DECISION-MAKING AND GAZE BEHAVIOR OF BASKETBALL PLAYERS IN 3-ON-3 PICK'N ROLL PLAY

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ABSTRACT

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Introduction. In complex play-situations such as basketball pick'n roll, players must use their vision to read the game, plan an action, and execute a motor response according to the goal. The eye-tracking research in sports offers an understanding of how gaze is related to performance and how athletes make decisions in complex and time-constrained situations. The critical visual information, advanced cue points, or search patterns could be identified, and this information could be used to develop coaching. The purpose of the current study is to assess the differences in gaze behavior between different decisions, defensive plays, and level of field of vision in 3-on-3 basketball pick'n roll.

Methods. Total of 22 Finnish national-level male basketball players were measured. In-situ gaze data was analyzed from a total of 24–30 pick'n roll trials per individual with Tobii Pro Glasses 2 -eye tracking glasses. The trials were executed against three different defensive plays: Switch, Soft, and Hard Hedge. All trials were recorded with an external GoPro Hero 3 camera. Additionally, the players were tested with vision perimetry for horizontal and vertical field of vision binocularly and separately. The field of vision was used to divide the players into two groups: Wide and Narrow field of vision. Both the decision-making data; made decision, quality and accuracy of decision; as well as the gaze data; fixations to 9 areas of interest, final fixation, fixation to correct option, percentage of viewing time, and two-fixation scan paths; were analyzed from the video image frame-by-frame. All variables were compared across correct and incorrect decisions, court side and groups of field of vision.

Results. Defense has a significant impact on frequency and accuracy of decisions ($p<.001$), and on two-fixation scan paths ($p<.05$). Decision accuracy was further related to percentage of the viewing time and to fixations to correct option ($p<.001$), while a made decision had a significant effect only on percentage of the viewing time ($p<.001$). Field of vision groups differed from each other in percentage of the viewing time, scan paths, and starting fixation of trial. Court side had no significant effect on any of the decision-making or gaze variables.

Conclusion. Defense influences decision-making and visual search behavior of experienced players whereas the athlete's field of vision had no such effect. Advance cue points in basketball pick'n roll are the screener/roller, the screen defender, and the positive space between players. By recognizing these cue points, basketball coaches can help players recognize and use the information prior to actually using the screen.

Key words: basketball, decision-making, sports vision, field of vision, visual search strategy

ABBREVIATIONS

AOI	Area of interest; point of gaze in visual display measured with eye-tracking camera
BH	Ball handler, the study participant in Pick’n Roll -test
BHD	Ball handler defender
CNS	Central nervous system
CP	Corner player
CD	Corner defender
FOV	Field of vision, field of view
QE	Quiet Eye
NEG	Negative space, space outside players and basket
NFOV	Narrow field of vision group
PnR	Pick’n Roll -test
POS	Positive space, space between players and basket
SR	Screener/roller
SD	Screen defender
WFOV	Wide field of vision group

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ABSTRACT

1 INTRODUCTION

Athletes across all sports rely on their vision to receive information, to read situations, to plan actions, and to execute motor responses in rapid, constantly changing environments. Eye movements are used to bring the visual information onto the neural processing systems (Vickers 2007, 2), to position critical targets on fovea, to scan rapidly over larger visual fields, and to allow visual information perception (La Valle 2019, 136). Any deficiencies in the ability to move eyes or to follow a moving target can influence the perception of the visual field and the assessment of spatial orientation and depth perception (Williams et al. 1999, 63).

Michael Jordan, one of the most revered players in basketball history, occasionally welcomed rookies to the NBA by shooting foul shots with his eyes closed proving that clear vision is not critical in such closed skill (Williams et al. 1999, 85). However, it is established that even superior technical skills cannot fully cover an athlete's difficulties in reading the game (Vickers 2007, 137). Especially on an elite level, the perceptual-cognitive skills discriminate athletes far more likely than, e.g., physiological profiles (Williams & Reilly 2000). Experts are found to be faster and more accurate in scanning the display, recognizing and anticipating patterns of play, detecting critical objects of information, interpreting opponents' postural orientations, anticipating opponents actions, identifying situational probabilities, and making decisions (Williams et al. 1999, 139; Williams & Ward 2007; Roca et al. 2013).

In a complex play-situation, like in basketball's pick'n roll, players have to read the game, decide on a plan, and perform a motor response to achieve their goal. The skill of decision-making – i.e. identifying and choosing options of plans (Kaya 2014) under time and environment constraints – is a source of power that separates athletes (Klein 1999; Vickers 2007, 144). With controlled visual search and eye movements, the athlete can analyze the display more efficiently (Williams et al. 1999, 145), and pick up information moments before the specific incident (e.g., 1-on-1 contact) occurs, allowing for the anticipation of the future response (Williams & Ward 2007). The perceptual-cognitive skills, such as advance cue utilization and future response anticipation, help to reduce the time delay that it takes for the brain to produce a conscious perception (Young & Sheena 1975).

Eye-tracking research in sports offers an understanding of how gaze is related to performance (Nagano et al. 2004), how athletes use their perceptual-cognitive skills so effectively (Vickers 2009) and how athletes make decisions (Maarseveen et al. 2018a) in complex and time-constrained situations. By studying elite athletes, the critical visual information, advanced cue points, or search patterns could be identified, and this information could be used in, e.g., teaching, coaching, and therapy (Vickers 2007, 4; Wimshurst 2012, 20). However, most of the eye tracking studies from the past 40 years have been limited to laboratory settings, closed skill testing, or artificial motor responses (see Kredel et al. 2017; Hüttermann et al. 2018). Additionally, most of the studies have explore the perceptual-cognitive skills separately from the on-court performance (Williams & Ward 2007). All these approaches fail to offer understanding of real athletic performance in real game situations (Maarseveen et al. 2018b).

Although the evidence behind advance cue utilization is consistent and the ability to use advance cues is highly appreciated, the mechanisms and specific perceptual information underlying the cue identification process are still unknown (Mann et al. 2007; Williams & Ward 2007). Previous research has shown that to gain insight into decision-making, advance cue utilization and visual search patterns in game situations, the experimental conditions must be as close to an actual game as possible (Abernethy et al. 2007; Afonso et al. 2014). The purpose of the current study is to assess the differences in made decisions, decision accuracy and gaze behavior between correct and incorrect decisions, with different defensive plays and with different level of field of vision in 3-on-3 basketball pick'n roll. The 3-on-3 drill offers conditions that imitate game conditions, and thus favor development of the perceptual-cognitive skills through continuous interactions, opportunities to seek information, variable of task solutions, and inclusion of advance cue points (Roca et al. 2013; Davids et al. 2015). Since the protocol is designed to be as close to a game-situation as possible, conclusions about game behavior can be drawn to further develop coaching cues.

2 VISION PHYSIOLOGY

With shifts of gaze visual information is brought onto the retina of the eye for the neural processing of the received information (Vickers 2007, 2). The retina covers more than 180° of the inner eye surface, and is covered with photoreceptors, light-sensitive cells which translate the light into nerve signals which propagate to the visual cortex (Williams et al. 1999, 68; La Valle 2019, 127). Visual cortex produces an inverted, two-dimensional "replica" of the environment, i.e. the experience of vision (Williams et al. 1999, 68; La Valle 2019, 131). It takes over 100 milliseconds for the brain to produce a conscious visual image, which is a composite work of the visual cortex and memory (Young & Sheena 1975; La Valle 2019, 131).

The two types of photoreceptors are cones used in higher illumination and rods used in lower illumination (Williams et al. 1999, 68; La Valle 2019, 127). Cone and rod receptors differ from each other in photoreceptor-retinal ganglion cell convergence. Cones may have only one-to-one converge resulting in high acuity color vision, when rods have many-to-one convergence resulting in high sensitivity for light and motion but lacking in sensitivity for details and colors (Williams et al. 1999, 146). Since the density of cones decreases and the density of rods increases outwards from the centre of the retina, the centre of vision is specialised in fine acuity and detailed, coloured vision (Williams et al. 1999, 69; 146). Conversely, the periphery has a better ability to detect movement in low light (Williams et al. 1999, 71; La Valle 2019, 130).

To perceive sharp and coloured images, eyes must be fixated straight to the object (Williams et al. 1999, 146). Fovea is the point of clear vision, since it is the point of the retina that has the greatest concentration of cone photoreceptors (Williams et al. 1999, 69; La Valle 2019, 130). Because the entire fovea is only 1.5mm (+/- 1mm) wide, the field of clear vision is very narrow, only 1-2° in both the vertical and horizontal planes (Williams et al. 1999, 91; La Valle 2019, 130). The angular range of 2.6°-7° is parafovea (La Valle 2019, 130), and rest of the angular range, up to 200° horizontally (figure 1) and 160° vertically (Harrington 1964), is the periphery where density of rod receptors dominates over cones (Williams et al. 1999, 71). According to Ruch (1965), the acuity of image decreases to 50% at 2.5°, to 25% at 7.5°, and to 4% at the extreme periphery.

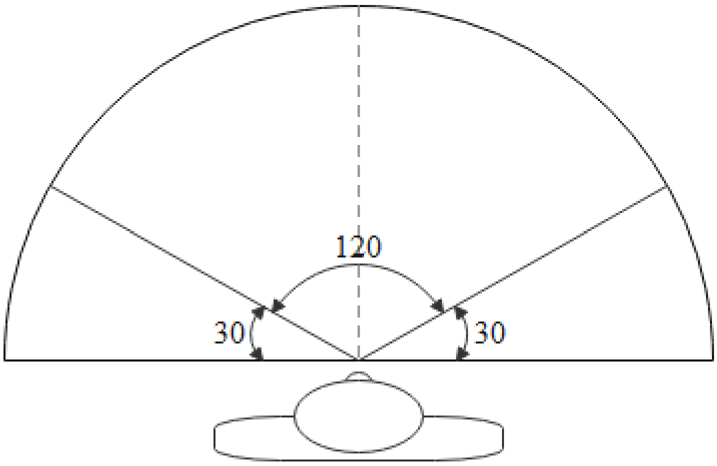

FIGURE 1. The binocular and monocular field of vision (modified from Aprile et al. 2014).

2.1 Eye movements

Eye movements are a crucial component of vision (Arines-Piferrer 2011). To view multiple objects clearly, the person must continually move their eyes to position different objects on the fovea (Williams et al. 1999, 146). Eye movements occur both voluntarily and involuntarily by six muscles innervated by three cranial nerves and attached to the surface of the eyeball (figure 2) (Williams et al. 1999, 71; Micic & Ehrlichman 2011; La Valle 2019, 140). Both eyes rotate synchronously over four visual axes: Horizontal, transverse, vertical and oblique (Williams et al. 1999, 66; 71). Since the visual system is paired with head and neck movements and balance control systems, eyes move together with head movements (Williams et al. 1999, 71). Vertical field of vision with eye movements only is at its maximum about 70° of monocular angle, while with combination of head movements it is around 180° (La Valle 2019, 142).

The first objective of eye movements is to position the area of interest (AOI) on the fovea (Williams et al. 1999, 69). If the target is large, eyes scan rapidly over it while fixating on some AOIs (La Valle 2019, 136). The second objective is to keep the vision fixated on the same stimuli to give the photoreceptors more time to produce a response, since it takes over 10ms for them to react on visual stimuli and over 100ms for a motor response to start (Young & Sheena 1975; La Valle 2019, 136). The third objective of eye movements is to prevent adaptation to a constant stimulus since the visual perception is dependent on eye motions and without movement the perception disappears. Eye movements allow a stereotypic 3D-view (La Valle 2019, 136.) Micic & Ehrlichman (2011) propose that the number of simultaneous tasks influences eye movements. To prevent interference, eye movements will alternate so that new external information will be brought from the task that requires the most visual-cognitive processing (e.g. visuo-spatial question) or attention (e.g. difficult). This can be achieved by reducing the frequency of saccades or directing the gaze. (Micic & Ehrlichman 2011.)

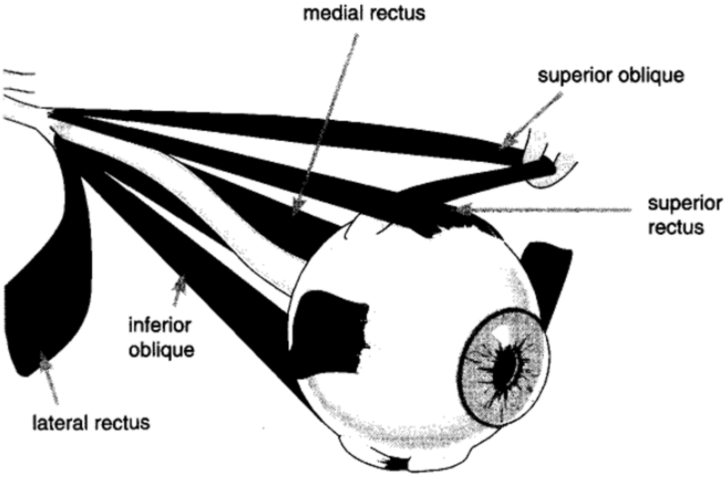

FIGURE 2. The muscles responsible for eye movements (Williams et al. 1999, 72).

The four most important eye movements are; 1) saccades: rapid movements used to fixate from one location to another; 2) smooth pursuit: tracking of an object with slower speeds while head remains still or with head movements; 3) vestibulo-ocular reflex: stabilisation of eyes and the image during head movements; and 4) vergence: inward or outward rotation of eyes to minimize double-images when fixating on different distances (Williams et al. 1999, 72; La Valle 2019, 140). They can be categorized also as blinks, tracking, saccades, and fixations (Vickers 2007, 4; La Valle 2019, 140). Saccadic eye movements are the only ones that deliver information on the fovea, when smooth pursuit, vergence and vestibular eye movements stabilize the image on the fovea (Micic & Ehrlichman 2011). Interaction between different types of eye movements is required for a functioning and efficient visual system (Williams et al. 1999, 73).

Saccades. The rapid eye movements or shifts of gaze among different points in the visual field are called saccadic eye movements (Williams et al. 1999, 72; Perez-Zapata et al. 2011). The constantly moving, ballistic, and high velocity saccades foveate efficiently on different locations to gather maximum information (Micic & Ehrlichman 2011; Perez-Zapata et al. 2011). The goal of saccades is to quickly relocate the fovea (i.e. locate previously extrafoveal on the fovea) and scan the image with highest visual acuity (Perez-Zapata et al. 2011; La Valle 2019, 139). Saccades typically last 30-120ms, with peak velocity of 600°/s (Micic & Ehrlichman 2011; Perez-Zapata et al. 2011). Normally a human averages three saccades per second, each lasting around 60-100ms (Vickers 2009). In dynamic and fast sporting environments athletes rely mostly on rapid saccadic eye movements (Williams et al. 1999, 148).

The bottom-up or stimuli-driven theory of gaze guidance suggests that the visual stimuli guide the saccades, and that any stimuli in periphery will trigger a new saccade (Perez-Zapata 2011). Thus, a different sensory stimulus controls the eye movement, not the perceived signals (Perez-Zapata et al. 2011). On the other hand, the top-down or goal-driven theory has found evidence for cognitive control of eye movements in which eye movements are task-dependent and focus is turned into relevant objects, targets or other critical areas (Perez-Zapata et al. 2011). It is possible that bottom-up and top-down processing are not totally different systems and the use of them is time-dependent (Pere-Zapata et al. 2011). During athletic performance, goal-driven eye movements are voluntary and driven by the need to pick up information from the periphery. Conversely, stimulus-driven shifts are involuntary and reflexive reactions to unexpected or rapid emergence of information (Williams et al. 1999, 154; La Valle 2019, 139).

Fixations. Fixations are steady saccades of a few hundred milliseconds, which allow the visual signals which enter the fovea to be fully processed by the visual brain and will lead to a conscious experience (Perez-Zapata et al. 2011). In research, fixations can be detected as the “stops” between eye movements, which enable stabilisation of the AOI and more detailed processing of the image (Williams et al. 1999, 148). Fixations may be manipulated by any stimulus (e.g., visual, auditive) that affects attention (Arines-Piferrer 2011). During locomotion, gaze can be directed towards objects when the gaze is stationary in the object but locomotion continues (object fixations), or the gaze can travel within the locomotion and information flows continuously (travel fixations) (Vickers 2007, 136).

The duration of fixations has been typically adjusted to ≥ 100-120ms in eye tracking research (e.g., Afonso et al. 2012; Roca et al. 2013; Timmis et al. 2014; Decroix et al. 2017). Research has shown that even in dynamic and open tasks experts fixate on specific AOIs for extended periods (e.g., Williams & Elliott 1997; Vaeyens et al. 2007; Padilha et al. 2016), and overall use fewer fixations with longer fixation durations (Mann et al. 2007). Quiet Eye (QE) is the final fixation before motor action initiation that lasts ≥100ms and moves within 3° of the visual angle (Vickers 2007, 10). The importance and complexity of the target and the task at hand affect the duration and frequency of fixations (Williams et al. 1999, 148; Murakami et al. 2006). In simple tasks with high expertise, a fixation as low as 100ms can be efficient (Vickers 1992, golf putt), but in dynamic, open-skill tasks fixations of over 1000ms have been reported (e.g., Williams & Davids 1998, soccer; Vickers et al. 2017, ice hockey).

2.2 Sports vision

Vision is a critical feature in sports, since practically all athletic performance requires athletes to see objects or situations during complex and rapid movements – to visually perceive the environment and execute an appropriate motor action according to those perceptions (Williams et al. 1999, 3; 61; Erickson 2007, 20). In a time-constrained performance, athletes rely mostly on saccadic eye movements to quickly scan from one AOI (e.g., ball) to another (e.g., basket), to gain information, and to predict future events (e.g., the end position of a ball) (Williams et al. 1999, 147-148). Any deficiencies in the ability to move eyes from one target to another and/or to follow a moving target while stationary or in motion can influence the perception of the visual field and the assessment of spatial orientation, and/or depth perception (Williams et al. 1999, 63). Sports vision can be improved to enhance performance (Erickson 2007, 19).

The vision can be divided into “visual hardware”, referring to the physiological features of the eyes, and into “visual software”, referring to the cognitive processes behind perceptions (Williams et al. 1999, 61-62). Statements like “great eye” and “excellent peripheral vision” point to the visual hardware and the quality of visual systems. Statements regarding, for example, court sense imply superiority in knowledge structures of the visual software (Williams et al. 1999, 83). In practice, these two processes rely on each other (Williams et al. 1999, 62).

Superiority in either visual abilities or the cognitive processes seems to offer an advantage in sporting performance (Erickson 2007, 19-20).

There is no standard method for measuring which visual skills are the most important in a sporting task (Wimshurst 2012, 72). The different visual elements that may have an effect on athletic performance are: 1) sight: visual acuity (the clarity of the image and ocular health); 2) motor and sensor: visually guided motor performance (the fixation stability, eye movements, accommodation, vergence and fusion); and 3) information processing: quick and accurate processing, interpretation and decision-making (Erickson 2007, 1). Visual acuity can further be separated into static or dynamic acuity (the athlete and/or the object is moving), and sport-specific acuity (e.g., the environment, dynamic/static situation, 3D-layout) (Williams et al. 1999, 85). Contrast sensitivity, depth perception, and peripheral visual field are aspects of visual acuity which have been studied in sports (Williams et al. 1999, 89-91).

The visual demands of performance vary significantly among different sports. For example, basketball as a dynamic and reactive sport requires different visual features than static and precise target shooting (Erickson 2007, 8). Erickson (2007, 9) itemized different task demands which affect the required visual skills in performance including static or nonstatic; dynamic or nondynamic; distance; contrast levels; target size/color/shade; positions; orientations; stress (cognitive and cardiovascular); and visual attention demands (central/peripheral/split attention). It is apparent that many sports contain fast and dynamic visual features which demand the athlete to balance central and peripheral awareness for choosing the best motor response (Erickson 2007, 16). For example, in team sports, many situations require more attention from a player's peripheral visual field than the central one (Erickson 2007, 16).

Despite the different task constraints, it is apparent that sporting performance requires a lot more than just the ability to see (Williams et al. 1999, 62). For example, a study by Applegate & Applegate (1992) compared basketball free-throw shooting performance between full acuity (6/6) and decreased acuity (6/75) produced with spherical lenses. They found no significant differences in shooting ability between the conditions, concluding that completely clear vision may not be critical at least in this type of closed skill (Applegate & Applegate 1992). In a study by Christenson & Winkelstein (1988) athletes performed significantly better in 8 out of 11 visual skill tests, such as motor reaction time and peripheral awareness, than non-athletes. This indicates superior abilities particularly in perceptual-cognitive processes and not only in vision physiology (Christenson & Winkelstein 1988). Similarly, in comparison between basketball players and non-players, players were found to have significantly better abilities in near point convergence, positive fusional vergences, halo discriminability, and eye-hand coordination, concluding that these visual abilities may have improved with practice (Vera et al. 2017).

Expert athletes have been found to have better visual function than novices, allowing them to see and perform better (Erickson 2007, 1). However, it is unclear whether the experts have better visual physiology, or if experts are just able to use the available visual information better, i.e. having superior cognitive ability (Erickson 2007, 19; Wimshurst 2012). Land & Macleod (2000) analyzed cricket players' batting and found that skilled players used an internal model of gaze behavior (fixation to the ball as the delivery leaves, followed by saccades) learned by playing the sport with environmental constraints. Erickson (2007, 20) provided an explanatory example of the differences in either visual hardware or software: When comparing two golfers with same skill levels (experts), the player with a higher level of contrast sensitivity (feature of visual hardware) has a better ability to read the contours of the green, thus having more information and an advantage on performance. On the other hand, when comparing golfers with different skill levels (expert and novice) but similar visual abilities, the two see the same display but the expert has more experience of similar situations and is able to interpret the contours of the green and distance of the hole better, resulting in a superior result (cognitive processes of visual software). These results indicate that even great cognitive processes cannot fully compensate deficiencies in the gathering of visual information (Erickson 2007, 20).

Based on previous research, it is certain that no single visual skill is unequivocally responsible for expert-novice differences in sport performance (Williams et al. 1999, 95). However, no further conclusions can be drawn due to limited study designs. The first limitation with using athletes vs. non-athletes or experts vs. novices in sports vision research is that no matter the results, it is difficult to make reliable distinctions between performances which are due to improvements in visual skills due to playing the sport and those which occur due to certain initial level of visual skills necessary in the endeavor (Williams et al. 1999, 141; Wimshurst

2012, 67). In addition, the used task sets up initial differences between groups both in skill levels and task familiarity, leading to differences in gaze behavior. Consequently, it is difficult to determine whether the differences between groups are due to visual or performance abilities (Williams et al. 1999, 141; Wimshurst 2012, 67.) Likewise, gaze behavior research with novices will not lead into conclusions about improving the expert athletes’ performance but studies with experts and comparison with other experts may lead to assumptions that can help novices to improve their performance (Hüttermann et al. 2018).

2.3 Peripheral vision

Peripheral vision refers to the ability to see and react to a stimulus outside the fovea (Williams et al. 1999, 91). First aspect of peripheral vision is *the field of view*, which is the hardware component of vision (Smythies 1996). It means the maximum arc of visual field on which a performer can detect a stimulus (Smythies 1996). Field of view is normally measured with a Perimeter, which requires a detection of flashing lights on the perimetry while fixating on a central reference point (Williams et al. 1999, 92). Second aspect is *the visual field*, which refers to the actual range of awareness, or the visual range from where an athlete can detect perceptions during performance (Smythies 1996) and is at least partly a software component (Williams et al. 1999, 93). The visual field is dependent on the task: The difficulty of the task on the fovea (foveal load), and level of stress, fatigue and/or excitement (Williams et al. 1999, 92).

Especially in team games, such as basketball, the role of peripheral vision is a highly respected performance quality (Williams et al. 1999, 91). Even though athletes have an efficient eye and head movement repertoire, some events require fixation on a target while simultaneously other critical events happen in the periphery (Williams et al. 1999, 91). In addition, peripheral vision provides athletes information of positioning on the court and orientation of the body in the environment (Williams et al. 1999, 92). Peripheral vision provides information about “where an object is”, when fixating on the object, whereas the foveal vision provides information about “what it is” (Trevarthen 1968).

Peripheral vision can be used subconsciously or consciously, while foveal vision is expected to be conscious (Williams et al. 1999, 147). As discussed under sports vision (chapter 2.2), there is no clear evidence if athletes have equal or better hardware or software visual skills. This concerns peripheral vision as well. It may be that athletes do not have larger fields of view, but they may have wider visual fields. This means that the athlete’s hardware component of peripheral vision may not be superior, but they possess superior ability on the cognitive processes to detect information wider on the periphery (Williams et al. 1999, 94).

3 DECISION-MAKING IN SPORTS

Kaya (2014) states that “decision-making is a fundamental element of any sport”. Especially in a complex, dynamic and time-constrained environment, like basketball, where the players have to read the game, as well as decide and perform appropriate motor responses to reach a specific goal (Maarseveen et al. 2018a; Kaya 2014; Araújo et al. 2006). Decision-making is an intellectual process of identifying and choosing alternatives – an idea must be selected from several different options that may or may not trigger an action (Kaya 2014). Good decision-making ability under all time- and environment-constraints is a source of power which separates superior athletes from others (Klein 1999). Decision-making involves gaining necessary visual information and using cognitive processes to evaluate the information and selecting an option (Maarseveen et al. 2018a). Good decision-making in sporting environment begins with the detection of perceptual cues (Vickers 2007, 140; Klein 1999). Efficient and accurate detection of information is extremely valuable in decision-making (Williams et al. 1999, 122).

Made decisions are highly dependent on the context of the task (Timmis et al. 2014; Decroix et al. 2017; Maarseveen & Oudejans 2018). Therefore, athletic decision-making can only be understood when studied in its typical environment (Williams et al. 1999, 287; Araújo et al. 2006). Even small changes in conditions or actions may multiply the opportunities for subsequent actions, and therefore, athletes cannot completely make their plan in advance (Araújo et al. 2006). Johnson (2006) recognized three features for decision-making in sports: 1) Decision-making is naturalistic: the task is somewhat familiar for the decision-maker; 2) decisions are dynamic and they reveal over time: either the information is gathered over time (internal dynamics) or the context of information is changing (external dynamics); and 3) decisions are made in real-time during the tasks or under intense time-constraints.

3.1 Theories of decision-making

Theoretical models allow for the study of ongoing processes during decision-making in sports (Williams et al. 1999, 7). However, theories can be misleading when social and philosophical aspects affect study designs, and consequently, the ideas of the processes in natural settings

(Williams et al. 1999, 7). Vickers (2009) notes that in Quiet Eye research, two theories have been used to explain the importance of the final fixation in motor performance: Cognitive psychology and ecological psychology. Few years earlier, she also listed these two as some of the most suitable theories for studying perception-action in fast and dynamic tasks (Vickers 2007, 12), such as the basketball pick'n roll. Therefore, cognitive psychology and ecological psychology theories of decision-making are further explored in this chapter.

Cognitive psychology. The cognitive psychology approach places a significant emphasis on the cognitive processes in decision-making, as perceptions do not make much sense without the contribution of cognitive processes which create the reality in the brain (Williams et al. 1999, 10). The perception-action coupling in cognitive psychology is normally explained with a computer metaphor. The brain takes in information, processes it, and initiates a resultant movement (Haywood & Gretchell 2009, 21). The goal of this cognitive perspective is to answer questions about perceptions, information and cue utilization which affect made decisions, decided motor responses, and performance (Vickers 2007, 3). In sporting performances, winners have discovered the best, specific information which leads to high-level winning performance even with opponents preventing certain perceptions or cues (Vickers 2007, 3).

Decision-making in cognitive psychology is explained with the *information-processing model*, which identifies three steps of information flow – perceptual mechanisms, decision mechanisms, and the effector mechanism – which operate sequentially with impact of feedback and memory (figure 3) (Erickson 2007, 21; Williams et al. 1999, 9). The perceptual mechanism refers to perceptual processes which detect, gather, recognize, and categorize information from the environment (Marteniuk 1976, 6; 20; Vickers 2007, 2). The decision mechanism selects and decides on an action in accordance with the goal and stores the information in the memory for later use in similar situations (Marteniuk 1976, 19; Vickers 2007, 2). The effector mechanism organizes and sends the motor commands to execute the decided motor response (Marteniuk 1976, 6; Vickers 2007, 2). Feedback in the information-processing model is received from the movement outcome, and is used, if necessary and time allowing, to correct the executed action (Marteniuk 1976, 6).

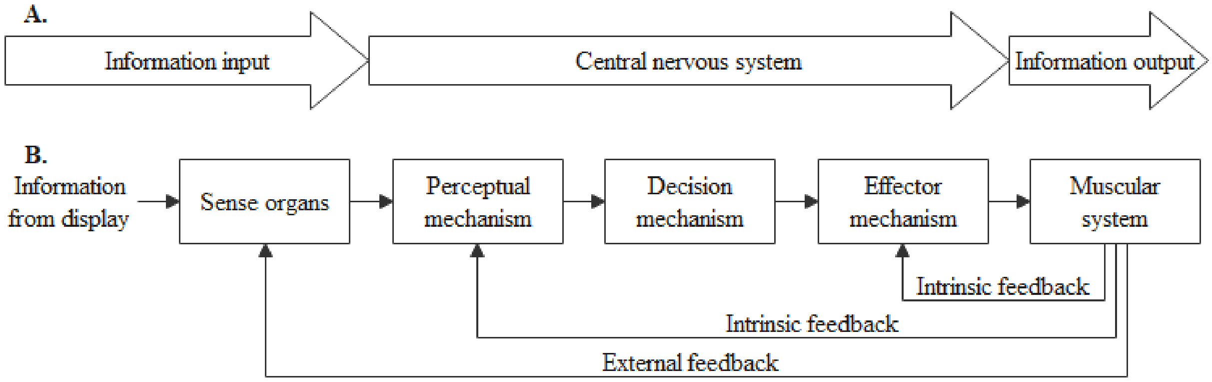

FIGURE 3. The simplified information processing model (A), and more precise human performance model (B) (modified from Marteniuk 1976, 5).

Even though cognitive psychology sees the three mechanisms working sequentially, they are all, in fact, inseparable parts of the central nervous system (figure 4), and thus, operate simultaneously on perceptual-motor action (Marteniuk 1976, 6-7). However, since motor actions are merely seen as end results for higher level cognitive processes (Marteniuk 1976, 6), perceptions can be studied, according to cognitive psychology, separately from actions (Williams et al. 1999, 12). To produce an optimal motor performance, visual information needs to be precise for the objective, and to activate the neural systems in an appropriate way (Vickers 2009). Optimal location, onset, offset, and duration of the visual cue produces an optimal outcome, whereas changes in these will decrease performance (Vickers 2009). Cognitive psychologists, according to Williams et al. (1999, 9), describe expert athletes as people able to identify critical information cues and ignore noncritical cues, able to use systematic and skilled visual search strategies, able to predict future events in time-constrained environments, and able to confirm the perceptual-information gathered (figure 4).

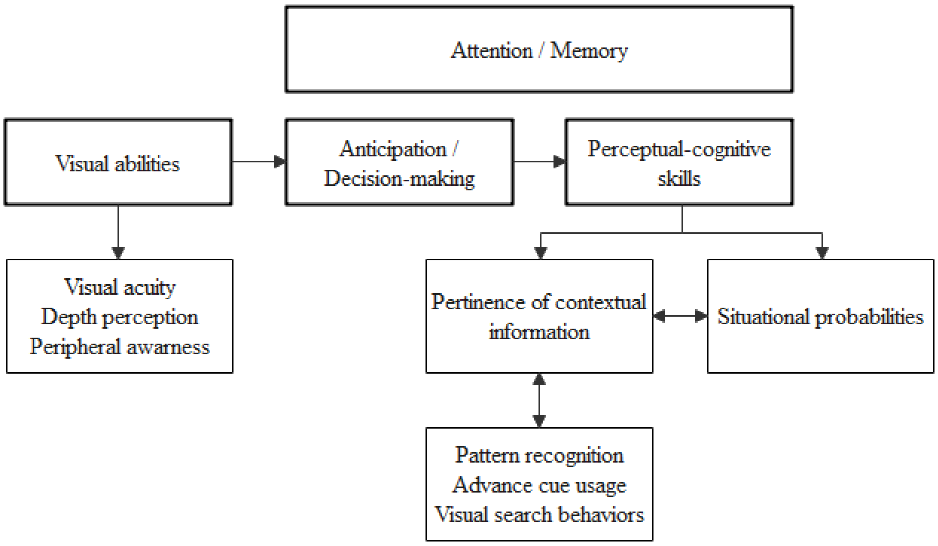

FIGURE 4. The information-processing based model of anticipation and decision-making skill in sports (Williams & Ward 2007).

Ecological psychology. Ecological psychology places less stress on the cognitive processes and combines psychology, biology, and physics to explain behavior in relation to the environment (Williams et al. 1999, 187). It argues that not all behavior is a result of conscious three stages, like in cognitive psychology, but instead some behavior is a result of subconscious perceptions of the environment. Some motor actions and performances happen without any awareness of them. (Vickers 2007, 7.) Additionally, ecological psychology argues that the central executive, which cognitive psychology decides all individual muscle actions based on calculations of perceptions, would be overwhelmed, resulting in a very inefficient way to move (Haywood & Gretchell 2009, 22). Instead, movement is seen as a result of neuromuscular activity that is spontaneous, task-specific, and goal-directed (Williams et al. 1999, 28).

The basis of *ecological dynamics* is in the performer-environment relationship (Davids et al. 2013). In it, the performer is seen as a complex neurobiological and self-organizational system who adapts their behavior in accordance with the task and the environment (Davids et al. 2013). Decision-making is seen to be strongly influenced by detection and use of information (Araújo et al. 2006). Expert athletes' actions are not either completely information-driven nor completely independent of the emerging information, but athletes modify their actions to achieve a goal through intentions, perceptions, and diverse sources of information (Davids et al. 2013; Davids et al. 2015). This system metastability highlights the perceptual control of action (Araújo et al. 2006), and the athletes' creativity, flexibility, and adaptability to changing conditions of the environment and the task (Araújo et al. 2009). Sport expertise is seen as a functional relationship in which the athlete adapts to all the various constraints affecting the system (Williams et al. 1999, 28; Haywood & Gretchell 2009, 22; Davids et al. 2015).

Newell's (1986) *constraints-led model* is a combination of cognitive, ecological, and dynamic systems perspectives (Vickers 2007, 7; Brymer & Renshaw 2010) emphasizing the relationship between the individual, the environment and the task (Haywood & Gretchell 2009, 22). The individual, the task and the environment are seen as constraints, or factors that encourage certain movements and concurrently discourages other movements (Haywood & Gretchell 2009, 7) which affect necessary motor coordination and control (figure 5) (Newell 1986). Any one of these constraints may play a bigger role in a given situation, but all of them play a role in the resultant motor action (Haywood & Gretchell 2009, 22). Internal constraints are individual's physical and mental characteristics within the body (e.g., maturation, injuries), while external constraints are outside of the body and known as environmental constraints (e.g., new opponents, change of rules) (Newell 1986; Williams et al. 1999, 28; Haywood & Gretchell 2009, 22; Davids et al. 2015). Task constraints are detailed parts of environmental constraints (e.g., objective, rules, and equipment) (Newell 1986; Haywood & Gretchell 2009, 7-8).

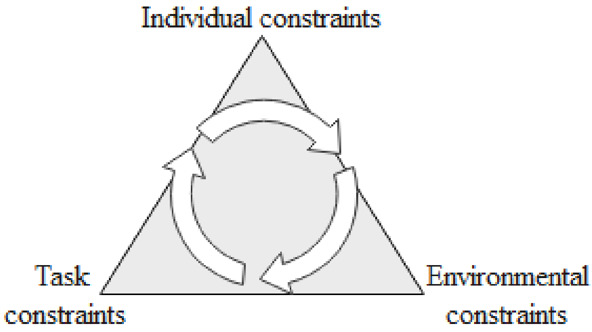

FIGURE 5. Newell's constraints-led model of motor performance (modified from Haywood & Gretchell 2009, 6).

In sports the changing attributes of an individual, the environment, and the task all affect the chosen action – if any of these factors change, the resultant action changes (Newell 1986; Haywood & Gretchell 2009, 6). Decision-making in constraints-led model is seen as a dynamic process from the initial conditions to the final outcome between the performer and the environment, where the performer needs to choose actions, specify information sources, and constrain the conditions to achieve the goal (figure 6) (Araújo et al. 2009). The process is cyclical – the closer the performer is to the final condition the more sensitive they are to momentary variations and the more constrained they are by past events (Araújo et al. 2009). Decision-making requires understanding of the environment and the task, which is why within the same environment and task different athletes may concentrate on different degrees of freedom, finding different solutions (Araújo et al. 2009). Since all solutions are complex and uncertain, a continuous search for new solutions is required to identify the most important degrees of freedom and information variables (Araújo et al. 2009).

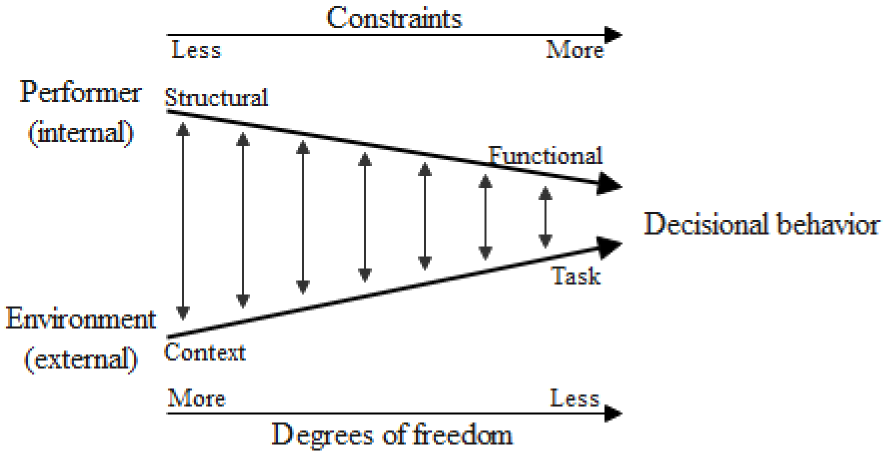

FIGURE 6. The ecological psychology perspective on decision-making (Araújo et al. 2009).

Cognitive vs. ecological psychology. In conclusion, the cognitive and ecological psychologies provide different and somewhat competing perspectives for perception-action coupling (Vickers 2009). Vickers (2009) offers a distinction where the cognitive perspective is generally better at explaining actions in slower tasks (movement times >200ms), while the ecological approach is more suitable for rapid tasks (<200ms). However, in all performances the two opposing systems work together allowing for a greater range of possible actions (Vickers 2009). In addition, Vickers (2009) notes that in research cognitive psychologists typically separate different types of gaze by coding, e.g., fixations, pursuit tracking and saccades independently, while ecological psychologists analyze all gaze types similarly without separation. The focus of the cognitive perspective is that it takes at least 100ms for the brain to process visual information, whereas the focus of the ecological approach is that each gaze detects information of the environment regardless of the processing time. (Vickers 2009.) This thesis focuses on a combination of these two perspectives, since the main point of interest is in the fixations of players’ in a rapid dynamic task of basketball pick’n roll (PnR).

3.2 Perception-motor action

Perception-motor control means the use of perceptions in motor performance (Kauranen 2011, 156). Perceptual-motor skill is an activity involving moving the body or body parts to perform a task with an objective (Marteniuk 1976, 13). It may also be called the “information-movement coupling” which highlights the cyclical nature of the process (Brymer & Renshaw 2010). For a motor action to be effective, information must be perceived and interpreted (Brymer & Renshaw 2010). Performers gain information from the environment and objects through perceptual systems (vision, audition, touch, taste, smell) to produce goal-directed actions (Vickers 2007, 2). The principal purpose of vision is to produce visual perceptions through the transformation, organization, and interpretation of light into a recognizable image (Williams et al. 1999, 73). Thus, vision is the leading system for athletes because it enables the interaction with the environment and guides body movements (Erickson 2007; Perez-Zapata et al. 2011).

Visuomotor coordination is the ability to use visual information, gained through shifts of gaze, to generate motor actions (Williams et al. 1999, 73; Vickers 2007, 2). Visual information is crucial for motor performance and motor learning (Vickers 2007, 2), and no superior size, strength, speed, or agility can fully make up for inefficient processing of this information (Erickson 2007, 1). Many failed performances are not due to poor equipment or execution of movement, but incorrect time or place of the action (Erickson 2007, 1). Since vision provides the athlete information about where and when to perform, it is the leading signal for the muscles (Erickson 2007, 1). After all, the athlete has difficulties to hit the ball, if the eyes do not tell where it is.

According to cognitive psychology, the use of information processing by the central nervous system (CNS) precedes actual movement, stressing the cognitive role of perception-action cycle (Marteniuk 1976, 13). Then again, in the ecological perspective, the perception-action is an important part of the performance since the perceptual information gained results in motor actions a in time-dependent way (Newell & McDonald 1994). The perception-action cycle varies between tasks (Vickers 2007, 10). The performance is affected by the constant change of perceptual-motor workspaces due to changes in, e.g., the performers and tasks (Newell & McDonald 1994). Within the workspace, visual information is gained and critical decisions are made (Newell & McDonald 1994; Vickers 2007, 10).

3.3 Perceptual-cognitive skills

Superior athletic performances can be seen from the stands, but the perceptual-cognitive mechanisms which affect the performance are generally less obvious (Mann et al. 2007). Perceptual-cognitive skills, such as anticipation, decision-making, advance cue utilization, pattern recognition, visual search behaviour, and the use of situational probabilities, are found to be crucial to all successful performances (Maarseveen et al. 2018b; Williams & Ward 2007). The portion of the different perceptual-cognitive skills on action varies among tasks, even though they all are seamlessly integrated on high-level performance (Williams & Ward 2007). Research in neuroplasticity has found that the cognitive processes behind visuomotor action in sports are improvable, if trained according to the specific demands of the competitive environment (Wimshurst 2012, 72). Vickers (2007, 3) separated seven perceptual-cognitive skills critical in sports which are further described below (figure 7).

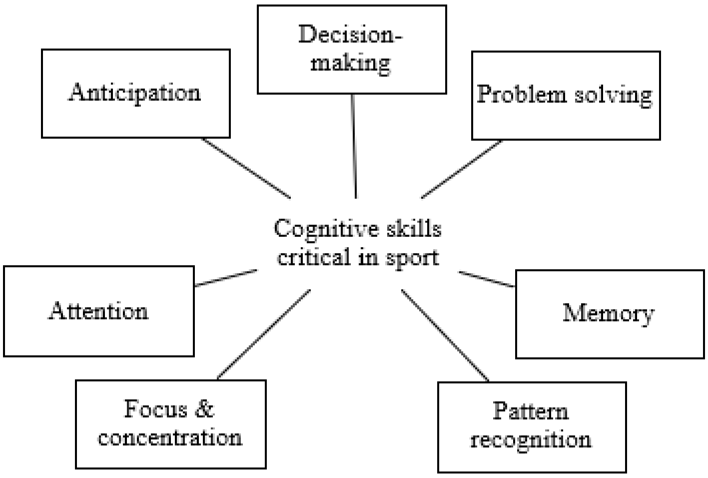

FIGURE 7. The seven perceptual-cognitive skills critical in sports (Vickers 2007, 3).

Decision-making. Decision-making in sports requires choosing the right motor action at the right time, according to the changing conditions (e.g., opponents), and performing the chosen action as efficiently and consistently as possible throughout a competition or match (Maarseveen et al. 2018b). Effective and efficient perceptions of the environment are the basis for successful decision-making in performance (Marteniuk 1976, 21). Multiple solutions are found for each of the situations in open-skill performances, and the ability to make quick decisions is related to the player's experience of similar situations (Marteniuk 1976, 22-23). Athletes must be able to identify and attend to the most critical information sources, detect the correct information accurately, anticipate the most important based on perceptions of key information, retrieve necessary information from memory, solve problems when they arise and make the right decision under time constraints (Williams et al. 1999; Araújo et al. 2006; Vickers 2007, 3).

Problem solving. According to Marteniuk (1976, 24), problem solving as a perceptual-cognitive skill refers to the modification of the decision mechanism. Decisions can be modified through internal feedback from the sensory receptors, but only one decision can be processed at a time. The time window of the processing of one decision (known as the refractory period) is very narrow but just enough for an opponent's fake to initiate a decision-making process, for example. Since the reaction to actual movement after the fake cannot be started before the decision mechanism has processed the response to the fake, the remaining reaction time for the actual movement will be too little resulting in poor execution. This will happen even if the player has not started a motor action in response to the fake. (Marteniuk 1976, 24.)

Anticipation. Anticipation is a complex, higher-order perceptual process that refers to the ability to predict the outcome from an early sequence of an event (Marteniuk 1976, 21; 101). An athlete must anticipate future events during performance to reduce their reaction time, the delay needed for processing the observed information and initiating a motor response (Marteniuk 1976, 98). Visual search behavior and the cognitive processes are critical in anticipation, since expert players have been found to make more accurate predictions of opponents' actions, resulting in more accurate decisions (Roca et al. 2013). The skill of anticipation is also related to memory, since previous related experiences – memories – are used to reduce the information needing to be detected and understood so that athlete can make a "best-bet" prediction of what will likely happen in current situation (Marteniuk 1976, 98). Through this, the athlete can decide, prepare and begin a motor response before the onset of an event (Marteniuk 1976, 98). This, in addition, decreases the reaction time, leading into disadvantage in decision-making for novice players: Novice players have less experience and are incapable to prepare a motor action plan in advance (Marteniuk 1976, 23; 98). The differences in the ability to anticipate future events is crucial to elite performance, and between skilled and less skilled performers it is most apparent at earliest, pre-contact occlusion conditions (Williams & Ward 2007).

Attention. Attention, the ability to maintain an optimal level of concentration allowing a maximum level of information processing (Marteniuk 1976, 39), affects all human behavior from perceptions to cognitions to actions (Abernethy et al. 2007). Three types of attention abilities in athletes are separated in literature: 1) selective attention: the selectivity of alertness between different tasks or information; 2) divided attention: the distribution of alertness across several tasks; and 3) alertness: the level of attention or readiness for action (Williams et al. 1999, 27-28). All three work simultaneously to limit or allow perceptions: An optimal level of alertness is necessary for efficient information selection, while information selection is necessary for optimal level of processing (Marteniuk 1976, 75; Abernethy et al. 2007).

Selective attention, the ability to pick critical information for detailed processing while prevent non-critical information, is vital for athletes, since in a fast and changing environments the critical information sources may be available only briefly while multiple non-critical sources are offered (Abernethy et al. 2007). Selective attention is also critical since the CNS has limited information processing capacity and it cannot interpret all the information in the environment (Marteniuk 1976, 75; Williams et al. 1999, 27). A certain task requiring attention takes up space from the CNS processing capacity (figure 8; Williams et al. 1999, 30), and when two or more tasks are being processed, the tasks interfere with each other with the one with higher information content taking up the most space of the total capacity (Marteniuk 1976, 46). The portion each of the tasks takes differs between situations and the level of players (Marteniuk 1976, 46). As shown in figure 8, an expert may not have difficulties in handling all three tasks at once, while a novice may have difficulties only to dribble the ball, requiring all their attention and leaving no capacity to observe the actions of teammates (Williams et al. 1999, 30).

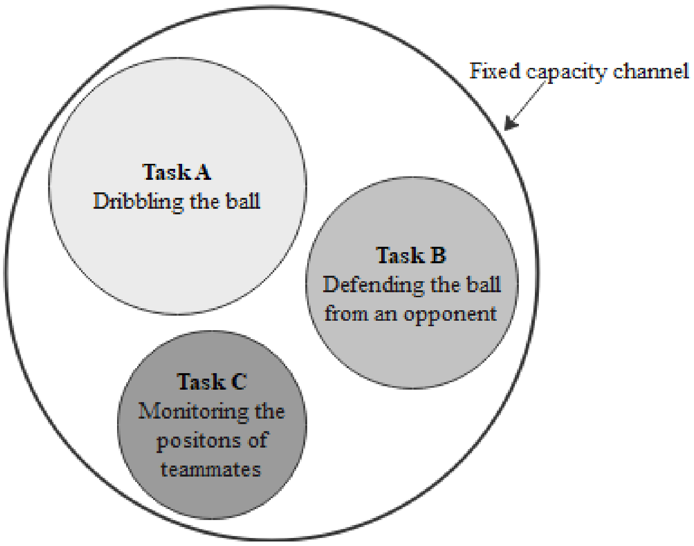

FIGURE 8. Fixed capacity theory of attention in basketball (Williams et al. 1999, 30).

Pattern recognition. Pattern recognition is the ability to recognize familiar structures or patterns of plays in an early stage of evolving situations (Roca et al. 2013). Simply fixating on a target or capturing a moving object is not enough in sports (Vickers 2007, 136). The ability to read complex patterns, either set-plays (e.g., pick'n roll, give'n go) or novel tactics, and to comprehend the positioning of moving athletes is necessary to achieve a desired goal (Vickers 2007, 136). Pattern recognition is highly dependent on memory and past experiences of similar situations, which help with future predictions, and therefore, decision-making (Marteniuk 1976, 22). Pattern recognition is part of visual-spatial intelligence along with the ability to access information efficiently and to get into position where targeting and interceptive timing tasks can be performed effectively (Vickers 2007, 136).

Memory. The use of memory is the basis of decision-making. Before the perceptual information can be interpreted, it must be compared to previous memories of similar experiences, resulting in recognition of patterns or anticipation of future events, further enabling decision-making (Marteniuk 1976, 21). Players gain feedback from the execution and result of a motor action, and this information is used in similar situations in the future (Marteniuk 1976, 19-20). Stimulus-response compatibility refers to the player's ability to associate the current event with earlier events and match up a specific plan of action belonging to the specific environmental situation (Marteniuk 1976, 23). As described with all the above perceptual-cognitive skills, memory plays an important role in decision-making, problem solving and anticipation (Marteniuk 1976; Williams et al. 1999).

Marteniuk (1976, 19-23) explained the perceptual skills required for athletic performance by using an example of a tennis player receiving a serve (figure 7). Firstly, the player's goal is to *anticipate future events*, e.g., what the opponent will do. They gain perceptions of the opponent and based on previous experiences in the *memory*, they make predictions of what will happen. Based on these expectations, the player pays *attention* selectively to most important parts of the opponent to gather the necessary information as quickly as possible. In addition, the player analyzes the opponent's movements just prior to the serve, and in combination with memories tries to *recognize a pattern*, thus making a more accurate expectation of the opponent's plan (Marteniuk 1976, 21-22.) Secondly, once the opponent has made their hit, the player must gain information of the ball and its flight path, while the information of the speed of the ball must be compared to memories and experiences to categorize the speed for complete recognition. (Marteniuk 1976, 21.) Thirdly, the player is now able to predict where the ball will land and when to initiate a swing to return it. In addition, they need to gain information through audition, vision, and proprioception from their positioning on the court (location in relation to the incoming ball) and positioning of their limbs (location of the racket in relation to initiating the swing). (Marteniuk 1976, 19-20.) Finally, in addition to the prediction and the information, the player must *make a decision* of what kind of return they want to hit and how it can be formed (Marteniuk 1976, 22).

The importance of perceptual-cognitive skills increases as the level of the athletes increases (Williams & Reilly 2000). On an elite level, these skills separate one athlete from another far more likely than anthropometric features or physiological profiles (Williams & Reilly 2000). Experts are found to be faster and more accurate in scanning the display, recognizing patterns of play, interpreting opponents' postural orientation, detecting critical objects of information in the visual field, anticipating future patterns of play and opponents actions based on visual cues, identifying situational probabilities, and making decisions (Williams et al. 1999, 139; Williams & Ward 2007; Roca et al. 2013). Most of prior research has examined the perceptual-cognitive skills separately (Williams & Ward 2007). However, Maarseveen et al. (2018b) questioned the use of specific perceptual-cognitive tests as a determining factor in sports performance, since they did not found correlation between perceptual-cognitive tests and on-field performance. Also, since there were differences in gaze behaviour parametric between pattern recall tests and both anticipation and decision-making tests, the process of anticipation and decision-making may be driven by different processes than pattern recall (Maarseveen et al. 2018b).

4 GAZE BEHAVIOR IN SPORTS

The goal of the gaze in complex sports situations, such as basketball offense, is to detect the most important cues to make the best suitable decision (Vickers 2007, 70). For an effective performance outcome, athletes must react rapidly and accurately to external stimuli (Sors et al. 2017). The recognition of critical cues present in the environment is made more difficult by moving objects, such as teammates, opponents and the ball, as well as severe time constraints, such as changing situations (Vickers 2007, 70). The changing conditions of the environment, objects and time constraints differ between sports, but are present in sports ranging from ice hockey to skiing (Vickers 2007, 70). Experts are shown to fixate on relevant areas for longer periods, and on irrelevant areas for shorter or fewer periods (Klostermann & Hossner 2018).

The four underlying principles of gaze control are 1) the number of visuomotor workspaces over which the gaze is controlled; 2) the number and types of locations and objects in the workspace; 3) the location of critical cues and the spotlight of attention; and 4) the gaze-action coupling: Optimal timing of the gaze, spotlight of attention and specific phases of motor action (Vickers 2007, 70). The visuomotor workspaces include the body, the space surrounding the body, the space of navigation, and the space of external representations (Vickers 2007, 137). Optimal gaze-action coupling requires that a specific spotlight of attention within each visuomotor workspaces is attended to. Typically, fixations are directed to the most familiar and used objects and locations. (Vickers 2007, 137.)

Gaze control in sports can be divided into targeting tasks, interceptive timing tasks, and tactical tasks (Vickers 2007, 10). Control of the gaze in tactical tasks can be subdivided into gaze control during locomotion and gaze control during offensive and defensive plays (Vickers 2007, 70; 136). However, tactical tasks differ from simple locomotor tasks, since the opponent in tactical tasks intends to make the workspace more complex (Vickers 2007, 136). Thus, during tactical tasks, the athlete needs to control their gaze and attention over multiple visuomotor workspaces with one or multiple spotlights of attention permitting successful performance (Vickers 2007, 136). In addition, both in locomotion and in offensive/defensive plays, gaze is controlled in targeting and interceptive timing tasks, as well as in reading complex patterns of moving objects such as players and balls (Vickers 2007, 136). For example, a basketball 3-on-3 situation requires all three types of gaze control: Tactical when reading the defense, interceptive timing when receiving a pass, and targeting when shooting (Vickers 2007, 10).

4.1 Advance cue utilization

Knowing where and when to look within the visual display, which often covers the full field of vision and is filled with both critical and uncritical information, is a crucial feature in any sports (Mann et al. 2007). An effective performance is based on extracting information from the display (Williams & Ward 2007) and focusing on the most crucial perceptual cues in it (Mann et al. 2007). Advance cue utilization is the ability to detect the critical information early in the developing pattern (Abernethy 1987), making accurate predictions of what is going to happen based on partial or advance sources of information (Williams et al. 1999, 105). Within each visuomotor workspace there might be a spotlight of attention, a critical cue, which is key to understanding the workspace. Over time, athletes develop an internal representation of all the workspaces in their sport, and by recognizing the critical cue quicker, they are able to produce an action with more ease and effectiveness. (Vickers 2007, 137.)

Advance cue utilization in sports is crucial, since it allows for anticipation of future events and minimizes the reaction and movement production times, thus allows rapid responses (Williams et al. 1999, 105). The relevant cues, e.g., from a flight path of the ball, must be identified early enough to allow time for the athlete to recognize the information, make an anticipation, and produce a motor response (Marteniuk 1976, 22). Cues can be obtained, e.g., from object, location, reaction-time, and memory, and the athletes' ability to make good decisions differentiate experts from novices (Vickers 2007, 144). This perception-action coupling is an integral part of visual-spatial intelligence, i.e. the ability to execute appropriate motor action according to perceptions in both expected and unexpected environments (Vickers 2007, 137).

Athletes, who can draw early information from the opponent and the environment, have an obvious advantage as they have more time to execute their motor response (Sors et al. 2017). For example, in time-constrained situations such as one-on-one in soccer, the defender could anticipate and react faster towards the course of the attacker by directing his gaze on the "off-the-ball" regions of the attacker, such as knee and hip (Nagano et al. 2004). Since movement and the course of the ball are outcomes of the movement of the knee and hip (Nagano et al. 2004). Williams & Ward (2007) determine that the sensitivity for picking up advanced perceptual information increases along with the increase in skill level of the performer.

Expert athletes have been found to detect the necessary cues and critical information earlier, and to use this information with previous experience to choose and implement a decision (Mann et al. 2009; Vickers 2009; Roca et al. 2013). The meta-analysis of Mann et al. (2007) concludes that, across all different sports from tennis to soccer, expert athletes "seek the most information-dense areas of a display while extracting task-relevant cues". In addition, Roca et al. (2013) finds that experts are better in using postural cues and gaining information from an opponent's or teammates movements. For example, an early study by Howarth et al. (1984) indicates that expert squash players rely on advance visual cues of the opponent's intentions, leading to negative viewing time (-87.5ms) prior to movement initiation, while novices relied on actual information of the opponents movements prior to making their own actions (+163ms).

In attempting to identify the advanced cues performers use in anticipating, researchers have used techniques of temporal and spatial occlusion, eye movement registration, verbal reports, and point-light displays of players in action (Williams & Ward 2007). However, although the evidence behind advance cue utilization is consistent and the ability to use advanced cues is highly appreciated in fast ball sports, the mechanisms and specific perceptual information underlying the cue identification process are still unknown (Mann et al. 2007; Williams & Ward 2007). The huge variability in research methods limit the practical conclusions which can be drawn, making it more difficult to extract suggestions for training (Mann et al. 2007).

4.2 Visual search patterns

Visual search is the tool to pick up advanced visual cues or to identify patterns of play (Williams & Ward 2007). With controlled visual search and eye movements, an athlete can analyze the display more efficiently (Williams et al. 1999, 145). In dynamic situations, such as a basketball game, the players have to balance between long fixations prior to motor response initiation and scanning the positions and movements of other players to decide and execute the best suitable action before a situation changes (Williams & Ward 2007). Players use fovea, parafovea, and visual periphery to extract all the relevant information to be able to perform effectively (Williams & Ward 2007). Visual search strategies may be controlled by the memories of previous experiences of task-specific situations (Williams et al. 1999, 184), allowing the athlete to find the advance cue points and to make predictions of outcome more efficiently.

The visual search behavior seems to vary according to the task, skill level and the role of the athlete, as well as the perceived level of exertion, especially in high intensity activity (Williams 2000; Timmis et al. 2014; Bagatin et al. 2017). In soccer, defenders use different visual search strategies than attackers, the used strategy differing based on the number of players on the field (1x1; 3x3; 11x11; Williams 2000). Roca et al. (2013) find that skilled soccer defenders use different visual search strategies than less-skilled players, who typically concentrated only on the ball. Additionally, skilled players alternated their search behavior between far defensive tasks (fixations of shorter duration and toward wider spectrum of locations) and near tasks (fewer fixations of longer duration, mostly on ball handler) (Roca et al. 2013).

Even though gaze behaviour is highly task dependent, Williams (2000) indicates that skilled performers generally scan the display more effectively and efficiently than their less skilled peers do. Indeed, skilled performers pick up information from, e.g., the opponent’s postural orientation moments before the specific incident (e.g., 1-on-1 contact), which allows them to anticipate the future response (Williams & Ward 2007). In a closed skill, players with better shooting accuracy did not change their gaze behavior between uncontested and contested jump shots, when players with lower shooting accuracy habited to shorter fixations and earlier final fixation offset in the contested shot (Maarseveen & Oudejans 2018). Expert players are also found to be better in adapting their visual search strategy and cognitive processes to the constraints of the task (Roca et al. 2013). For example, in 2vs1 soccer play, skilled defenders fixated longer on the ball handler while lower skilled players fixated on the ball (Padilha et al. 2017). Nagano et al. (2003) posit that advance cues are located on the body of the ball handler and therefore skilled players used visual search strategy based on their points of interest, allowing them to use anticipation in decision-making (Padilha et al. 2017).

Fixation location, signaling the locations of advance cues, as well as number of fixations with fixation duration, signaling the information-processing requirements, are the most used indicators of visual search strategies in research (Williams et al. 1999, 153). However, it must be noted that fixation may not be related to perception and vice versa – an athlete may fixate on a target without extracting information from it, and they may be extracting information from a target on periphery even without fixating on it (Williams et al. 1999, 153). This is the difference between "looking" and "seeing" (Williams et al. 1999, 154). Even when there is strong evidence of an athlete shifting gaze from one location to another while the point of attention also shifts towards the a location (Vickers 2009; Hüttermann et al. 2014), shifts of attention are independent of gaze behavior (Williams et al. 1999, 154). The duration of gaze and the duration of attention on the location may not be corresponding – attention shifts only for a moment but is voluntarily divertible even if the fixation remains still (Vickers 2009).

4.3 Center-looking visual search strategy

Individuals are usually unaware of their gaze behavior, their visual search strategies, and the fixation patterns they use, even though gaze direction usually go hand-in-hand with the focus of attention (Hüttermann et a. 2014). Center-looking visual search strategy uses a fixation on a centrally located anchor, while using peripheral vision to evaluate the whole situation. The total recognition rate is lower when one of two or more objects are perceived with high resolution in the fovea, and other(s) with worse resolution, than when both objects are perceived in the periphery (Hüttermann et al. 2014). In addition, a saccadic scan may be a suitable strategy only under no-time pressure since visual perception from two or more objects is reduced due to too little time on one target (Belda-Maruenda 2004).

Hüttermann et al. (2014) concludes that in the soccer penalty kick, fixating between the ball and the goalkeeper has possible positive effects on performance compared to fixating to either one of the targets or using saccades to scan the display. Similarly in the penalty kick, Timmis et al. (2014) find that the end-location of the ball is related to the fixation location. In placement kicks, the players fixate wider on the goal and kick the ball to corners, while in power kicks players fixate on the ball and the center of the goal, and kick the ball more centrally (Timmis et al. 2014). However, the center-looking strategy may feel difficult and odd in a closed skill, since it is not instinctive to not look at the target from which information is tried to be gathered (Hüttermann et al. 2014). The use of a centrally located anchor must be practiced for optimal use, and the ones who are used to it are more likely to benefit from it (Hüttermann et al. 2014).

On the other hand, studies with karatekas have shown that, when the situation requires reading the opponent, fixating centrally on the opponent’s head or chest, and extracting information peripherally from the limbs, helps predicting the moves of the opponent (Williams & Elliott 1997). Vaeyens et al. (2007) discover that skilled soccer defenders use a more goal-oriented visual search strategy and successful decisions were related to more time spent fixating on the ball handler and sifting gaze more frequently between the ball handler and other AOIs. Additionally, Roca et al. (2013) find that skilled soccer defenders fixate on multiple distinct locations in a far task to gain an oversight of the whole display. In a near task, the skilled players rely on focusing on the ball handler trying to extract information from their postural orientation, thus, anticipating what they were about to do (Roca et al. 2013).

In conclusion, the center-looking strategy is beneficial when dividing attention equally between two (or more) objects is required (Hüttermann et al. 2014). The free-gaze strategy may be more useful in analyzing the whole complex open-skill situation, and identifying familiarity and patterns of play, while the center-looking strategy is useful in drawing exact information from advance cue points (Roca et al. 2013). When exhausted, measured with perceived exertion, players possibly prefer a centrally located anchor (Bagatin et al. 2017). Of course, if one cue needs more detailed processing than another, fixating on the more critical one will be beneficial (Nagano et al. 2004). Lastly, the point of gaze can also be used in bluffing. Fixating on an object and passing to another will make it more difficult for the opponent to read the game (Williams et al. 1999, 154).

5 EYE TRACKING RESEARCH

Eye-tracking glasses, visio-oculographic apparatus or mobile eye tracking devices are wearable and hands-free devices which capture a subject's first-person perspective (Tobii Pro 2019). The use of eye-tracking in sports enables gaze behavior research by recording all eye movements and fixations (Wimshurst 2012, 20). They offer an understanding of athletes' decision-making in real, complex, and time-constrained situations (Maarseveen et al. 2018a). The goal of eye-tracking research in sports is to understand how athletes use their perceptual-cognitive skills so effectively under severe time constraints (Vickers 2009), and how gaze behavior is related to performance in various open-skill situations (Nagano et al. 2004).

Prior eye tracking studies can be divided into sub-categories according to the applied methods. The study designs used normally involve laboratory and on-field conditions which can be further divided according to the task requirements: No head movements/allowed head movements or artificial/natural response (Hüttermann et al. 2018). Although artificial motor responses (e.g., verbal reaction, button pressing, joystick use) in a laboratory context have been the dominant eye tracking design in sports (42/65 studies), mobile eye-tracking devices have increased the opportunities and usage of on-field study designs (Kredel et al. 2017). In a recent study by Maarseveen et al. (2018a), no effect was found for frequency or accuracy of made decisions from wearing eye-tracking glasses in performance. This proves that eye-tracking is powerful method for analyzing decision-making in complex game-like situations.

Studies researching eye-tracking can also be divided by the type of sports and situations – open situations show dynamic, variable, and uncontrollable settings, whereas closed situations are more stable, static and controllable (Hüttermann et al. 2018). Hüttermann et al. (2018) make additional distinction between studies of ball games and non-ball games, since the speed of the game in ball sports, such as soccer and tennis, make investigations of gaze behavior even more complex. However, exploration of closed situations in ball games, such as the penalty kick in soccer or free throws in basketball, is still a frequently used study design (see Hüttermann et al. 2014; Timmis et al. 2014; Maarseveen & Oudejans 2018).

Two comprehensive review articles in eye-tracking in sports have been published recently: One by Kredel and colleagues (2017; 65 articles from 1976-2016), and another one by Hüttermann et al. (2018; 86 articles from 1987-2016). Both reviews reveal a large variance in used methods and analyses. As Vickers (2007, 70) predicted, studies in tactical tasks were the ones to change the most in eye-tracking research. From 2007-2011 to 2012-2016, the number of studies with free-to-move eye-tracking devices was doubled from 7 to 14 (Hüttermann et al. 2018). 51% of studies with mobile eye tracking devices were conducted under in-situ conditions and 76% required natural responses (Kredel et al. 2017).

From the 65 studies reviewed by Kredel et al. (2017), 24 were executed in-situ, and 23 out of the 24 included a natural motor response. Only 14 of the 24 studies were completed in an open-skill setup with the subject reacting to the opponent’s unpredictable moves, with only 9 of these exploring team sports (Kredel et al. 2017; see Vickers & Adolphe 1997, volleyball; Martell & Vickers 2004, ice hockey; McPherson & Vickers 2004, volleyball; Nagano et al. 2004, soccer; Panchuk & Vickers 2006, ice hockey; Dicks et al. 2010, soccer; Afonso et al. 2012, volleyball; Afonso et al. 2014, volleyball; Hüttermann et al. 2014, soccer). Additionally, 70 out of the 86 studies of elite performance reviewed by Hüttermann et al. (2018) investigated ball games. Only 17 of the 70 were executed in-field, and only 2 of the total 86 publications used real game situations instead of “dead ball” situations (see Martell & Vickers 2004, ice hockey; Vickers 2017, ice hockey). In addition, studies with game situation in team sports were conducted by Laaksonen (2017, floorball) and Maarseveen et al. (2018a, basketball).

Gaze behavior training, ideal gaze patterns (if such exist at all) and the effects of physical stress on gaze behavior are areas of research requiring more attention (Hüttermann et al. 2018). By studying elite athletes, critical visual information, advanced cue points and search patterns could be identified, and this information could consequently be used in, e.g., teaching, coaching, and therapy (Vickers 2007, 4; Wimshurst 2012, 20). However, no researcher can know where a subject is really looking (Williams et al. 1999, 153; Holmqvist et al. 2012). The fovea can be slightly misaligned from the point where the subject says they are looking, or the subject’s attention may be on the periphery although fovea is located to one point (Holmqvist et al. 2012). Similarly, the depth of focus, i.e. if the athlete is gathering information from an AOI in the foreground or from behind it, cannot be detected by these explorations (Wimshurst 2012, 20).

6 PURPOSE OF THE STUDY

Most of gaze data research in sports has been limited to laboratory set-ups, closed skills, or artificial motor responses. In basketball, Maarseveen et al. (2018a) were the first trying to analyze player's gaze behavior in game-like situation. The purpose of this study is to follow Maarseveen et al.'s (2018a) footsteps to further analyze the decision-making and gaze patterns of ball handler in 3-on-3 Pick'n Roll. The protocol has been modified with more variable defensive styles: Switch, Soft Hedge and Hard Hedge over Under, Over and Hard Hedge (Maarseveen et al. 2018a). Additionally, the protocol has been advanced with a lift move from the corner offender, and free decision of the corner defender to either help or stick with his own player. This will result in more diverse situations, thus, more game-like situations. Of special interest are the differences between different defensive plays, correct and incorrect decisions (Maarseveen et al. 2018a), and the effects of field of vision on gaze and decision-making data.

Research questions and hypotheses.

1. Do different defensive plays affect made-decisions, decision accuracy, or used visual search strategy?
   Hypothesis: YES.
   It is apparent that both decision-making and visual search strategies are highly task-dependent (e.g., Dicks 2010; Afonso et al. 2012; Roca et al. 2013; Afonso et al. 2014; Timmis et al. 2014; Decroix et al. 2017; Maarseveen & Oudejans 2018).

2. Does handling the ball with dominant or nondominant hand influence made decisions or decision accuracy?
   Hypothesis: YES.
   Maarseveen et al. (2018a) discover in similar Pick'n Roll test that handling the ball with dominant or non-dominant hand does affect made decisions.

3. Does gaze behavior change between correct and incorrect made decisions?
   Hypothesis: YES.

Quicker and more accurate decision-making in team sports has been found to be related to different gaze behavior, including number of fixations, fixation durations, and location of fixation (Martell & Vickers 2004; Mann et al. 2007; Padilha et al. 2007). However, a study with alpine skiers could not offer a distinction between the effect of performance to gaze behavior (Decroix et al. 2017).

4. Is a wider field of vision related to different made decisions, decision accuracy, or visual search strategy?
   Hypothesis: NO.
   Due to the lack of studies using homogenous groups, not much can be hypothesized. However, Williams et al. (1999, 94) assume that experts may not have wider fields of vision, but they may use it more effectively. Similarly, Vickers (2007) note that a better use of the visual field may result in easier solutions in decision-making.

7 METHODS

7.1 Participants

A total of 23 male basketball players from three different teams participating in Finland's division 1B or higher-level national leagues during the 2018–2019 season were tested. The exclusion criteria for study participants were abnormal training conditions either due to a musculoskeletal injury or sickness, and the inability to participate on both measurement days. Ultimately, a total of 22 players were included with an average of 13.8 ± 3.8 years of playing experience. The players trained basketball on average 4 times per week plus games. The group included 10 guards, 9 forwards and 3 centers with an average age of 21.2 ± 3.8 years and a height of 188.0 ± 7.6 cm. Three of the players had left as their dominant hand. Five out of 22 players use prescription glasses, but only one of them use prescription contact lenses during basketball activities. They were also used during this study. The protocol included two separate data collections per player; 1) the basketball pick'n roll test (PnR), and 2) the peripheral vision and reaction screening. All data collection was executed between August and October 2019.

The study was conducted in accordance with the Helsinki declaration and it has an approval of the Ethics Committee of the University of Jyväskylä. All participants signed an informed consent.

7.2 Data collection

7.2.1 Pick'n Roll test

Apparatus. The eye movements were recorded with Tobii Pro glasses 2 -mobile eye-tracking device (Tobii AB, Sweden) and Tobii Pro Glasses Controller -software. The tracker consists of a head unit and a recording unit connected to each other with an HDMI cable (figure 9a). In addition, the recording unit is connected via a Wireless Ethernet connection to a tablet (Windows 10) on which the data can be live-viewed and managed. The head unit consists of a wearable eye tracker with two cameras per eye recording the movements of the pupils at 25 Hz, and a Full HD scene camera, placed between the eyes, filming the first-person perspective. The Tobii system algorithms and 3D processing automatically define the direction of the eyes and point-of-gaze (marked with a red circle) into the video image of the scene camera (figure 9b).

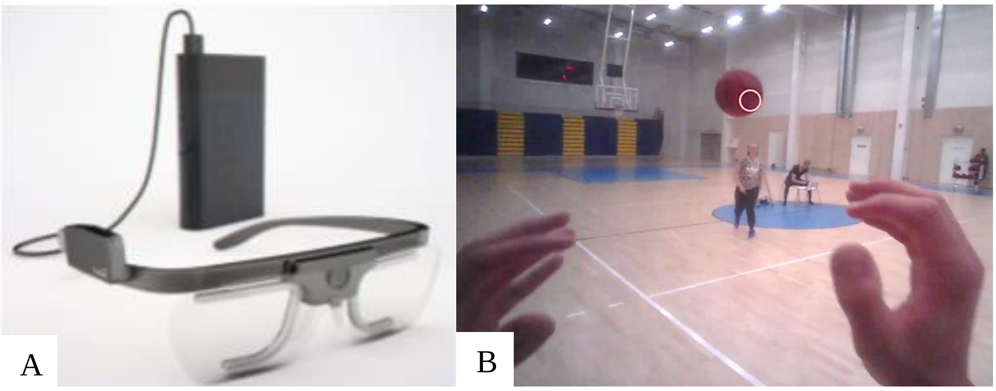

FIGURE 9. A) The Tobii Pro Glasses 2 head unit and recording unit, attached to each other with a HDMI cable (Tobii Pro 2018). B) Tobii Pro Glasses 2 video image from first-person perspective. The red circle indicates the direction of eyes.

Participants carried the recording unit on a running belt around their waist, underneath the shirt, so that no wires were visible having minimal effect on basketball performance (figure 10). The glasses were calibrated with their own one-point calibration before every trial set (at the beginning and at the change of court side), and additionally if necessary due to possible contact, Tobii system error, etc. Tobii Pro 2 has an accuracy of 0.62° (±0.23°) for optimal conditions and 3.05° (±1.13°) for large gaze angles outside regular range of eye movement (Tobii Pro 2017). The precision of Tobii Pro Glasses 2 differs from 0.05° to 0.62° (Tobii Pro 2017).

FIGURE 10. Study participant with the Tobii Pro Glasses 2 on. The recording unit is placed underneath the shirt with a running belt, and all wires go to underneath the shirt from the neck.

The video image of the eye-tracking glasses is referred to as the internal camera (figure 9b). On top of the eye-tracking glasses, one external camera (GoPro Hero 3, GoPro, Inc., USA) was used to register the trials at 60 Hz. The external camera recorded the movements of the participants and the ball. Figure 11 demonstrates the video image of the external camera.

FIGURE 11. Video image of the external camera (GoPro Hero 3, GoPro, Inc., USA). Red players are the offense, facing the baseline in the starting position. Green players are the defenders, facing the central court from where the desired defensive play is shown (white paper on the right corner).

Protocol. The Pick'n Roll (PnR) test was designed to match Maarseveen et al. (2018a), with the exception for the "lift" move of the corner player. The test was a 3 vs. 3 pick'n roll drill operated with 6 players at once. Each player served as the ball handler (BH), the participant with the eye-tracking glasses, in turns, whiles others played supportive roles either as defenders or attackers. All players were on the ball side of the court; in the corner and at the free-throw line (figure 12a). The trial started with all offensive players facing baseline and all defensive players facing the middle of the court from where the defensive style for each trial was revealed (figure 11).

When the examiner gave the call to start, the offensive players turned, and the ball was passed from the examiner to the ball handler. After receiving the ball, a teammate from the free-throw line came to set a screen towards the center of the court. The BH was ordered to use the screen and to only use it once (FIGURE 12b). The player who set the screen was ordered to roll towards the basket. The teammate who started from the corner, was ordered to make a “lift”; run from the corner to the wing position as soon as there was room following the screen (FIGURE 12c).

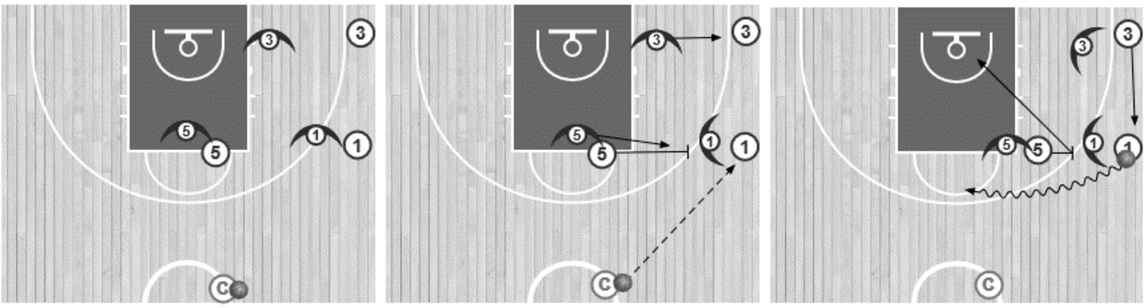

FIGURE 12. A) The starting position of the Pick’n Roll test, where all offenders face the baseline and defenders face the middle of the court. B) The trial started from the examiners’ (C) call, followed by a pass to the participant. C) The obligatory starting moves of the attackers. O1 = ball handler.

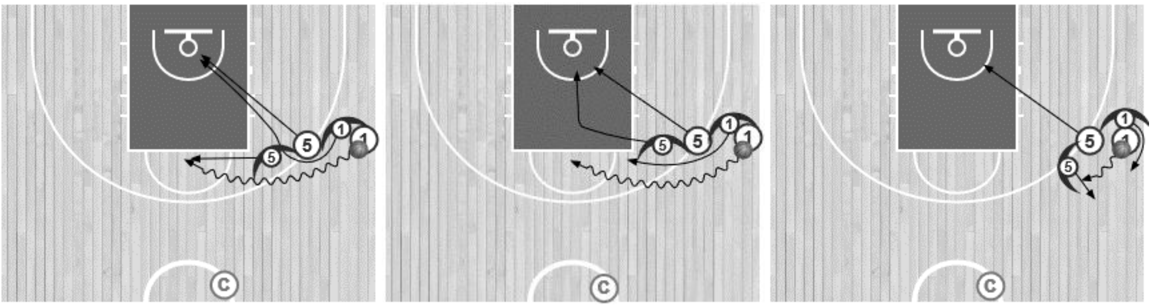

FIGURE 13. A) “Switch” defense. B) “Soft” defense. C) “Hedge” defense. O1 = participant, ball handler; O5 = screener/roller; D1 = ball handler defender; D5 = screen defender.

Three different defensive plays were used. The defenses were in a randomized order, the order being different for all participants. Due to the starting positions of trials (figure 12a), none of the offensive players knew which defense was executed. Defense 1: “Switch”, in which the screen defender (SD) and the ball handler defender (BHD) switch players (figure 13a). Defense 2: “Soft Hedge” (Soft), in which the SD positions himself horizontally to deny an immediate drive to the basket while the BHD trails the screen (figure 13b). And defense 3: “Hard hedge” (Hedge), in which the SD positions himself vertically to deny any penetration after the screen (figure 13c). In hard hedge, the option was to “trap” the BH. In defenses 2 and 3 players were not allowed to switch. The defender of the corner player (CD) was not instructed further – they could either stick to their own player or drop to the paint to help.

Participants executed a minimum of 48 trials – 24 per side and 8 per defense per side. However, some of the trials were excluded already in the data collection phase due to inadequate execution (e.g., wrong defense; bad timing of screen; loss of ball before decision), or technical issues (e.g., camera battery exhaustion). The excluded trials were repeated within the next three trials – the real range of trials executed by a participant was from 48 to 54. On average, a trial lasted for 2.65±0.84ms, and a set of trials for one player approximately 15-20 minutes.

7.2.2 Field of vision perimetry

Apparatus. The kinetic perimetry was specifically manufactured for this project in the bachelor's thesis by Vekki (2019). The perimetry consists of four poles of WS2812B RGB-LED-light strips, two remote controllers ("buttons") and two head rests for two different test conditions: the horizontal and vertical field of vision tests (figure 14). The head rests standardize the position of the player to 80cm from the center point in the horizontal test and to around 13.4cm in the vertical test. The actual distance of participant was confirmed with an ultrasound (HY-SRF05) measurement with an accuracy of 2mm at 2cm to 450cm. For example, in the vertical test, the distance of 13.4cm would mean a maximum angular binocular range of 150° and a 1cm error would affect the calculated range by 1°. The height of the perimetry was adjustable to the height of the player with a magnetic fastening system. (Vekki 2019.)

FIGURE 14. Kinetic perimetry device by Vekki (2019). Vertical LED-string laid on the floor; horizontal LED-strings pointing upwards; center point with ultrasound device at the crossing of vertical LED-string and the black bar; two buttons connected with wires. (Vekki 2019)

The perimetry was connected to a computer with an USB cable. The brightness and colors of the lights, and the selection of the desired test was done with Adobe Air-based software specific for this perimetry. During field of vision tests, one LED was on for 150ms at a time to minimize saccadic eye movements, and it took 4 button presses, or observed lights, per side to complete. The perimetry automatically calculate the binocular angular range from the averages of the locations of the four lights on each side, with the center point of the head rest, or the midpoint, between the eyes. The results are indicated in degrees with zero decimal accuracy. The error is dependent on the conditions (e.g., ambient light, settings, chosen program, location of the LED) and the location of the gaze, but is approximately 2.3° at the lowest (Vekki 2019).

Protocol. The peripheral vision and reaction screening were executed individually with all participants. The whole measurement took approximately 30 minutes per player, with six (6) different tests of field of vision and peripheral reaction. To minimize measurement errors, all tests were done with a red color and the brightness level at low. In this study, only the vertical and horizontal field of vision tests are analyzed, drawn from the first two tests of the pattern.

The field of vision was measured binocularly and separately for the horizontal and vertical directions. In both tests, the participant stood still at a standardized distance with the head placed on the head rest (Vekki 2019). Red LED lights started to blink one by one starting from outside of the field of vision. The participants were instructed to stare the center point of the perimetry device marked with red triangle, and to press a button whenever they saw a red-light blink on the perimetry. In the horizontal field of vision test, the LED could turn on either on the left or the right side (figure 15b), and in the vertical test, either up or down (figure 15a). In the device, one of the buttons is marked left/down and the other right/up. Depending on the test used, participant was supposed to press the correct button. Whenever a correct button was pressed, the LED started closing from outside of the field of vision again until a total of four reactions per side is measured. The measurement took in total around 2–3 minutes per test. The result was calculated automatically by the perimetry and expressed in degrees, with an accuracy of zero decimals (Vekki 2019).

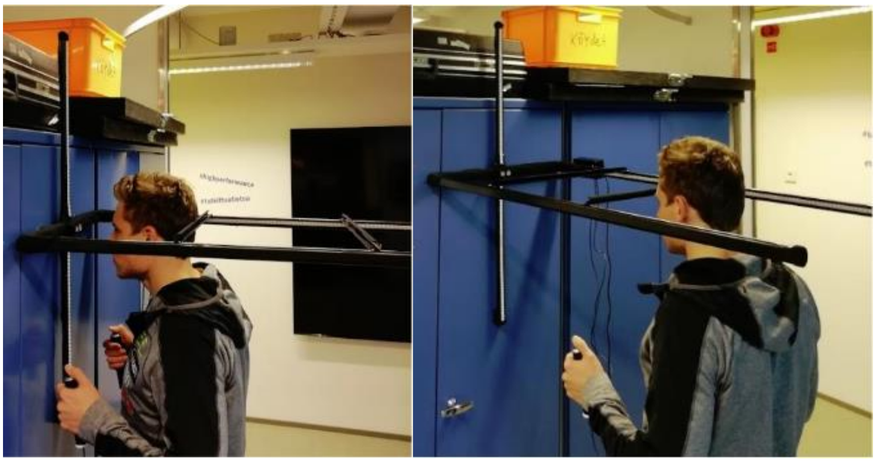

FIGURE 15. A) Placement of the participant in the vertical field of vision test. B) Placement of the participant in the horizontal field of vision test.

7.3 Video data analyses

Both internal and external video material were edited into trial-specific clips. The exclusion criteria in the video analysis phase were inadequate execution (same criterion as in data collection phase) or technical issues with the video image (e.g., blurry video image, incomplete execution visible). Due to further exclusion, five (5) trials from each player per defensive style per court side were picked for further analysis, resulting in a total of 27-30 trials per player (7-10/defense/side/participant). All video analyses were made by one observer.

The court side was defined as the side where the player could start dribbling with the dominant hand at initiation of trial. Thus, for right-handed players the dominant side is the left court side, and vice versa for left-handed players. The execution time was defined with the starting point being the first frame where the ball is in both hands of the player, and the ending point being the first frame in which the player does not touch the ball at all anymore. The external camera video was used to analyze decision-making data: 1) which decision was made (a drive to the basket, a shot, a pass to the screener/roller, a pass to the corner player); 2) whether the decision was successful (quality of decision; made basket or optimal pass to receiver); and 3) whether the decision was a correct one (accuracy of decision). The accuracy of decision was analyzed by FIBA certified basketball coach according to the spacing on-court. The coach was not related to any of the teams. Three points were given for a correct decision, two points for decent decisions and one point for an incorrect decision. If an incorrect decision was made, the correct decision was given by the analyzer. In the statistical analysis only two categories were used (as in Maarseveen et al. 2018a), thus, points 3 and 2 were labeled as “correct” and point 1 as an “incorrect” decision.

The frames in the internal video were synchronized with the execution time frames in the external video and analyzed frame-by-frame for the duration of the trial. Even though, in eye-tracking research, all gaze to all locations could be analyzed (Vickers 2007, 10), this thesis’ focus was, as in Maarseveen et al. (2018a), on fixations to 9 AOIs. Fixation was defined as a period equal or in excess of 120ms or three sequential frames. The nine AOIs were: 1) ball handler defender (BHD); 2) screener/roller (SR); 3) screener/roller defender (SD); 4) corner player (CP); 5) corner defender (CD); 6) ball; 7) basket; 8) positive space (POS); and 9) negative space (NEG) (Maarseveen et al. 2018a). Furthermore, blinks or absences of a focus point in the video were categorized as missing. The average fixation duration and frequency, the percentage of the viewing time (percentage of time spent in fixation on each AOI), the final fixation and fixation to correct option were analyzed. Fixation to correct option refers to the decision-accuracy evaluation. If the correct decision was to shoot or drive, the correct option, or target AOI, was basket. Similarly, if the correct decision was to pass, the correct option was the target player.

7.4 Statistical analyses

Statistical analysis started with additional data exclusion. The gaze samples from the original Tobii Pro -videos, reported by Tobii Pro software, were on average 83.1% (55-95%). However, since the videos were edited into shorter execution time -specific clips, the gaze samples for each trial clip were calculated. All trials with missing frames for ≥20% of the execution time were excluded. This resulted in the exclusion of 19 trials from 10 participants. Lastly, since special attention was given to the differences between correct and incorrect decisions, 21 trials missing the decision accuracy or corrected option in the case of a wrong decision were excluded. All in all, 613 trials from 22 players were included in the statistical analysis: 24-30 trails per player; 6-10 per player per defense; 307 from dominant and 306 from non-dominant side; 209 against switch; 203 against soft; and 201 against hedge (figure 16).

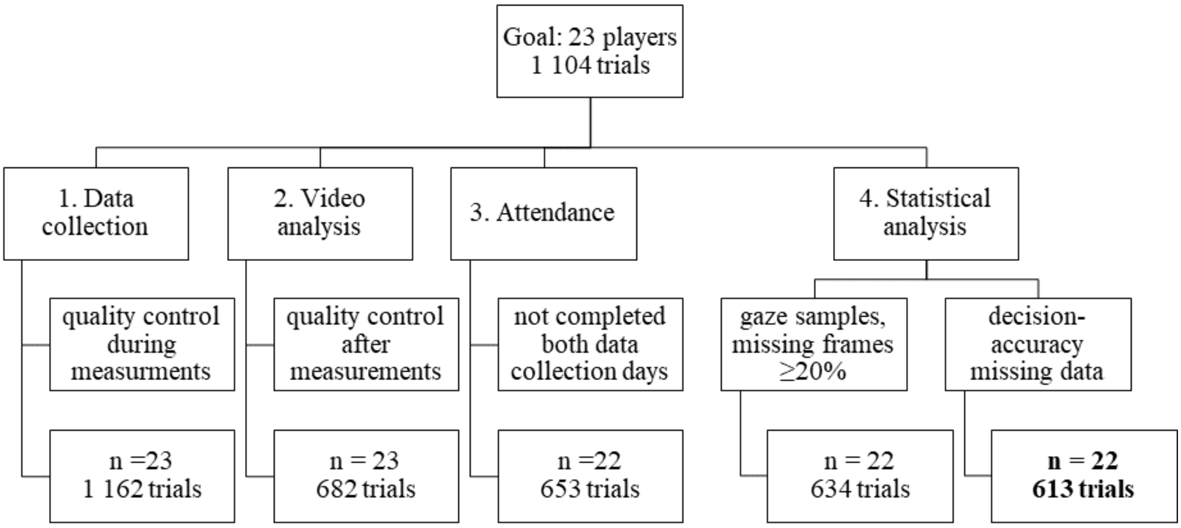

FIGURE 16. Flow chart of the exclusion criterion during different phases of the study.

Separate Likelihood Ratio Chi-Square test was used to analyze the differences in gaze data between field of vision groups. Chi-Square test was additionally used to analyze the number of trials where the final fixation was on the chosen option (player's choice) or on the correct option (coach's assessment) when players made correct or incorrect decision. The accuracy of decisions and the frequency of decisions were analyzed with court side (2) x defense (3) ANOVA with repeated measures on both factors.

As in the study by Maarseveen et al. (2018), the percentage of viewing time was calculated for each of the nine AOIs to evaluate where players were looking during the trial. This was then further analyzed with repeated measures ANOVA as AOIs as within-participant-factor (9) and accuracy of decisions between-participants factor (2), repeated measures on both factors. Similarly, repeated measures ANOVA was used to analyze decisions (4) x AIOs (9), repeated measures on the second factor. Spearman's correlations were calculated to evaluate the relationship between the percentage of viewing time towards the nine AOIs and the percentage of trials in which the player chose the correct option.

Two-fixation transition probabilities, or scan paths from one AOI to another, were analyzed with binomial tests (Maarseveen et al., 2018). The expected probability, or test proportion, was set to 1/8 or 0.125. All transition probabilities which exceeded this with $p<.05$ were included in the analysis. Any refixations within the same AOI or retransitions (e.g. two times from SC to POS within the trial) were excluded from the analysis. If the transition probability was significant, separated Chi-Square tests with Bonferroni correction were used to analyze the between-group differences among decision accuracy and defensive plays.

All significant ANOVAs were followed by Dunn’s pairwise comparison post hoc and significant effect on Likelihood Chi-Square test with z-test, both with Bonferroni correction. The effect sizes for ANOVAs were reported as eta squared ($\eta p2$) and for Chi-Square as Cramer’s V. The significant effect level was set at $p<.05$.

8 RESULTS

8.1 Pick'n roll -gaze data

On 59.1% of the trials, players laid final fixation on the option they chose, and on 17.3% they did not fixate on the chosen option at all. The final fixation on the chosen option lasted on average 404.4 ± 209.7ms. There was no significant difference between the trials with final fixations on the chosen option when making a correct (277 out of 475) or incorrect decision (85 out of 138), $\chi 2$ (1) = .478, p=.489. On 75.9% of all trials, players fixated on the correct option at some point of the trial. A significant difference was found on trials with fixation on the correct option when making a correct (386 out of 475; 81.3%) or incorrect decision (79 out of 138; 57.2%), $\chi 2$ (1) = 30.981, p<.001.

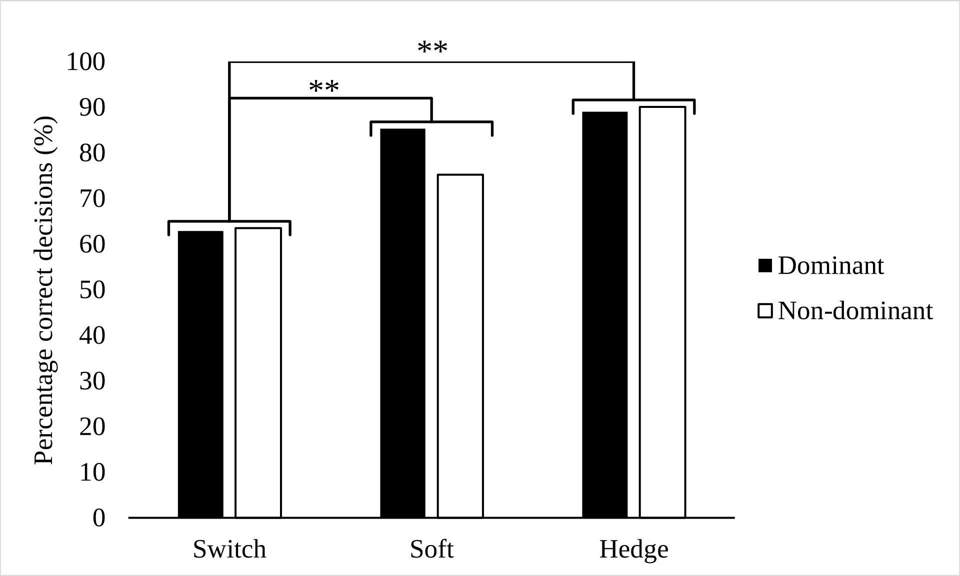

FIGURE 17. The percentage of correct decisions for three defensive plays and the dominant or non-dominant side of the court. ** = significant difference between Switch and Soft and Switch and Hedge, p<.001.

A significant difference between correct and incorrect decisions and defensive plays (F(2, 607) = 22.592, p<.001, η^2=.069) was found, but not so between dominant or non-dominant court side (F(1,607)=.726, p=.394, η^2=.001) nor an interaction effect of defense and court side

(F(2,607)=1.236, p=.291, η^2=.004). The differences in decision accuracy were between Switch and Soft (p<.001), and Switch and Hedge (p<.001; figure 17).

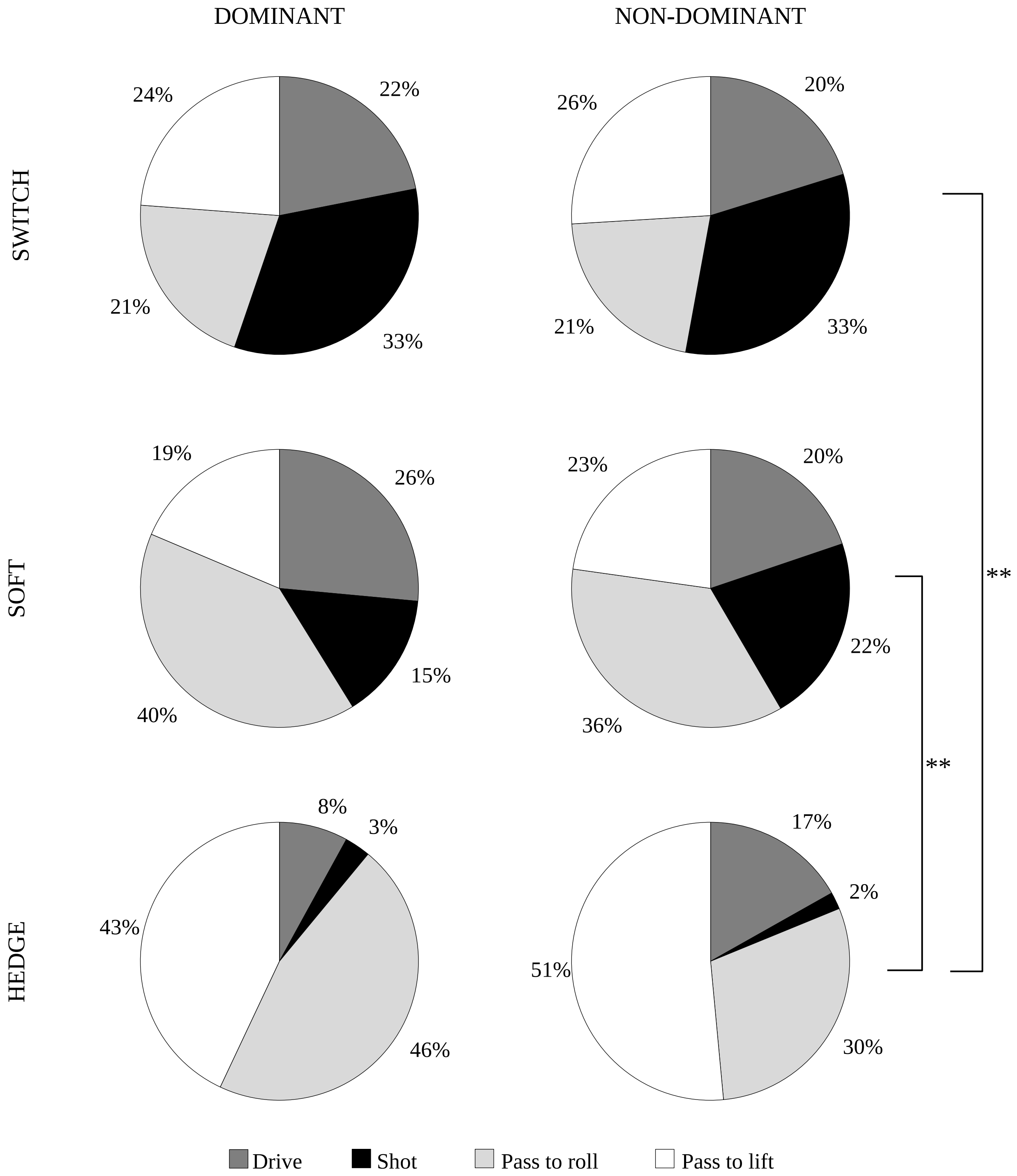

FIGURE 18. The distribution of decisions per defensive play and court side. ** = Significant difference between Switch and Hedge, and Soft and Hedge (p<.001) on both sides of the court.

No significant differences were found between number of decisions and court side (F(1, 607) = .112, p=.738, η^2=.000), nor the interaction effect of court side and defense (F(2, 607) = .438, p=.645, η^2=.001). However, different defensive plays did have an effect on the distribution of decisions (F(2, 607) = 27.936, p<.001, η^2=.084). The effect of defense on the made decision was significant on level p<.001 on both sides of the court (dominant F(2, 304) = 18.635, η^2=.109; non-dominant F(2, 303) = 10.237, η^2=.063). Post hoc with Bonferroni correction revealed differences in frequency of decisions between Switch and Hedge (p<.001) and Soft and Hedge (p<.001) at both sides of the court (figure 18).

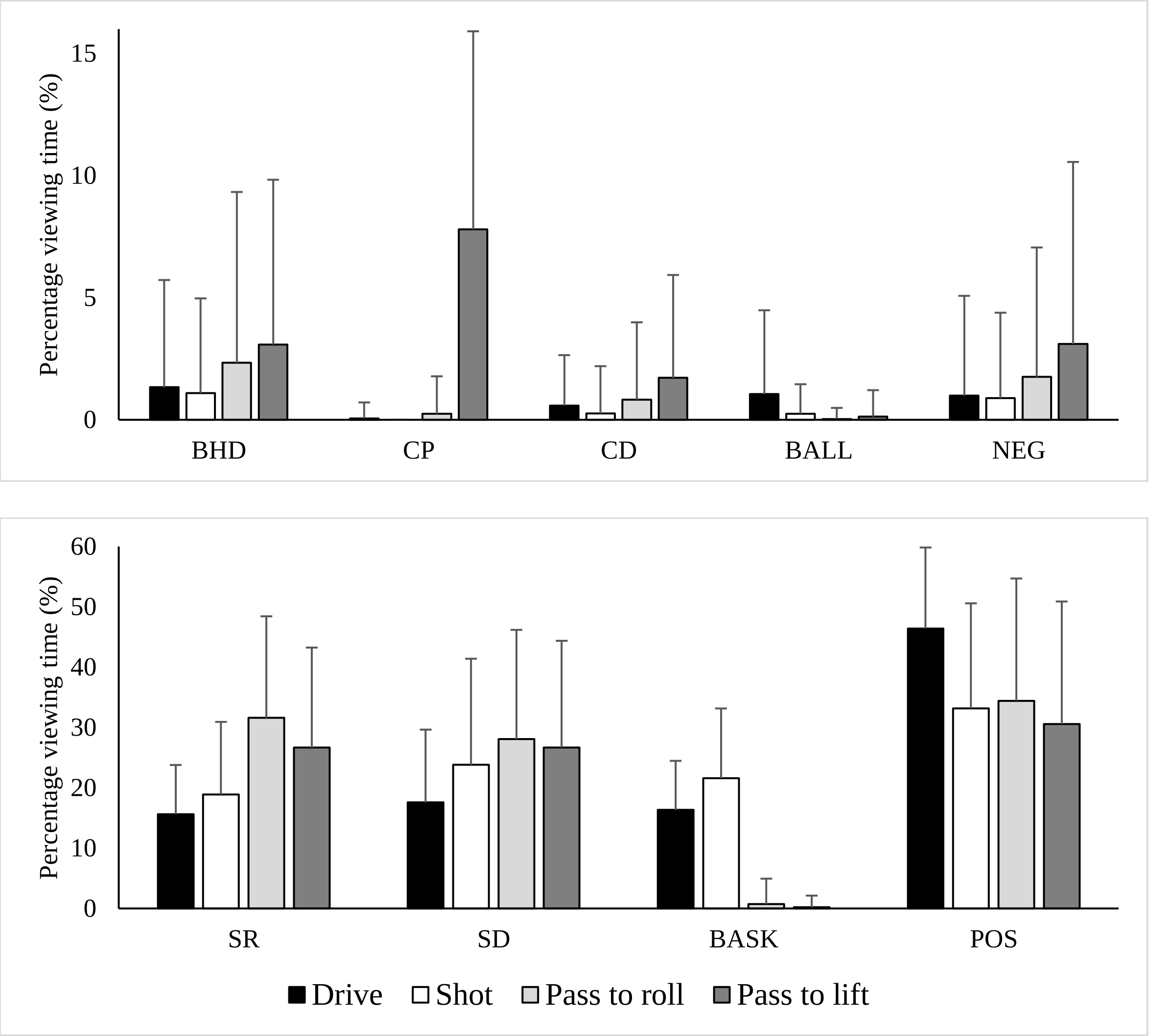

FIGURE 19. Percentage of viewing time towards A) the five least viewed areas of interest (AOIs), and B) the four most viewed AOIs across different made decisions. The made decisions had a significant effect on percentage viewing time locations (p<.001). BHD = ball handler defender; CP = corner player; CD = corner defender; BALL = ball; NEG = negative space; SR = screener/roller; SD = screen defender; BASK = basket; POS = positive space.

In analyzing the % of view for frequency of made-decisions, significant effect was found for AOI location (F(2.825, 1720.523) = 816.011, p<.001, η^2=.573), and decision-AIO interaction, (F(8.475, 1720.523) = 37.059, p<.001, η^2=.154) (figure 19). When analyzed with decision-accuracy, % viewing time was found to differ across AOI locations (F(3.116, 1903.898) = 517.494, p<.001, η^2=.459) and for decision-accuracy x AOI interaction (F(3.116, 1903.898) = 6.984, p<.001, η^2.011). Similarly, defense-AOI location interaction was significant, F(6.278, 1914.882) = 12.366, p<.001, η^2=.039.

Players spent most time fixating on SR, SD and POS, and in most of the cases these three were the starting AOI; SR 60.7%, SD 16.6.% and POS 22.0% of trials. From the nine AOIs, the viewing time towards SC (r_s =.080, n=613, p<.05) was significantly positively related and NEG (r_s =-.110, n=613, p<.01) significantly negatively related to made correct decisions (table 1). No other correlations were found for % viewing time and % correct decisions.

TABLE 1. Spearman’s correlations between the percentage of correct decisions and percentage of viewing time towards nine areas of interest. Significance level adjusted to p<.05.

	r_s	**p**
Ball handler defender	-.066	.102
Screener/roller	.080	.049
Screen defender	-.075	.063
Corner player	.001	.972
Corner defender	.010	.796
Ball	.025	.534
Basket	.054	.183
Positive space	.022	.591
Negative space	-.110	.007

Except for the transition from POS to SD (0.369 right; 0.339 wrong; $\chi 2$ (1) =5.459, p<.05, Cramer’s V .015), and from SD to Basket (0.194 wrong; $\chi 2$ (1) = 32.460, p<.001, Cramer’s V .000), there were no significant differences among two-fixation scan paths between right and wrong decisions (figure 20). No chi-square results for scan paths between different decisions are reported, since in most cases, the expected count was lower than 5 for >20% of cells. The transition probabilities for all made decisions are seen in figure 20. The transitions between POS, SD and SR were significant in all comparisons (figure 20; figure 21). The transitions to basket and to CP differed among decisions (figure 20).

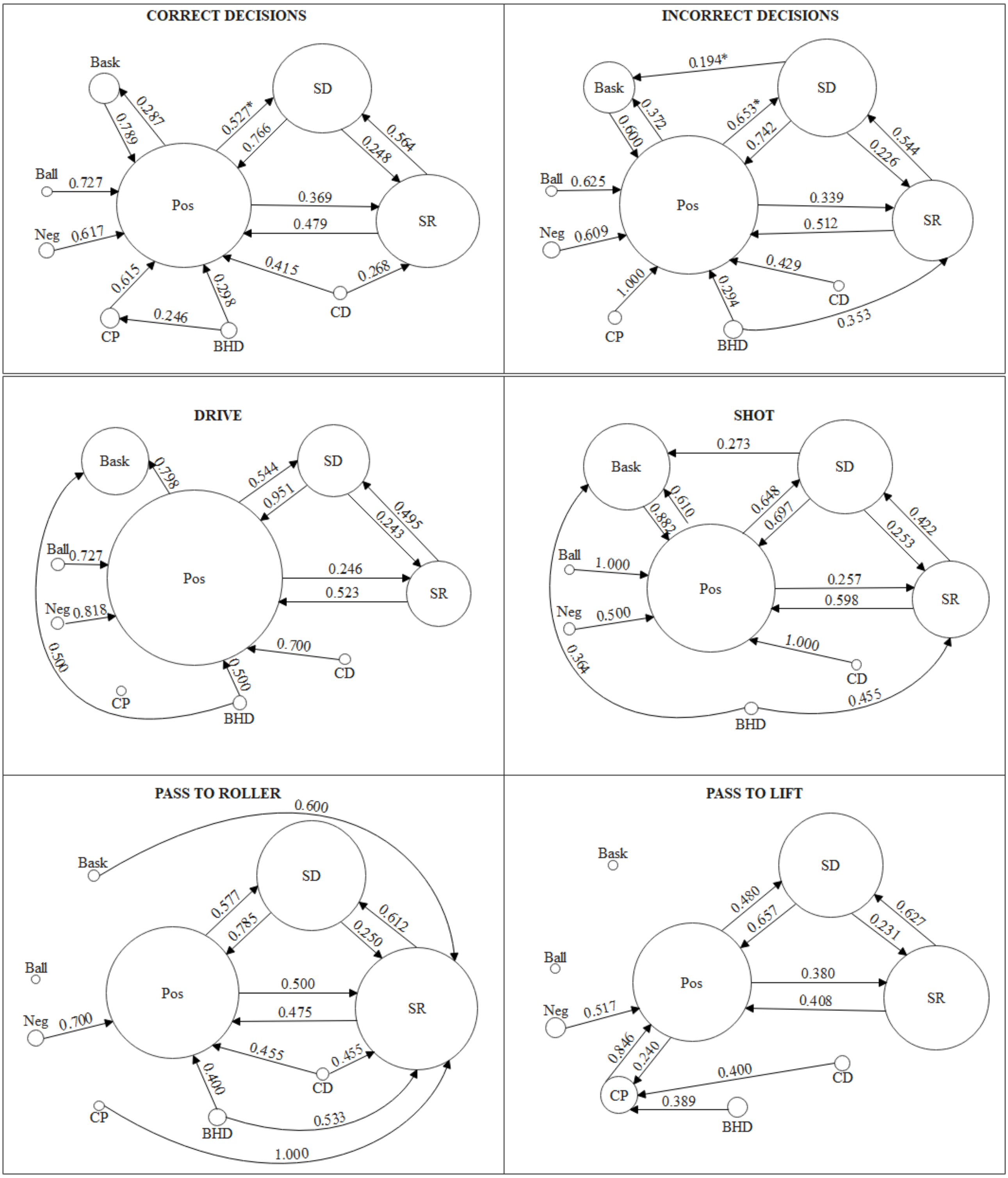

FIGURE 20. Two-fixation scan paths exceeding the transition probability (0.125, p<.05) between right and wrong decisions, and four different chosen options: drive, shot, pass to roll and pass to lift. The size of the AOI circle signifies the percentage viewing time: the bigger the circle, the more time players spent fixating on it. * = Significant difference between right and wrong decisions; BHD = Ball handler defender; SR = screener/roller; SD = screen defender; CP = corner player; CD = corner defender; Bask = Basket; POS = Positive space; NEG = Negative space.

The defensive plays had the strongest impact on scan paths (figure 21); transitions from BHD to CP (0.412 hedge; χ2 (2) = 19.579, p<.001, Cramer's V .000), and to basket (0.273 switch; χ2 (2) = 10.917, p<.01, Cramer's V .008) differed among Switch-Hedge; from SR to SD (0.565 soft; 0.439 switch; 0.678 hedge; χ2 (2) = 21.690, p<.001, Cramer's V .000) with Switch-Soft, and Soft-Hedge; from SR to POS (0.572 soft; 0.393 hedge; χ2 (2) = 11.935, p<.01, Cramer's V .003) with Soft-Hedge; from SD to POS (0.798 switch; 0.846 soft; 0.643 hedge; χ2 (2) = 21.892, p<.001, Cramer's V .000), from POS to SD (0.563 switch; 0.707 soft; 0.373 hedge; χ2 (2) = 38.843, p<.001, Cramer's V .000) and POS to basket (0.372 switch; 0.348 soft; 0.184 hedge; χ2 (2) = 17.337, p<.001, Cramer's V .000) with Switch-Hedge and Soft-Hedge. The transition probability from POS to SD also differed between Switch-Soft.

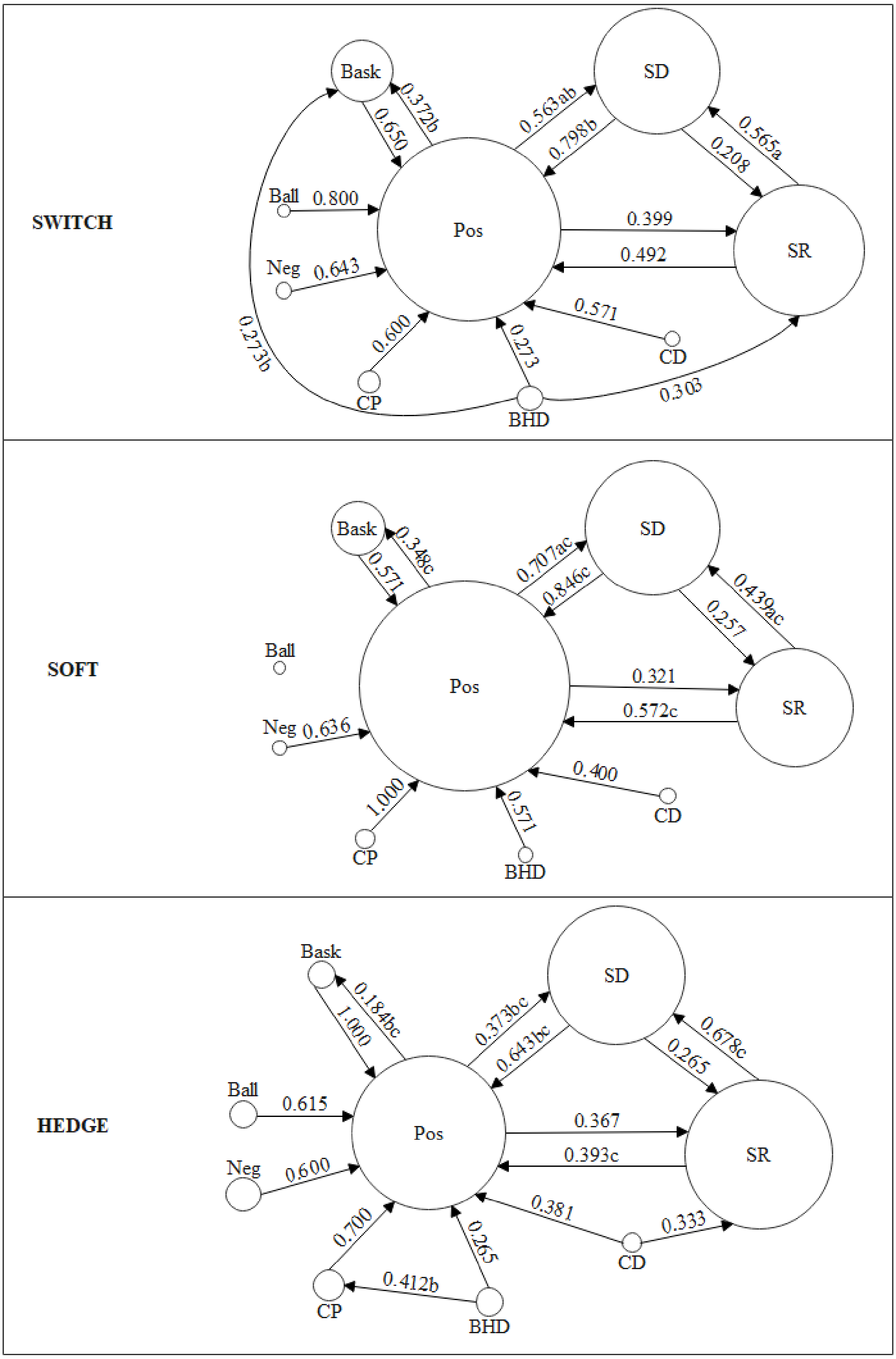

FIGURE 21. The two-fixation scan paths for different defensive plays. All transitions that exceeded the probability 1/8 =0.125 by p<.05 are included in the diagram. a = Significant difference between Switch and Sof, p<.05; b = Significant difference between Switch and Hedge, p<.05; c = Significant difference between Soft and Hedge, p<.05; BHD = Ball handler defender; SR = screener/roller; SD = screen defender; CP = corner player; CD = corner defender; Bask = Basket; POS = Positive space; NEG = Negative space.

8.2 Field of vision

The players show an average vertical field of vision of 121.4° ± 7.7° and horizontal field of vision of 187.5° ± 12.6°. These averages are presented in table 2 with standard deviation as well as minimum, maximum, and the point of 50%. The differences between wide field of vision (WFOV) and narrow field of vision (NFOV) group were significant both in horizontal (p<.001) and vertical (p<.01) fields of view (figure 22).

TABLE 2. Horizontal and vertical field of vision of study participants, N = 22.

	rv	Mean	SD	Min	Max	<50%
Horizontal field of vision	200°	187.5°	12.6°	165.0°	213.0°	186.0°
Vertical field of vision	130°	121.4°	7.7°	108.0°	137.0°	120.0°

rv = reference values from Harrington (1964); Mean = average; SD = standard deviation; Min = minimum; Max =maximum; <50% = point where 50% of the data fall below.

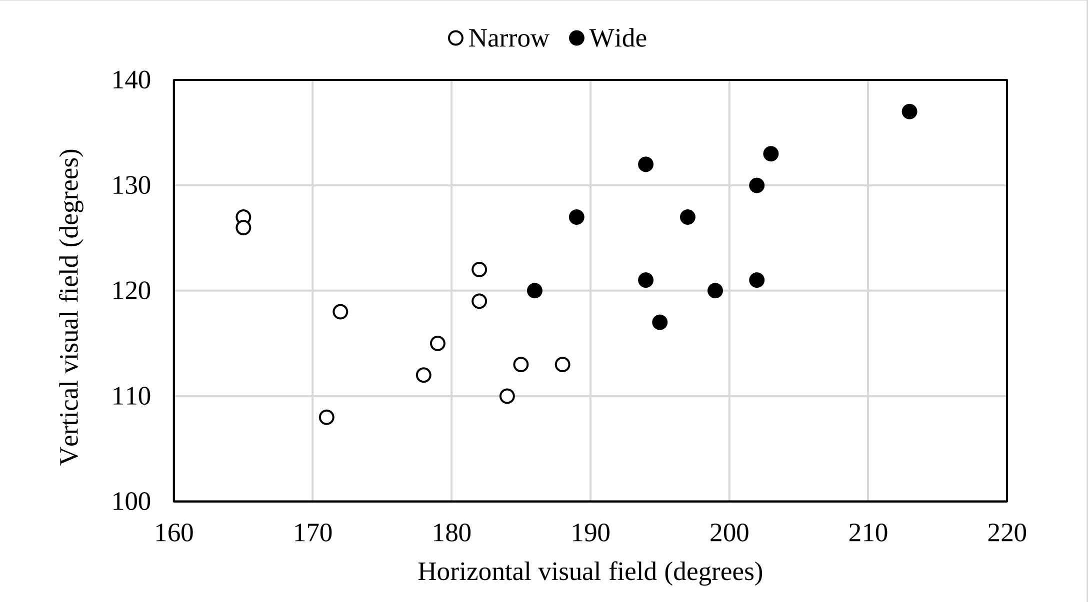

FIGURE 22. The participants divided into two groups according to total field of vision. The difference in total field of vision was significant between the two groups, p<.01. N = 22.

8.3 Effects of field of vision in the Pick'n Roll -gaze data

No differences between WFOV and NFOV group were found in the final fixation to chosen option (X^2 (1)=.078, p=.779, Cramer's V=.011), or any fixation to correct option (X^2 (1)=.028, p=.868, Cramer's V=.007), or number of correct decisions (X^2 (1)=.046, p=.830, Cramer's V=.009). Similarly, no between-groups differences in total effect of made decisions (X^2 (3) = 5.091, p=.165, Cramer's V = .091). However, when made-decisions was analyzed with defense, WFOV decided to pass to lift (31) more often than NFOV (11) against Soft (X^2 (3) = 12.681, p<.01, Cramer's V = .007). No significant differences were found against Switch (p=.120) nor Hedge (p=.808).

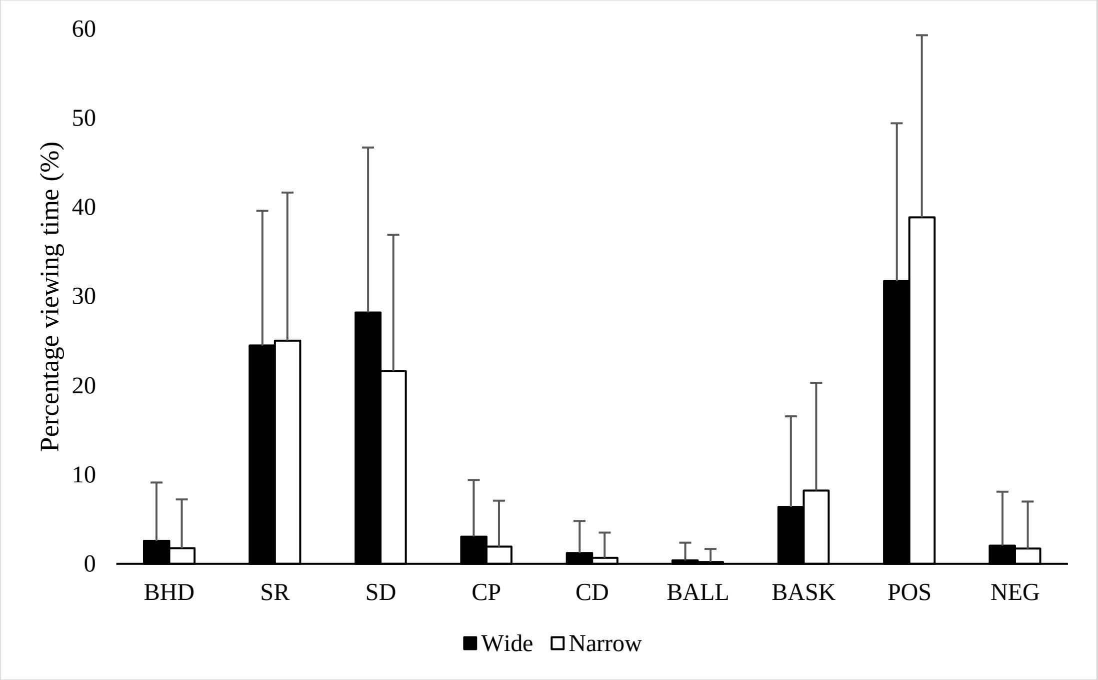

FIGURE 23. Percentage of viewing time towards the nine areas of interest (AOIs) between the two groups; wide and narrow field of vision. The group had a significant effect on total percentage viewing time locations (p<.001). BHD = ball handler defender; SR = screener/roller; SD = screen defender; CP = corner player; CD = corner defender; Ball = ball; Bask = basket; POS = positive space; NEG = negative space.

The FOV group had a significant effect on % of viewing time locations, F(3.187, 1947.392) = 767.846, p<.001, η^2=.557, and AOI x group interaction F(3.817, 1947.392) = 13.442, p<.001, η^2=.022. WFOV spent more time fixating on SD (wide 28.19 ± 18.51 %; narrow 21.61 ± 15.30 %), CP (wide 3.06 ± 5.34 %; narrow 1.93 ± 5.15 %), and CD (wide 1.22 ± 3.59 %; narrow 0.69 ± 2.81 %), while NFOV spent more time fixating on basket (wide 6.38 ± 10.16 %; narrow 8.22 ± 12.08 %) and positive space (wide 31.71 ± 17.70 %; narrow 38.86 ± 20.43 %) (figure 23). WFOV were more likely to use SR (198 trials out of 306 wide; 174 trials out of 307 narrow) and SD (61 wide; 41 narrow) as the starting fixation, while NFOV more often started the trial from fixating on positive space (46 wide; 89 narrow), χ2 (4) =24.978, p<.001, Cramer’s V .000.

The Wide group had significantly higher probability to transit gaze from SR to SD (0.616 vs 0.502; χ2 (1) =7.490, p<.01, Cramer’s V .006) and from SD to SR (0.314 vs 0.165; χ2 (1) = 16.685, p<.001, Cramer’s V .000). On the other hand, wide group had significantly lower transition probability from BHD to POS (0.043 vs 0.258; χ2 (1) =7.032, p<.01, Cramer’s V .009), from SR to POS (0.444 vs 0.530; χ2 (1) =4.250, p<.05, Cramer’s V .039), and from POS to SR (0.276 vs 0.443; χ2 (1) =16.020, p<.001, Cramer’s V .000) (figure 24).

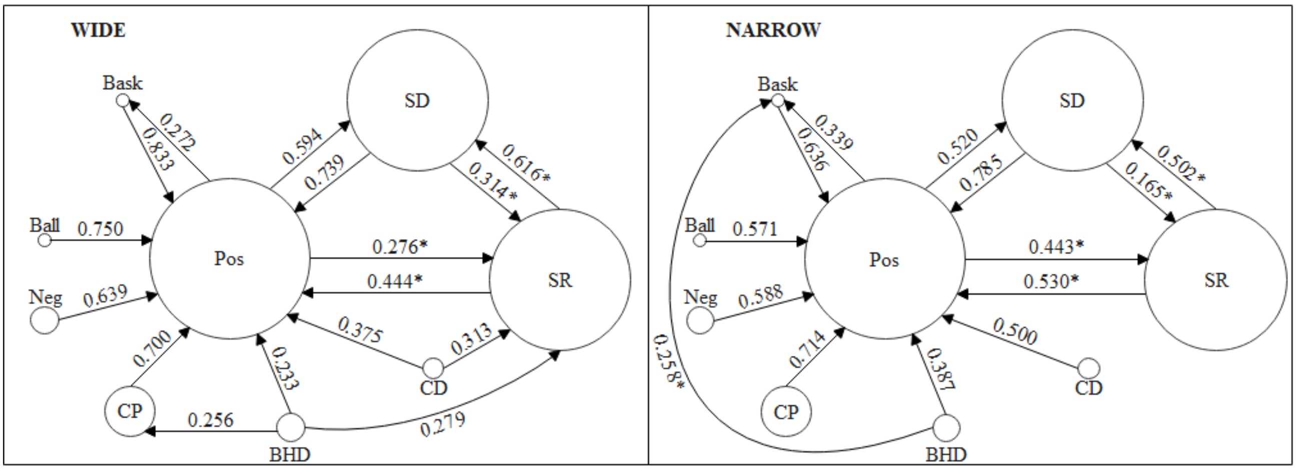

FIGURE 24. Two-fixation scan paths that exceeded the transition probability (0.125, p>.05) between “wide” and “narrow” field of vision groups. The size of the AOI circle represents the percentage viewing time – the bigger the circle, the more time players spent fixating on it. * = Significant difference between groups; BHD = Ball handler defender; SR = screener/roller; SD = screen defender; CP = corner player; CD = corner defender; Bask = Basket; POS = Positive space; NEG = Negative space.

9 DISCUSSION

The results indicate that defense has a significant impact on the frequency and accuracy of decisions and the two-fixation scan paths. Decision-accuracy was further related to percentage viewing time and to fixations to correct options, while made decision had significant effect only on % viewing time. Field of vision groups differed from each other in percentage viewing time, scan paths, and starting fixation of trial. Court side had no effect on any of the gaze variables.

Effect of defensive play on decision-making and gaze behavior. The pick'n roll defense affects the frequency and accuracy of decisions on both sides of the court. Players made more accurate decisions against Soft/Hedge than against Switch, which may be because solution options are more diverse against Switch due to, e.g., spacing, and timing of actions, resulting in difficulties making correct decisions against it. Maarseveen et al. (2018a) did not find differences in decision-accuracy across defenses but did find some in made decisions, although no statistics were reported. Similar distribution of decisions can be seen against Hedge. With their dominant hand, the players decided to pass to roll on 46% and to lift on 43% of trials while corresponding numbers in Maarseveen et al. (2018a) were 49% and 40%. Even though the difference in made-decisions across Switch and Soft were not significant in the current study, it is clear that, against Switch, players used all options with a preference to shoot while against Soft, players preferred to pass to roll. The frequency of decisions is in line with the expectations that the "free space" to score is found in lift for Hedge, in roll for Soft, and in shot/drive for Switch.

In addition, the two-fixation scan paths differed across all three defenses. As the three chosen defenses closed space from the participant differently, they were forced to remarkably different running paths resulting, as a natural response, in different paths of gaze. Due to the distribution of made-decisions, players were more likely to transfer their gaze towards the basket during Switch and Soft. Against Soft, players were more likely to transfer their gaze from SR to POS than towards SD, as in Switch and Hedge, and between SD and POS. This may be explained by the positioning of the SD in Soft allowing free space between the participant and basket and/or other players. The players fixated their own defender mostly against Switch, when transitions to basket or to screener were used, and against Hedge, when transitions happened mostly towards corner player. However, based on these two-fixation transition probabilities, little conclusions can be drawn, since it cannot be separated when the transition happened nor what happened after it. Even though the probability is higher than change (0.125), the role of the transition in visual search strategy of players cannot be defined. In addition, even when differences in scan paths are found, the fixations and transitions focus on positive space, screen defender and screener/roller against all three defenses.

Effect of court side on decision-making. The ability to start the trial dribbling with the dominant or non-dominant hand did not affect made-decisions or decision-accuracy. This result differs from Maarseveen et al. (2018a) which found that decision accuracy was the same for both sides, but the players made different decisions on different court sides. This finding may be explained by the differences in playing experience of the study participants. Maarseveen et al. (2018a) uses approximately 17-year-old females with 8.4 years of playing experience, while the current study used about 21-year-old male players with 13.8 years of playing experience. As Wimshurst (2012, 25) argues with regards to college athletes, the younger players may not have fully developed their sport-specific visual skills nor technical skills to perform at an "expert" level.

Differences in gaze behavior between correct and incorrect decisions. Incorrect decisions were associated with non-fixation towards the correct option, i.e. when a player made an incorrect decision, they did not look at the correct option at all. Maarseveen et al. (2018a) report the same association, which stands in contrast with the idea of using peripheral attention to make decisions. It may be correct, however, that while peripheral vision may be an important basis for decision-making, execution relies more on the central vision (Maarseveen et al. 2018a). Additionally, it seems like there may not be a certain two-fixation scan path related to more accurate decision-making, as the only significant transitions were from POS to SD in right decisions and from SD to basket in wrong decisions. As discussed later, the SD may have served as an advance cue point or a centrally located anchor offering critical information for the execution of a correct decision, whereas fixations towards the basket were mostly due to the decision to drive or shoot, with most of the shots being judged as wrong decisions. There is no point in looking at the basket, if that is not the optimal option to score.

The correlations between % viewing time and % correct decisions suggest that in successful trials, players used more time fixating on the screener/roller, and less time on the negative space. NEG includes all the space outside the active playing area – everything besides the players and the space between players and basket. It is logical, that fixating on non-active space less will result in better decision-making. However, the relationship between time spent fixating on SR and correct decisions should be further examined. In many trials, players fixated on the SR before and after the use of the screen. It may be that fixating on SR who is running towards the basket does work as a centrally-located anchor. SR was in the center of all actions and fixating on them could help evaluate the movements of defenders and the CP.

Since the percentage of time spent fixating on certain AOI differed across trials with different chosen options and correct/incorrect decisions, it can be argued that the players were actually reading the game. In contrast to this, Maarseveen et al. (2018a) found that there was no influence between the frequency or accuracy of decisions and % viewing time spent on the nine AOIs, resulting in assumptions that the % viewing time may not be a sufficient variable to examine visuals search strategies. However, based on the current study's contradictory findings, the role of % viewing time should be assessed further. The idea of gaze behavior being task-specific is especially intriguing – if the player decides what to do or which options they prefer prior to the start, the player will modify their gaze behavior to search for these pre-decided options, which in addition affects the results. The results may indicate that a certain % viewing time is related to certain decisions, but no conclusion can be made since it cannot be stated reliably whether the decision was made based on the defense or prior to starting.

Advance cue points. As in Maarseveen et al. (2018a), the players spent the most time fixating on SR, SD and POS. These AOIs were centrally located, suggesting that they may have been used as centrally located visual anchors. Especially SR and POS are in the center of the action in all trials, and, as discussed before, the position of SD in the paint during Soft is similarly in the center of action. Thus, it is an AOI which serves as help in a center-looking strategy as an anchor point allowing the player to use peripheral vision to evaluate the whole situation.

However, to fully separate the visual search strategies into free-gaze and center-looking, the AOIs should be defined into smaller areas. In this study, fixating to POS could mean fixating only to the floor with nothing else in the visual field, or between four players with a full image of the action. In addition, it may be assumed that SD served as critical cue point allowing the player to read the first defender and to anticipate the upcoming defensive strategy, allowing to find the correct solution more easily (see Nagano et al. 2004; Williams & Ward 2007). Similarly to POS, SD could be divided into smaller pieces to give a better image on the visual cue points. It still remains unknown to which extent athletes can recognize subtle changes in postural orientation (Williams & Ward 2007). To detect the source of information about SD's intentions, differences in fixations with smaller AOIs (leg, hip, torso, arms) should be investigated.

Differences between field of vision groups. Between wide and narrow field of vision groups, no significant differences were found in decision-making data or simple fixation data. However, there were significant differences in advance gaze data, such as % viewing time and two-fixation scan paths, proving that the athlete's field of vision is not associated with decision-making ability but it does affect the used visual search strategies. It was assumed that the WFOV group could spend more time fixating on central locations and use their peripheral vision to evaluate the full situation. The opposite to this was proven: Wide field of vision is associated with more % viewing time towards distant AOIs (CP, CD, and even negative space where the difference is not significant) than narrow field of vision. While this finding is inconsistent to the hypothesis, it does go together with previous assumptions that hardware of vision is not enough but the ability to use the software visual skills is what matters (Vickers 2007, 306).

The two field of vision groups were created "a posteriori". As discussed by Maarseveen & Oudejans (2018), this is not a common procedure but valid when comparing two groups in gaze behavior, not the field of vision. Wimshurst (2012, 67) argues that to actually gather information on the relationship of visual skills and expert performance, the tactical skill level and familiarity with the task between study participants should be minimized. The current protocol proved that the comparison between trials and between groups can be successfully made with players with broadly the same experience level and task familiarity, and still find significant results. This also proves that not enough is known about the visual search strategies and gaze behavior of players in team sport performance.

9.1 Strengths and limitations

The results indicate that the correct options differ within a defense, proving that the advanced PnR protocol by Maarseveen et al (2018) with CP lift and uninstructed CD results in more diverse situations within the same defense, requiring the player to actually read the game. Then again, the execution and timing of the screen, lift, and defenses differed across trials. A familiarization session, as in Martell & Vickers (2004) and Afonso et al. (2004), could be used to minimize this variance in performance. However, Mann et al. (2007) argue that a realistic on-court protocol results in greater measurement sensitivity in between group and optimal-nonoptimal comparisons, meaning this study design succeeded to be as sports-specific as possible to detect the actual on-court differences in gaze behavior between trials.

To enhance the reliability and validity of results, all video analyses were done by one examiner, and all decisions were evaluated by a single external coach. The decision accuracy evaluation was determined consistent as no between visual-field group differences were found (p=.057). However, some individual preference was detected, as 61.2% of shots were evaluated as wrong decisions, and 0/228 corrected options were shots. The 613 trials from 22 players compose the largest amount of trials analyzed in eye tracking research in-situ, when typically in-situ protocols use only about 10 participants with around 20 trials (Kredel et al. 2017). In future research, a solution should be found to keep the trial amount as high as possible, but the drill duration shorter than 2 hours. In the current study, a decrease in motivation and intensity were inevitable. Since a significant number of trial exclusions were done both before and after video analysis, the remaining trials should be trusted to offer a good cross-section of the behavior in actual PnR situation.

9.2 Conclusions

The purpose of this study was to examine basketball players’ gaze behavior in 3-on-3 PnR game situation, for the purposes of evaluating whether certain visual search strategies are related to correct decisions. Since the current study was one of the first studies of natural responses in game contexts of team sports overall, and the second one exploring basketball, only cautious conclusions can be drawn. Based on the results, the court side does not affect decision-making or visual search behavior of experienced players. However, the tactics of opponents do have an influence indicating that players actually try to read the game to produce correct solutions. Both this thesis and Maarseveen et al. (2018a) conclude that critical cue points in basketball PnR are screener/roller, screen defender, and positive space between players. In addition, the athlete’s field of vision may not be related to decision-making, and wider field of vision does not automatically result in a more optimal visual search strategy.

In future research, longer scan paths should be analyzed to get an insight in the visual search patterns of players. Also, the AOIs should be further cut into more detailed areas to define the advance cue points more precisely. Additionally, in future research, the time before execution start could be fascinating to study, since it may be that players read and react to opponents’ actions already prior to using the screen. The evaluation of gaze behavior from before catching the ball to using the screen could reveal critical information expert players use to anticipate the opponents’ actions and decide on a response.

9.3 Practical applications

The results show that correct decisions were associated with longer fixations towards screener/roller, a centrally-located anchor enabling using peripheral vision in evaluating the situation. Also, the screen defender and positive space seem to be important visual information sources which result in more efficient decision-making. Both the screen defender and positive space between players and basket may serve as critical information sources and/or centrally-located anchors. However, the time players spent fixating on certain objects or scanning the image differs across trials. Since players are able to selectively tune their perceptions to certain situations (Marteniuk 1976, 22; Araújo et al. 2009), by knowing the critical cue points, coaches can help players recognize and use the information already prior to actually using the screen. Basketball coaches can give players instructions about the important visual cue points and use of peripheral vision with a central anchor. However, since different search strategies were associated to correct decisions, more precise interference in gaze behavior may not be useful.

REFERENCES

Abernethy, B. 1987. Selective attention in fast ball sports: II Expert-novice differences. Australian Journal of Science and Medicine in Sport 19 (4), 3–6.

Abernethy, B., Maxwell, J. P., Masters, R. S. W., Van Der Kamp, J. & Jackson, R. C. 2007. Attentional processes in skill learning and expert performance. In G. Tenenbaum & R. C. Eklund (eds.) Handbook of sport psychology. John Wiley & Sons Inc., 245–263.

Afonso, J., Garganta, J., Mcrobert, A., Williams, A. M. & Mesquita, I. 2012. The perceptual cognitive processes underpinning skilled performance in volleyball: evidence from eye-movements and verbal reports of thinking involving an in situ representative task. Journal of Sports Science and Medicine 11 (2), 339–345.

Afonso, J., Garganta, J., McRobert, A., Williams, M. & Mesquita, I. 2014. Visual search behaviours and verbal reports during film-based and in situ representative tasks in volleyball. European Journal of Sport Science 14, 177–184. doi:10.1080/17461391.2012.730064.

Applegate, R. A. & Applegate, R. A. 1992. Set shot shooting performance and visual acuity in basketball. Optometry and vision science: official publication of the American Academy of Optometry, 69 (10), 765–768. doi: 10.1097/00006324-199210000-00004.

Aprile, I., Ferrarin, M., Padua, L., Di SIpio, E., Simbolotti, C., Petroni, S., Tredici, C. & Dickmann, A. 2014. Walking strategies in subjects with congenital or early onset strabismus. Frontiers in human neuroscience, 8 (484). doi:10.3389/fnhum.2014.00484.

Araújo, D., Davids, K. W. & Hristovski, R. 2006. The ecological dynamics of decision making in sport. Psychology of Sport and Exercise, 7 (6), 653–676.

Araújo, D., Davids, K., Chow, J. Y. & Passos, P. 2009. The development of decision-making skill in sport: an ecological dynamics perspective. In D. Araújo, H. Ripoll, & M. Raab (eds.) Perspectives on cognition and action in sport. US: Nova Science Publishers Inc., 157–169.

Arines-Piferrer, J. 2011. Fixational eye movements and ocular aberrometry. In D. P. Anderson (ed.) Eye movement: theory, interpretation, and disorders. US: Nova Science Publishers Inc., 67–80.

Bagatin, R., Padilha, M., Milheiro, A., Rodrigues, G., Tavares, F. & Casanova, F. 2017. Perception and action in soccer: Performance comparison under different perceived effort intensities in small-sided and conditioned games. Revista Portuguesa de Ciências do Desporto (17), 367–374. doi:10.5628/rpcd.17.S1A.367.

Belda-Maruenda F. 2004. Can the human eye detect an offside position during a football match? BMJ, 329 (7480), 1470-1472. doi:10.1136/bmj.329.7480.1470. Erratum in BMJ 2005, 330 (7484), 188.

Brymer, E. & Renshaw, I. 2010. An introduction to the constraints-led approach to learning in outdoor education. Australian Journal of Outdoor Education, 14 (2), 33–41.

Buszard, T., Farrow, D. & Kem, J. 2013. Examining the influence of acute instructional approaches on the decision-making performance of experienced team field sport players. Journal of Sports Sciences, 31 (3), 238–247. doi:10.1080/02640414.2012.731516.

Christenson, G. N. & Winkelstein, A. M. 1988. Visual skills of athletes versus nonathletes: Development of a sports vision testing battery. Journal of the American Optometric Association, 59 (9), 666–675.

Davids, K., Araújo, D., Vilar, L., Renshaw, I. & Pinder, R. 2013. An ecological dynamics approach to skill acquisition: Implications for development of talent in sport. Talent Development & Excellence, 5 (1), 21–34.

Davids, K., Araújo, D., Seifert, L. & Orth, D. 2015. Expert performance in sport: An ecological dynamics perspective. In J. Baker & D. Farrow (eds.) Routledge handbook of sport expertise. New York, US: Routledge/Taylor & Francis Group, 130–144.

Decroix, M., Norjali, R., Zeuwts, L., Deconinck, F., Lenoir, M. & Vansteenkiste, P. 2017. Expert - Non-expert differences in visual behaviour during alpine slalom skiing. Human Movement Science 55, 229–239.

Dicks, M., Button, C. & Davids, K. 2010. Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. Attention, Perception, & Psychophysics 72, 706–720. doi:10.3758/APP.72.3.706.

Erickson, G. B. 2007. Sports vision – Vision care for the enhancement of the sports performance. St. Louis, MO: Butterworth-Heinemann.

Haywood, K. M. & Getchell, N. 2009. Life span motor development. 5th edition. Champaign, IL: Human Kinetics.

Harrington, D.O. 1964. The visual fields: a textbook and atlas of clinical perimetry. 2nd edition. St Louis, MO: Mosby.

Holmqvist, K., Nyström, M., & Mulvey, F. 2012. Eye tracker data quality: What it is and how to measure it. ETRA '12: Proceedings of the Symposium on Eye Tracking Research and Applications, 45–52. doi:10.1145/2168556.2168563.

Hout, M. C. & Goldinger, S. D. 2015. Target templates: the precision of mental representations affects attentional guidance and decision-making in visual search. Attention, Perception, & Psychophysics, 77, 128–149.

Howarth, C., Walsh, W. D., Abernethy, B. & Snyder, C. W. Jr. 1984. A field examination of anticipation in squash: Some preliminary data. Australian Journal of Science and Medicine in Sport 16, 7–11.

Hüttermann, S., Memmert, D. & Liesner, F. 2014. Finding the happy medium: an analysis of gaze behavior strategies in a representative task design of soccer penalties. Journal of Applied Sports Psychology, 26 (2), 172–181.

Hüttermann, S., Noël, B. & Memmert, D. 2018. Eye tracking in high-performance sports: Evaluation of its application in expert athletes. International Journal of Computer Science in Sport, 17 (2). doi:10.2478/ijcss-2018-0011.

Johnson, J. G. 2006. Cognitive modelling of decision making in sports. Psychology of Sport and Exercise 7 (6), 631–652.

Kauranen, K. 2011. Motoriikan säätely ja motorinen oppiminen. Tampere, Finland: Tammerprint oy.

Kaya, A. 2014. Decision making by coaches and athletes in sport. Procedia - Social and Behavioral Sciences 152, 333–338.

Klein, 1999. The sources of power: how people make decisions. 20th edition. Cambridge, MA: MIT Press.

Klostermann, A. & Hossner, E-J. 2018. The Quiet Eye and motor expertise: explaining the "efficicency paradox". Frontiers in Psychology 9 (104). doi:10.3389/fpsyg.2018.00104.

Kredel, R., Vater, C., Klostermann, A. & Hossner, E-J. 2017. Eye-tracking technology and the dynamics of natural gaze behavior in sports: a systematic review of 40 years of research. Frontiers in Psychology, 8 (1845). doi:10.3389/fpsyg.2017.01845.

Laaksonen, A-M. 2017. Havainnointi ja päätöksenteko naissalibandypelaajilla. University of Jyväskylä. Department of Sport Sciences. Master’s thesis.

Land, M. F. & McLeod, P. 2000. From eye movements to actions: how batsmen hit the ball. Nature neuroscience, 3 (12), 1340–1345. doi:10.1038/81887.

La Valle, S.M. 2019. Virtual reality. Referred 20.7.2020. http://vr.cs.uiuc.edu/vrbookbig.pdf.

Maarseveen, M. J. J. & Oudejans, R. R. D. 2018. Motor and gaze behaviors of youth basketball players taking contested and uncontested jump shots. Frontiers in Psychology 9 (706). doi:10.3389/fpsyg.2018.00706.

Maarseveen, M. J. J., Savelsbergh, G. J. P. & Oudejans, R. R. D. 2018a. In situ examination of decision-making skills and gaze behaviour of basketball players. Human Movement Science, 57, 205–216.

Maarseveen, M. J. J., Oudejans, R. R. D., Mann, D. L. & Savelsberg, G. J. P. 2018b. Perceptual-cognitive skill and the in-situ performance of soccer players. Quarterly Journal of Experimental Psychology, 71 (2), 455–470.

Mann, D. T. Y., Williams, A. M., Ward, P. & Janelle, C. M. 2007. Perceptual-cognitive expertise in sport: a meta-analysis. Journal of Sport and Exercise Psychology, 29, 457–478.

Martell, S. G. & Vickers, J. N. 2004. Gaze characteristics of elite and near-elite athletes in ice hockey defensive tactics. Human Movement Science, 22, 689–712.

Marteniuk, R. G. 1976. Information processing in motor skills. New York, NY: Holt, Rinehart and Winston.

McPherson, S. L. & Vickers, J. N. 2004. Cognitive control in motor expertise. International Journal of Sport and Exercise Psychology 2, 274–300. doi:10.1080/1612197X.2004.9671746.

Micic, D. & Ehrlichman, H. 2011. Eye movements in non-visual cognition. In D.P Anderson (ed.) Eye movement: theory, interpretation, and disorders. US: Nova Science Publishers Inc., 1–52.

Murakami, I., Kitaoka, A. & Ashida, H. 2006. A positive correlation between fixation instability and the strength of illusory motion in a static display. Vision research 46, 2421–2431.

Nagano, T., Kato, T. &Fukuda, T. 2004. Visual search strategies of soccer players in one-on-one defensive situations on the field. Perceptual and Motor Skills 99 (3), 968–974. doi:10.2466/pms.99.3.968-974.

Newell, K. M. 1986. Constraints on the development of co-ordination. In M. G. Wade & H. T. A. Whiting (eds.) Motor development in children: Aspects of co-ordination and control. Dodrech: Martinus Nijhoff, 341–360.

Newell, K. M. & McDonald, P. V. 1994. Learning to coordinate redundant biomechanical degrees of freedom. In S. Swinnen, H. Heuer, J. Massion & P. Casaer (eds.) Interlimb Coordination. New York, NY: Academic Press, 515–536.

Padilha, M., Bagatin, R., Milheiro, A., Tavares, F., Casanova, F. & Garganta, J. 2017. Visual search behavior and defensive tactical performance during small-sided conditioned soccer games. Revista Portuguesa de Ciências do Desporto (17), 358–366 doi:10.5628/rpcd.17.S1A.358.

Panchuk, D. & Vickers, J. N. 2006. Gaze behaviors of goaltenders under spatial-temporal constraints. Human Movement Science 25, 733–752. doi:10.1016/j.humov.2006.07.001.

Perez-Zapata, L., Sole-Puig, M. & Supèr, H. 2011. What we see and where we look: bottom-up and top-down control of eye gaze. In D. P. Anderson (ed.) Eye movement: theory, interpretation, and disorders. US: Nova Science Publishers Inc., 103–118.

Roca, A., Ford, P. R., McRobert, A. P. & Williams, A. M. 2013. Perceptual-cognitive skills and their interaction as a function of task constraints in soccer. Journal of Sport & Exercise Psychology, 35, 144–155.

Ruch, T. C. 1965. Vision. In T. C. Ruch and H. D. Patton (eds.) Physiology and Biophysics. Philadelphia: Saunders.

Smythies, J. 1996. A note on the concept of the visual field in neurology, psychology, and visual neuroscience. Perception, 25 (3), 369–371. doi:10.1068/p250369.

Sors, F., Murgia, M., Santoro, I., Prpic, V., Galmonte, A., & Agostini, T. 2017. The contribution of early auditory and visual information to the discrimination of shot power in ball sports. Psychology of Sport and Exercise, 31, 44–51.

Timmis M. A., Turner K., & van Paridon K. N. 2014. Visual search strategies of soccer players executing a power vs. placement penalty kick. PLoS ONE 9 (12), e115179. doi:10.1371/journal.pone.0115179.

Tobii Pro. 2017. Eye tracker data quality report: accuracy, precision and detected gaze under optimal conditions – controlled environment, Tobii Pro Glasses 2 firmware v1.61. Tobii AB, US. Referred 25.4.2019. https://www.tobiipro.com/siteassets/tobii-pro/accuracy-and-precision-tests/tobii-pro-glasses-2-accuracy-and-precision-test-report.pdf.

Tobii Pro. 2018. Product description Tobii Pro Glasses 2, version 1.95. Referred 24.4.2019. https://www.tobiipro.com/siteassets/tobii-pro/product-descriptions/tobii-pro-glasses-2-product-description.pdf/?v=1.95.

Tobii Pro. 2019. Tobii Pro Glasses 2 – The world's most innovative wearable eye tracking system for real-world research. Referred 24.4.2019. https://www.tobiipro.com/siteassets/tobii-pro/brochures/tobii-pro-glasses-2-brochure.pdf/?v=6.

Trevarthen, C. 1968. Two mechanisms of vision in primates. Psychologische Forschung. 31, 299–348. doi:10.1007/BF00422717.

Vaeyens, R., Lenoir, M., Williams, A. & Philippaerts, R. 2007. Mechanisms underpinning successful decision making in skilled youth soccer players: an analysis of visual search behaviors. Journal of Motor Behavior, 39, 395–408. doi:10.3200/JMBR.39.5.395-408.

Vekki, S. 2019. Näkökentän mittauslaitteen suunnittelu ja kehitys. JAMK University of Applied Sciences. Department of Technology. Bachelor's thesis.

Vera, J., Jiménez, R., Cárdenas, D., Redondo, B. & García, J. 2017. Visual function, performance, and processing of basketball players versus sedentary individuals. Journal of Sport and Health Science. doi:10.1016/j.jshs.2017.05.001.

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

Vickers, J. N. & Adolphe, R. M. 1997. Gaze behaviour during a ball tracking and aiming skill. International Journal of Sports Vision, 4, 18–27.

Vickers, J. N. 2007. Perception, cognition and decision training: the quiet eye in action. Champaign, IL: Human Kinetics.

Vickers, J. N. 2009. Advances in coupling perception and action: the quiet eye as a bidirectional link between gaze, attention, and action. In M. Raab, J. Johnson, & H. Heekeren (eds.) Progress in Brain Research, 174. US: Elsevier B.V., 279–288.

Vickers, J. N., Causer, J., Stuart, M., Little, E., Dukelow, S., Lavangie, M., Nigg, S., Arsenault, G., Morton, B., Scott, M. & Emery, C. 2017. The effect of the look-up line on the gaze and head orientation of elite ice hockey players. European Journal of Sports Science, 17 (1), 109–117. doi:10.1080/17461391.2016.1220627.

Williams, A. M. & Elliott, D. 1997. Visual search strategy in karate kumite: A function of experience and anxiety. Innovations in Sport Psychology: Linking Theory and Practice, Netanya, Israel: ISSP.

Williams, A. M. & Davids, K. 1998. Visual search strategy, selective attention, and expertise in soccer. Research Quaterly for Exercise and Sport, 69 (2), 111–128. doi:10.1080/02701367.1998.10607677. PMID: 9635326.

Williams, A. M., Davids, K. & Williams, J. G. 1999. Visual perception and action in sport. London, UK: E & FN Spon.

Williams, A. M. & Reilly, T. 2000. Talent identification and development in soccer. Journal of Sports Sciences, 18 (9), 657–667. doi:10.1080/02640410050120041.

Williams, A. M. 2000. Perceptual skill in soccer: Implications for talent identification and development. Journal of Sports Sciences, 18 (9), 737–750.

Williams, A. M. & Ward, P. 2007. Anticipation and decision making: exploring new horizons. In G. Tenenbaum & R.C. Eklund (eds.) Handbook of sport psychology. John Wiley & Sons Inc., 203–223.

Wimshurst, Z. 2012. Visual skills in elite athletes. University of Surrey. Doctoral Thesis.

Young, L. R. & Sheena, D. 1975 Survey of eye movement recording. Behavior Research Methods & Instrumentation, 7 (5), 397–429.