijkgedrag met een 0. Vervolgens vergeleken we het kijkgedrag voor en na mLoS. De resultaten waren in overeenstemming met de verwachtingen. De schutters met een lage schiettechniek keken alleen naar het doel voor mLoS voor een duur van ongeveer 1 s in de vrije worp en voor ongeveer een halve seconde in het sprongschot, zonder enige consequenties voor de schotnauwkeurigheid. De schutters met een hoge schiettechniek, daarentegen, keken consistent naar het doel na mLoS in zowel de vrije worp als het sprongschot voor minder dan een halve seconde (circa 400 ms).

In Hoofdstuk 5 onderzochten we de optische basis van basketbalschieten in een reeks van drie experimenten. Uit een theoretische analyse bleek dat de afstand van de schutter tot de basket (d) en de elevatiehoek (α) samen de exacte locatie van de basket zouden kunnen bepalen. Een alternatieve mogelijkheid is dat de locatie van de basket bepaald wordt door ofwel d ofwel α te combineren met de hoogte van de basket, die zich altijd bevond op dezelfde officiële hoogte. Uit het eerste experiment bleek dat elite basketbalspelers een goede nauwkeurigheid van schieten behouden wanneer alleen informatie over d en α beschikbaar is tijdens de bewegingsuitvoering. Uit het tweede experiment bleek dat de schotnauwkeurigheid behouden bleef wanneer informatiebronnen gerelateerd aan d werden verwijderd, hetgeen impliceert dat deze informatiebronnen minder relevant zijn voor succesvol basketbalschieten. Tenslotte onderzochten we het gebruik van α door de hoogte van de basket te manipuleren zonder dat de proefpersonen hiervan bewust waren. Consistent met het gebruik van de elevatiehoek, onderschatten de proefpersonen de locatie van de verhoogde baskets en overschatten zij de locatie van de verlaagde baskets. We concludeerden daarom dat de elevatiehoek, gecalibreerd naar de officiële hoogte van de basket, gebruikt wordt in basketbalschieten.

Samenvattend kan gesteld worden dat de beschreven experimenten duidelijke inzichten in de visuele basis van basketbalschieten hebben opgeleverd. Zij onderstrepen het belang van het online gebruik van visuele informatie tijdens de bewegingsuitvoering, alsmede het belang van visuele informatie die pas laat wordt opgepikt in de beweging. Een variable die waarschijnlijk wordt opgepikt tijdens de schietbeweging is de elevatiehoek, die informatie verschaft over de afstand van de schutter tot het doel mits zowel waarneming als schothandeling gecalibreerd zijn naar de officiële hoogte van de basket. Deze inzichten hebben brede theoretische implicaties, alsmede diverse mogelijke toepassingen, die besproken worden in het zesde en laatste hoofdstuk van dit proefschrift.

:. Summary in Portuguese

Rita and Duarte

Percepção visual para o lançamento no basquetebol

O tema da investigação apresentada nesta tese é a percepção visual para o lançamento ao cesto no basquetebol. O Capítulo 1 apresenta uma revisão da literatura específica deste tópico. Os diversos estudos existentes acerca da percepção visual no basquetebol focam principalmente os seus aspectos temporais. Olhar o cesto longamente antes de iniciar o lançamento (Ripoll et al., 1986; Vickers, 1996), e orientar rapidamente o olhar para o cesto mantendo depois a cabeça e olhos estabilizados (Ripoll et al., 1986), foram identificados como sendo factores essenciais ao sucesso do lançamento, bem como uma marca diferenciadora do nível de perícia. Em contraste com estes resultados, um estudo mais recente salientou os benefícios de olhar para o cesto relativamente tarde durante o lançamento (Oudejans et al., 2002). Para tentar resolver esta aparente divergência, no Capítulo 2 examinamos quando é que, durante o movimento de lançar ao cesto, os basquetebolistas preferem ver o cesto, no Capítulo 3 estudamos os efeitos do controlo visual do lançamento ser feito online ou offline, e no Capítulo 4 analisamos o padrão de visualização do cesto ao longo das fases de preparação e lançamento. Para além destes aspectos temporais da visão, investigámos também as fontes de informação que são usadas para guiar o lançamento ao cesto no Capítulo 5. De seguida resumimos com maior detalhe o conteúdo destes capítulos.

No Capítulo 2 investigámos quando é que os basquetebolistas preferem recolher informação visual durante o movimento, tendo em conta diferentes estilos de lançamento. O estilo de lançamento é definido pela possibilidade de ver o cesto após o momento em que a bola e as mãos passam pela linha de visão (mLoS). Com um estilo baixo, a flexão do ombro e a extensão do cotovelo ocorrem em simultâneo de modo que após mLoS o cesto é ocultado pelas mãos e bola. Com um estilo alto, a flexão do ombro ocorre primeiro trazendo a bola acima da linha de visão seguido pela extensão do cotovelo de modo que após mLoS o cesto continua visível até à libertação da bola. Tendo em conta esta distinção, formulámos a hipótese que basquetebolistas experientes preferem recolher informação visual acerca do cesto tão tardiamente quanto o seu estilo de lançamento permite. Para manipular a visão do cesto, utilizámos óculos de cristais líquidos que se tornavam transparentes e opacos intermitentemente (durante 350 e 250 ms, respectivamente). Para determinar mLoS e o momento de libertação da bola utilizámos uma câmara de vídeo e o sistema Optotrak para registo 3D de movimentos. Neste estudo participaram doze basquetebolistas experientes, cinco com estilo baixo e sete com estilo alto de lançar. Não encontrámos diferenças significativas nas percentagens de cestos convertidos sob visão intermitente e sob visão normal, e entre os dois estilos de lançamento. De seguida, correspondemos mLoS e os eventos definidos nos óculos (i.e., transparência e opacidade) e empregámos estatística circular para investigar a presença de padrões de mLoS-óculos que fossem dependentes do estilo de lançamento. Os resultados mostraram que no grupo de estilo baixo, mLoS ocorreu próximo do momento em que os óculos se tornaram opacos, o que significa que estes jogadores preferiram ver o cesto nos últimos momentos antes de mLoS (note-se que após este momento o cesto é ocultado pelas mãos e bola). No grupo de estilo alto, mLoS ocorreu próximo do momento em que os óculos se tornaram transparentes, o que significa que estes jogadores preferiram ver o cesto nos últimos momentos antes da libertação da bola. Posto sucintamente, ambos os grupos recolheram informação visual acerca do cesto tão tardiamente quanto possível pelo seu estilo de lançamento. Estes resultados confirmam a hipótese, sugerindo que a informação visual é recolhida e utilizada durante o lançamento ao cesto.

Esta sugestão foi examinada mais profundamente no Capítulo 3, onde se relata a experiência que efectuamos para determinar se no lançamento ao cesto os jogadores usam principalmente informação visual recolhida antes de iniciar o movimento ou durante o movimento. Formulámos a hipótese que, para manter bons níveis de prestação, os jogadores precisam de recolher e utilizar informação visual durante o lançamento. Para testar esta hipótese, usámos os mesmos óculos de cristais líquidos para impor um intervalo de zero, um, ou dois segundos entre os jogadores verem o cesto e poderem lançar. Usámos o sistema Optotrak para registo 3D de movimentos do dedo mindinho e anelar, mão, pulso, cotovelo, e ombro. Os registos em vídeo das trajectórias das bolas foram usados para estimar a posição final da bola no plano do (aro do) cesto. Neste estudo participaram dezassete basquetebolistas experientes, oito com estilo baixo e nove com estilo alto de lançar. As análises da percentagem de cestos convertidos e da posição final da bola, revelaram decréscimos da prestação nas condições com intervalos entre ver o cesto e lançar em comparação com quando os basquetebolistas tiveram visão durante o lançamento. Não encontrámos diferenças significativas entre os dois estilos de lançamento. Adicionalmente, efectuámos uma análise aos coeficientes de covariância entre diferentes articulações. Os resultados revelaram que condições visuais mais severas estavam associadas à diminuição do acoplamento e aumento da variabilidade entre as articulações do braço. Embora este estudo não ponha de parte o uso de informação visual recolhida antes do movimento, sublinha a importância da recolha e uso de informação visual durante o lançamento.

No Capítulo 4 investigámos se o padrão visual de basquetebolistas experientes depende do seu estilo de lançamento e da técnica de lançamento. De acordo com estudos anteriores, prevemos que jogadores com estilo baixo de lançamento olhassem para o cesto longamente em preparação do lance livre mas não tanto no lançamento em suspensão, e prevemos que jogadores com estilo alto olhassem para o cesto entre mLoS e a libertação da bola tanto no lance livre como no lançamento em suspensão. Convidámos seis basquetebolistas experientes, três com estilo baixo e três com estilo alto de lançar, a fazer dez lances livres e dez lançamentos em suspensão enquanto registámos o seu olhar com um sistema de localização ocular (eye-traker). O registo do olhar foi codificado ao longo de cada repetição de modo que olhar o aro do cesto valeu 1, a rede do cesto ou o pequeno quadrado da tabela valeu .8, o resto da tabela valeu .6, outras localizações do olhar valeram .4, e ausência de olhar valeu 0. De seguida analisámos o olhar dirigido ao alvo (cesto e tabela) antes e depois de mLoS. Os resultados confirmaram as nossas previsões. Os basquetebolistas com estilo baixo olharam o alvo apenas antes de mloS durante 1 s no lance livre (tal como os resultados de Vickers) mas apenas metade dessa duração no lançamento em suspensão sem que a prestação fosse afectada. Em contraste, os basquetebolistas com estilo alto olharam o alvo durante cerca de 400 ms após mLoS tanto no lance livre como no lançamento em suspensão.

No Capítulo 5 investigámos que fontes de informação visual são utilizadas no lançamento em três experiências. Teoricamente, a distância absoluta entre o jogador e o cesto (d) e o ângulo de elevação com que o jogador olha o cesto (α) podem ser usados em conjunto para determinar a localização exacta do cesto. Alternativamente, a localização do cesto pode ser determinada pelo uso de d ou α em combinação com a altura oficial do cesto que é invariante. Os resultados da primeira experiência mostraram que basquetebolistas experientes mantêm a sua prestação quando d e α são as únicas fontes de informação disponíveis durante o lançamento. Os resultados da segunda experiência mostraram que a sua prestação é mantida quando fontes de informação relacionada com d são retiradas, o que significa que estas são menos importantes para a prestação. Na terceira experiência, manipulámos a altura do cesto sem que os basquetebolistas se apercebessem para testarmos o uso de α. Tal como seria de esperar com o uso de α, os basquetebolistas percepcionaram alvos alteados como estando mais próximos e alvos de baixados como estando mais distantes. Assim, concluímos que o ângulo de elevação, calibrado para a altura oficial do cesto, é usado no lançamento ao cesto no basquetebol.

Globalmente, os estudos apresentados nesta tese permitem uma série de conclusões acerca das bases visuais no lançamento ao cesto. Dão suporte à ideia de que a informação visual é usada durante a execução do lançamento e salientam o valor da informação visual detectada e usada na fase final do movimento. A variável que os basquetebolistas experientes parecem usar para lançar é o ângulo de elevação, ou seja, o ângulo dos olhos relativamente à cabeça, da cabeça relativamente ao pescoço, do pescoço relativamente ao tronco, quando o jogador olha para o cesto. O ângulo de elevação informa acerca da distância entre jogador e cesto desde que as percepções e acções do jogador estejam calibradas com a altura oficial, ou invariante, do cesto. Estas conclusões têm implicações teóricas importantes e várias aplicações que abordamos no sexto e último capítulo desta tese

:. Summary in French

Frédéric and Annick

L'objectif des recherches rapportées dans cette thèse était de mieux comprendre les bases visuelles du tir au basket-ball. Le premier chapitre propose un état de lieu de la recherche dans ce domaine. Les recherches antérieures réalisées sur ce sujet se sont concentrées sur les aspects temporels de la perception visuelle. Elles ont montré que la rapidité avec laquelle nous orientons et stabilisons notre tête et les yeux sur la cible, d'une part, et que de longues fixations de la cible, d'autre part, sont les ingrédients nécessaires à la performance et sont les marques distinctives de l'expertise. Toutefois, une étude récente a mis en avant certains avantages à regarder la cible plus tardivement. Pour éclairer ce problème, nous avons examiné dans le chapitre 2 la préférence temporelle de prise d'information visuelle, puis les effets du contrôle visuel "online" et "offline" dans le chapitre 3, et enfin le déplacement du regard durant la préparation et l'exécution du mouvement de tir, dans le chapitre 4. En plus des aspects temporels de la perception visuelle, nous avons étudié les sources d'information utilisées pour guider le tir au basket-ball au travers de trois études rapportées au chapitre 5. Les expériences présentées dans cette thèse amènent un éclairage nouveau sur les bases visuelles du tir au basket-ball. Les résultats vont dans le sens d'une utilisation "online" des informations visuelles durant l'exécution du mouvement, tout en renforçant la valeur de l'information visuelle extraite et utilisée dans les dernières phases du mouvement. Une variable pouvant probablement être extraite et utilisée pour guider le mouvement du tir en appui est l'angle d'élévation du regard, fournissant des informations sur la distance entre le joueur et le panier, montrant que la perception et l'action du joueur sont calibrés par rapport à la hauteur officielle du panier. Les implications théoriques et les applications possibles de ces observations sont exposées dans le sixième et dernier chapitre de cette thèse.

:. Summary in German :: Melanie and Olaf

Die Studien in der vorliegenden Dissertation behandeln das visuelle Verhalten während des Basketballwurfes. Das erste Kapitel bietet eine Übersicht der einschlägigen Literatur. Bisherige Studien richteten sich vor allem auf zeitabhängige Aspekte der optischen Wahrnehmung. Die Geschwindigkeit womit Kopf und Augen stabil auf das Ziel gerichtet werden, sowie eine lange Fixierung des Blicks auf das Ziel erwiesen sich als wichtige Voraussetzung für einen erfolgreichen Wurf und konnten in der Expertiseforschung verwendet werden um Experten von Anfängern zu unterscheiden. Im Gegensatz dazu erläutert eine neuere Studie daß es besser sei um den Blick erst spät auf das Ziel zu richten. Um diese gegensätzlichen Resultate zu verstehen, haben wir im zweiten Kapitel den bevorzugten Zeitpunkt für die optische Wahrnehmung analysiert. Im dritten Kapitel untersuchten wir die

Effekte von ‚online' und ‚offline' Kontrolle der optischen Wahrnehmung und im vierten Kapitel wurde das Blickverhalten während der Vorbereitung und Ausführung des Wurfes analysiert. Zusätzlich zu den zeitabhängigen Aspekten vom Sehen, untersuchten wir im 5. Kapitel mit drei Experimenten die Informationsquellen die durch den Spieler während des Basketballwurfes beobachtet werden. Die Experimente die innerhalb der vorliegenden Dissertation präsentiert werden, ermöglichen folgende Erkenntnisse über das visuelle Verhalten eines Schuetzen während der Ausführung des Basketballwurfes: Visuelle Informationen werden ‚online' wahrgenommen während der Bewegungsausführung, sogar in einer zeitlich fortgeschrittenen Phase der Bewegungsausführung. Eine Variable die möglicherweise wahrgenommen wird und demzufolge verwendet wird um die Wurfbewegungsausführung zu leiten ist der Steigungswinkel. Der Steigungswinkel liefert Informationen über den egozentrischen Abstand zu dem Ziel, sodass die Wahrnehmung und Aktionen von dem Schuetzen zu der wirklichen Höhe von dem Korb festgelegt werden können. Diese Erkenntnisse haben weitreichende theoretische Implikationen und einige praktische Anwendungsbereiche, welche in dem sechsten Kapitel dieser Dissertation erläutert werden.

:. **Summary in Italian** :: Francesco

Lo scopo generale delle ricerche riportate nella presente tesi era di chiarire le basi visive dell'azione del tiro nel gioco della pallacanestro. Il capitolo 1 fornisce una panoramica sulla letteratura rilevante. Studi precedenti su questo argomento si sono focalizzati sugli aspetti temporali della visione e hanno identificato la rapidità di orientare e stabilizzare la testa e gli occhi sul bersaglio e le osservazioni prolungate del bersaglio come elementi necessari per un'efficace prestazione e come discriminanti dell'esperienza. In contrasto con i risultati delle ricerca sopra citata, una ricerca piu' recente ha evidenzioato i vantaggi dell'osservare tardi il bersaglio. Allo scopo di aiutare la soluzione di questa questione abbiamo esaminato la linea temporale della raccolta di informazioni visive nel Capitolo 2, gli effetti del controllo visivo online e offline nel Capitolo 3, e i movimenti oculari durante la preparazione e l'esecuzione dei movimenti di tiro nel Capitolo 4. In aggiunta agli aspetti temporali della visione, abbiamo investigato anche le fonti di informazione che sono usate per guidare il tiro nella pallacanestro con tre esperimenti riportati nel Capitolo 5. Gli esperimenti presentati in questa tesi hanno fornito le seguenti evidenze sulla base visiva del tiro nella pallacanestro. Gli esperimenti danno supporto all'idea di un uso online di informazioni visive durante l'esecuzione del movimento ed evidenziano il valore aggiuntivo che hanno le informazioni visive raccolte ed usate in stadi successivi del movimento. Una variabile probabile che potrebbe essere raccolta ed usata per guidare i movimenti di tiro è l'angolo di elevazione, che informa sulla distanza egocentrica dal bersaglio nel caso in cui le percezioni e le azioni del giocatore sono calibrate all'altezza ufficiale del canestro. Questi risultati hanno ampie implicazioni teoriche ed alcune possibili utilizzi che sono considerati nel sesto e ultimo capitolo di questa tesi.

:. **Summay in Spanish** :: Ilona and Xavier

El objetivo general de la investigación de esta tesis fue dilucidar las bases visuales del lanzamiento en baloncesto. Capítulo 1 da una visión general pertinente sobre lo escrito en esta materia. Los estudios realizados sobre este tema se enfocaron en los aspectos temporales de la visión y han identificado la rapidez de orientación y estabilización de la cabeza y ojos en el objetivo, y en objetivos a distancia, como ingredientes necesarios para la ejecución con éxito y como característica de pericia. En contraste con las últimas conclusiones, un estudio más reciente ha destacado los beneficios de mirar el objetivo relativamente tarde durante el lanzamiento. Para ayudar a resolver este asunto examinamos en el Capítulo 2 el momento preferente de mirar el objetivo, en el Capítulo 3 los efectos del control visual 'online' y 'offline', y en el Capítulo 4 el comportamiento de la mirada durante la preparación y ejecución del lanzamiento. Además de los aspectos temporales de visión, investigamos las fuentes que se usan para guiar el lanzamiento de baloncesto con tres experimentos, elaborados en el quinto capitulo. Los experimentos presentados en esta tesis han proporcionado las siguientes conclusiones de la base visual del lanzamiento en baloncesto; Prestan apoyo al uso online de la información visual durante la ejecución del movimiento y destacan el valor incrementado de la información visual, detectada y usada en la última fase del movimiento. Una probable variable que los jugadores pueden usar para guiar el lanzamiento es el ángulo de elevación en el cual miran la canasta. La elevación angular informa en cuanto a la distancia hasta el objetivo, para que la percepción y las acciones del jugador estén calibradas a la altura oficial de la canasta. Estas conclusiones tienen implicaciones teóricas importantes y varias aplicaciones que se abordan en el sexto y último capítulo de esta tesis.

:. **Summary in Swedish** :: Eefke

Det övergripande målet för forskningen som framläggs i denna avhandling var att klarlägga visuella basen av basketbollskjutning. Kapitel 1 ger en översikt av den relevanta litteraturen. Tidigare studier rörande detta ämne fokuserade på synens temporala aspekter och identifierade hastigheten av orienteringen och stabiliseringen av huvudet och ögonen på målet och långa-måls fixering som nödvändiga ingredienser för framgångsrik presterande och kännetecken på expertis. I uppenbar kontrast till dessa fynd, en färskare studie framhävdade fördelarna med att titta på målet sent i relation till rörelse realisering. För att hjälpa med att lösa detta problem undersökte vi prefererade val av tidpunkt för upptagning av optiska information i Kapitel 2, effekterna på sk. online och offline visuellkontroll i Kapitel 3 och blick fixerings beteende under förberedelse och genomförande av skjutande rörelserna i Kapitel 4. Vi undersökte förutom synens temporala aspekter informationskällorna som används för att vägleda basketbollskjutning med tre experiment som är redovisade i Kapitel 5. Experimenten som presenteras i den aktuella avhandlingen skaffade fram följande insikter i den visuella basen av basketbollskjutning. De stöttar den sk. online användning av visuell information under rörelseutförande och understryker tilltagande betydelsen av visuell information som fångas upp och används under senare delen av en rörelse. En möjlig variabel som kan fångas upp och användas för att vägleda skjutande rörelserna är vinkelstorleken varifrån spelaren tittar på basketkorgen. Vinkelstorleken ger information angående det egna centrala avståndet till målet under förutsättning att perceptionerna och aktionerna av spelarna är kalibrerade till officiella höjden av basketkorgen. Dessa insikter har stora teoretiska implikationer och några möjliga tillämpningar som är diskuterade i 6: e och sista kapitlet av denna avhandling.

:: Acknowledgements

I would like to publicly express my appreciation for a number of people whose involvement and interest were crucial for the completion of this thesis and for my improvement as a researcher and as a person.

Peter Beek :: I treasure every hour I spent working with you on manuscripts, learning the magic of transforming dull and unclear paragraphs into nice stories. In key moments you provided incentive, trusted me, and supported my autonomy. There are two things about you that I find really beautiful, Peter. That you can be so excited about getting a paper accepted, and that you can laugh so easily and so loud.

Raôul Oudejans :: I am full-heartedly grateful that you gave me the opportunity to be in this project. I admire your curiosity in research and your enthusiasm for basketball both of which provided a different angle to the issues I investigated. We have been through some rough patches but managed to overcome our divergences. Therefore I take special pleasure in celebrating the completion of this thesis with you.

Piet van Wieringen :: I appreciate your willingness to comment on manuscript drafts, replies to reviewers, and replies to journalists, but most of all I appreciate our outings! I enjoy our long Sunday afternoons discussing performances, visiting exhibitions, or walking into mysterious narratives.

Raôul Huys :: Thank you for getting involved in my basketball affairs and for your patience and wit in answering all my questions.

Hans de Koning :: Your availability, humour, and bright practical ideas for the basketball setup make you a dream technician!

Berry den Brinker :: For someone who studies visual perception for sports you are the ultimate example of human resourcefulness! I would like to thank you for developing the methodology for the precise estimation of ball landing positions.

Ellen Vaessen and Tjitske Boonstra :: Supervising your master project was easy because you were very dedicated students, I was lucky to work with you.

Joost Dessing :: Despite your busy agenda you always make time for my last-minute invitations for dinner, cinema or science discussions over a beer. I look forward to my next Sinterklaas slash birthday poem.

Arne Ridderikhoff :: Thank you for your endless patience satisfying whatever curiosity came to my mind and for being such a sweet guy underneath that hard shell.

Anke van Mourik :: We evolved from a bitchy hi and bye in the corridor to funny casual conversations at parties to being true well-wishers and I hope we remain in this latter stage for a long time.

Rui Henrique :: You offered to develop the layout of this thesis and the outcome went far beyond my expectations. I am glad our friendship survived all the vicissitudes of life and hope that we can continue to share precious moments together. Of course the company of our little group of scouting friends from Tomar is most welcome too.

Ben Kreukniet :: I like to visit your little world of emerging light and sound.

Maria Krahe and Patrícia Matos :: For the endless friendship and hospitality.

Angelique and Hanneke :: Those beach volleyball days are over but with you on my back the indoor season will be a blast!

My Colleagues :: I would like to thank the colleagues at the Faculty of Human Movement Sciences for building the warm atmosphere in the corridors, coffee room, parties, and outings. A special word goes to those colleagues who were most generous in their kindness and intellectual exchange Alistair, Floor, Olaf, Melvyn, Harjo, Nicolette, Claudine, Johan, Chris, Martijn, Hemke, Tjeerd, Bregje, Chris Elschot, Karin, Vana, Simone, Maaike, Fred, and Melanie. Outside this faculty but always available to discuss my ideas were Duarte, Toy, Passos, Xavier, Fil, Amika, Gil and Mário.

Rolf van de Langenberg :: We walk along canals discussing work, art, and philosophy, then each takes a different path and later we meet again for more. Being with you is exhilarating! Together with Dinant the discussions run timeless.

Dinant Kistemaker :: It is hard to pass an idea through your logic's scrutiny but always worth the while. I have learned much and shared many things with you. Thank you for caring so much. You and Rolf spoil me with mimo and I love it!

My Family :: Mena you have always been an inspiration to me and I still think I could not have had a more caring sister. I feel very much welcome with you and Miguel, and I always feel like a crazed super-hero when I laugh and play with little Rodrigo.
Mamã and Papá your unconditional love and support are inestimable...

:: Curriculum Vitae

Rita Ferraz de Oliveira

I was born on the 5th of December, 1977, in Torres Novas but spent all my childhood in Tomar, a historical city in the centre of Portugal. There I went to school and developed an interest in psychology, biology, sports, and Portuguese and English language. In my free time I wrote short stories such as 'The misterious reappearance of the blue sock', and went swimming, or scouting with groups of friends. In 1995 I moved to Lisbon where I studied sport sciences and sport psychology and got increasingly interested in scientific research. I was often voluntary staff to research studies and conferences, and started to attend international conferences. My first jobs were as free-lance translator and swimming teacher. My other interests were the performing arts, painting, and surfing. I spent study periods abroad first in Finland for five months, then in Norway for two weeks, and finally in The Netherlands where I conducted the experiment for my master thesis in two months. That is how I met Raôul Oudejans who later invited me to apply for an assistant research position in The Netherlands. As a result of that application, I moved to Amsterdam in 2003 and initiated the research project on the visual perception for basketball shooting under the supervision of Raôul Oudejans and Peter Beek at the Faculty of Human Movement Sciences, VU University Amsterdam.

:. Education

2003-2007 :: Human Movement PhD student at the Institute for Fundamental and Clinical Human Movement Sciences, VU University Amsterdam, The Netherlands.

2000-2002 :: Sport Psychology graduate student at the Faculty of Human Kinetics, Technical University of Lisbon, Portugal. In 2001, student of the European Master in Sport Psychology at the University of Sport and Physical Education of Oslo, Norway, and at the Faculty of Human Movement Sciences, VU University Amsterdam.

1995-2000 :: Sport Sciences undergraduate student at the Faculty of Human Kinetics, Technical University of Lisbon, Portugal. In 1998, student of the Erasmus exchange programme in the Faculty of Sport and Health Sciences, University of Jyväskylä, Finland.

:. Professional

2003-2007 :: Research assistant (PhD student) at the Faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands.

2003-2007 :: Research coordinator and newsletter editor for the European network of young specialists in sport psychology, ENYSSP (voluntary work).

2001-2002 :: Assistant lecturer of sport and exercise psychology at the Institute of Health Sciences, Monte da Caparica, Portugal.

1999-2003 :: Physical education teacher and sports coordinator for teenagers at several public schools, Portugal.

1998-2000 :: Free-Lance Portuguese-English translator with regular works to the Portuguese enterprise Mota & Companhia.

:. Publications

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