**ANGLIA RUSKIN UNIVERSITY**

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**AND**

**VISION AND EYE RESEARCH UNIT**

# VISUAL SEARCH STRATEGIES OF JUDO COACHES

**PAUL JAMES ROBERTSON**

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**The visual search strategies of judo coaches**


**Abstract**

Judo contests present complex situations to judo coaches observing them. The visual search strategies employed by coaches when observing contests will be used to inform coaching decisions. To date, there have been no investigations of judo coaches' search strategies; therefore, this series of exploratory experiments investigated the search strategies of elite, sub-elite, and non-judo coaches when observing elite-level judo contests. Participants observed video footage of contests, with eye movements recorded using a mobile eye tracker. Participants were instructed to provide verbal instructions at set times to improve a specified *judoka's* (judo athlete) performance. Eye movements from contest preparation phases was analysed using summary fixation data, and entropy and transition data derived from Markov chain modelling.

A preliminary investigation of approaches used for analysing summary fixation data was undertaken (chapter 5: Experiment 1). This chapter, which served to inform subsequent experimental chapters, identified minimal differences between dwell- and fixation-based approaches during contest preparation phases. Chapter 6: Experiment 2 identified that elite coaches fixated more frequently and for longer on the specified *judoka's* upper body compared to the opponent's upper body and other areas in the display. However, sub-elite and non-judo coaches demonstrated no difference in fixation frequency or duration between the *judokas'* upper bodies. Chapter 7: Experiment 3 and chapter 8: Experiment 4 respectively examined the influence of prior exposure to contest information, and previously viewing a contest. Sub-elite and elite coaches did not change their search strategies despite prior exposure to contest information, or when viewing previously observed contests. However, chapter 7: Experiment 3 identified that non-judo coaches altered their search strategy, becoming similar to elite coaches following prior exposure to contest information. It is possible that use of on-screen instructions contributed to the change in search strategy. Chapter 9: Experiment 5 investigated transitions between areas of interest (AOIs) and entropy. No between-group differences in transitions or entropy were observed.

Elite coaches' strategy of fixating more frequently and for longer on the specified *judoka's* upper body is likely the result of employing this AOI as a visual pivot, using central vision to obtain information about the *judoka,* and peripheral vision to obtain information about the opponent. Sub-elite coaches appeared to rely on central vision to obtain information about each *judoka*. Developing a similar strategy to elite coaches may benefit sub-elite coaches.



**Keywords:** Coaching, judo, visual search, expertise, Markov chain modelling, entropy

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**Abbreviations**

| | |
|---|---|
| **AOI:** | area of interest |
| **BL:** | blue lower |
| **BU:** | blue upper |
| **CARE:** | computer aided replay |
| **IJF:** | International Judo Federation |
| **INT:** | international |
| **NAT** | National |
| **NJ:** | non-judo |
| **OTH:** | Other |
| **QE:** | quiet eye |
| **REF:** | Referee |
| **SB:** | Scoreboard |
| **SP:** | Space |
| **TXT:** | screen text |
| **WL:** | white lower |
| **WU:** | white upper |

## Japanese judo terminology

***Hajime:*** begin

***Ippon:*** full score

***Judogi:*** judo suit

***Judoka:*** judo athlete

***Kumi-kata:*** grip fighting

***Matte:*** pause

***Ne-waza:*** ground combat

***Shido:*** penalty

***Tachi-waza:*** standing combat

***Tatami:*** matted area for practice or contest

***Tokui-waza:*** a *judoka's* favoured technique(s)

## Copyright declaration

# 1. Introduction

In sport coaches are required to observe their athletes during training and competition. Based upon these observations coaches can then provide feedback or make changes to training plans. Where coaches look (i.e., their visual search strategy) when observing their athletes, either in training or competition, may influence their subsequent decision-making regarding the feedback provided to their athletes (Moreno et al., 2006), and subsequent training plans. Surprisingly, currently there are a limited number of investigations of coaches' visual search strategies, so little is known about how coaches obtain visual information when coaching. Of the research that has been published only a few sports including gymnastics (Moreno et al., 2002), swimming (Moreno et al., 2006), tennis (Giblin et al., 2013; Moreno Hernandez et al., 2006), and basketball (Damas and Ferreira, 2013) have been investigated. Moreover, the absence of investigations of coaches' visual search strategies during competition means that at present there is no understanding of how coaches obtain visual information during competition.

For judo coaches, observing their *judoka* (judo athlete) during competition (i.e., judo contests) presents a complex situation. This complexity is due to the combination of physical, technical, tactical and psychological demands, the multiple periods and phases that constitute a contest (Lahart and Robertson, 2009; Miarka et al., 2012; Santos et al., 2015), and the limited opportunities to provide feedback to their *judoka* (International Judo Federation; IJF, 2014). As feedback provided by the coach has the potential to enhance performance (Halperin et al., 2016), being able to obtain relevant information from the complexity of a judo contest is important. Yet, there have been no investigations of judo coaches' visual seach strategies during competition (or training).

A judo contest can be won by scoring *ippon* (a full score). *Ippon* can be achieved by throwing an opponent directly onto their back, pinning them to the ground, or forcing them to submit using chokes, strangles or elbow joint locks (IJF, 2014). If *ippon* is achieved the contest will end. If *ippon* is not achieved a contest can be won by the accumulation of fractional scores (IJF, 2014). A contest consists of two reoccurring periods: the *hajime-matte* (begin-pause) period (or block) in which combat occurs, and the *matte* period where the contest is paused (Challis, 2010). The *hajime-matte* period can be sub-divided into two types of combat: standing combat (commonly referred to as *tachi-waza*), and ground combat (commonly referred to as *ne-waza*). In *tachi-waza judokas* (judo athletes) attempt to grip their opponent and throw them to the ground, and in *ne-waza judoka* attempt to immobilise their opponent or force them to submit. Contests (and resumption of contests) begin in *tachi-waza*. *Tachi-waza* can be sub-divided into several phases: the preparation phase, where *judokas* aim to control the space between themselves and their opponent, and attempt to establish their first grip on their opponent whilst avoiding their opponent's attempts to grip; the *kumi-kata* phase, where a *judoka* obtains a grip with one or both hands; an attack (i.e., attempt to throw); and a (possible) fall leading to *ne-waza* or a score that wins the contest (i.e., *ippon*; Calmet, Miarka and Franchini, 2010; Challis, 2010; Marcon et al., 2010; Miarka et al., 2012; Santos et al., 2015).

During a contest coaches are only permitted to provide feedback to their *judoka* during the *matte* period. *Matte* periods are typically short (~ 11 s; Franchini, Artioli and Brito, 2013; Miarka et al., 2012), and are signaled by the referee in response to events that occur during a contest, such as the allocation of penalties (i.e., *shidos*), or the cessation of *ne-waza* due to no progress towards a score being made (IJF, 2014). The short duration of *matte* periods, and the possibility that they could occur at any point during a contest, means that judo coaches must ensure that they look at relevant areas consistently throughout a contest if their feedback is to be well informed. However, due to the absence of investigations into judo coaches' visual search strategies during contests it is not known where judo coaches look, and what areas may be relevant to their contest coaching. Thus, investigating the visual search strategies of judo coaches during contests will help to develop an understanding of where coaches look and the areas relevant to their coaching. In particular, gaining an understanding of where elite coaches look has the potential to influence coach education, as their search strategy may represent the most appropriate strategy for coaches to adopt when observing judo contests. Additionally, such research will be able to inform investigations of coaches' competition visual search strategies in other combat sports, where coaches must obtain relevant visual information and use it to inform feedback to be given to the athlete during time constrained periods (e.g., rest periods between rounds in boxing; Halperin et al., 2016).

# 2. Literature review

Vision is typically the dominant sense in individuals with normal visual function (Goodman and Tremblay, 2018). The human visual system (consisting of the eyes and brain) allows individuals to obtain and perceive information (Bisley, 2011; Moreno et al., 2006; Tovee, 2008), thus facilitating individuals' interactions with their environment (Bisley, 2011; Goodman and Tremblay, 2018). Where individuals look when attempting to obtain visual information (i.e., their visual search strategy) can provide an indication of their attention, and indicate the relevance of areas in the visual scene to the individual (Kingstone et al., 2003; Spitz et al., 2016). In dynamic, fast-paced situations (e.g., sport), where the visual scene may comprise a large area containing both relevant and irrelevant information, locating and attending to relevant visual information is important (Mann et al., 2007), due to its potential influence on subsequent decision making (Raab and Helsen, 2015; Spitz et al., 2016). This chapter will identify how individuals are able to obtain visual information via the visual system, and how individuals' visual search strategies are investigated (i.e., the tracking of eye movements). Moreover, this chapter will present the literature that has investigated the visual search strategies of those involved in sport (i.e., athletes, officials, and coaches), and how aspects such as expertise and task demands influence visual search behaviour.

## 2.1 The human visual system

**2.1.1 Structure of the human visual system.** The human visual system consists of the eyes and brain, and the neural connections between these organs (Duchowski, 2007; Tovee, 2008). The basic function of the eye is to capture and focus light. Once captured, light energy is converted into neural signals that travel via the optic nerve to the visual areas of the brain where processing of visual information can occur (Duchowski, 2007; Tovee, 2008). Processing of visual information can then lead to interpretation of the information (i.e., perception), allowing individuals to make decisions, and initiate action to interact with their environment (Goodman and Tremblay, 2018; Milner and Goodale, 2008; Tovee, 2008).

The structure of the eye (Figure 2.1) facilitates the capture and focusing of light. Light enters the eye through a hole (the pupil) in the centre of a ring of smooth muscle known as the iris (Tovee, 2008). The iris controls the amount of light entering the pupil; the circular muscles contract to decrease pupil size and reduce the amount of light that can enter the eye, whilst the radial muscles contract to increase pupil size and increase the amount of light that can enter the eye (Tortora and Derrickson, 2009). Being able to control the amount of light that enters the eye allows humans to respond to changing environmental lighting conditions. For example, in dark environments the radial muscles will contract, increasing pupil size to maximize the amount of light that enters the eye; whereas in bright environments contraction of the circular muscles decreases the size of the pupil as light is plentiful (Tortora and Derrickson, 2009).

Prior to light entering the eye via the pupil it passes through the cornea (a transparent, curved, layer covering the iris). The cornea, due to its curvature, causes refraction (bending) of the light entering the eye. The cornea is the first of two structures that alter the path of light through the eye, and accounts for approximately 70 % of the eye's ability to focus (Tortora and Derrickson, 2009; Tovee, 2008).

Having passed through the cornea, light passes through the anterior chamber, which contains a watery, nourishing fluid called aqueous humour. The anterior chamber is located between the cornea and the iris (Tortora and Derrickson, 2009). Light then enters the eye via the pupil and passes through the posterior chamber (located between the iris and the lens and also containing aqueous humour; Tortora and Derrickson, 2009), before reaching the lens.

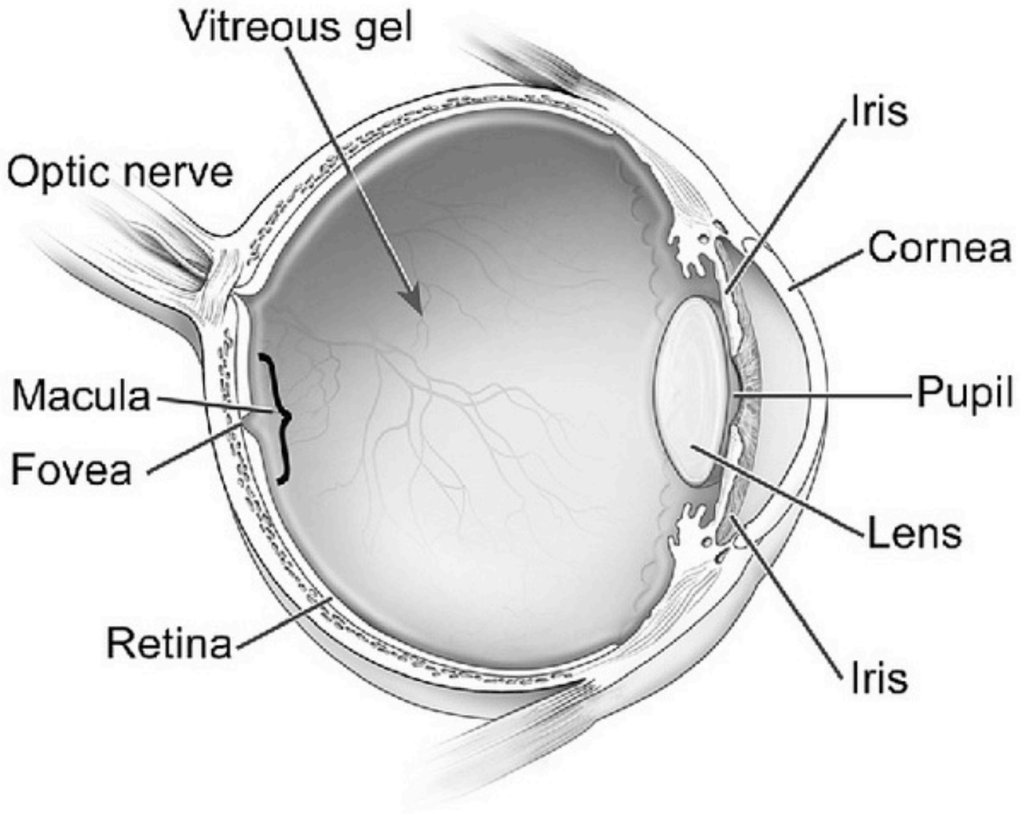


**Figure 2.1** Structure of the eye (National Eye Institute, National Institutes of Health, 2012).

The lens is the second structure that focuses light on the back of the eye, and is situated behind the iris and posterior chamber. As light passes through the lens it inverts the image that is focused on the retina. However, this is not a concern as the brain interprets the correct orientation of objects as the spatial positioning of objects is typically preserved (Tortora and Derrickson, 2009; Tovee, 2008). Furthermore, unlike the cornea, the focusing of the image by the lens is adjustable (Tovee, 2008). The shape of the lens can be manipulated by the ciliary muscles, attached to the lens via the ciliary process and zonular fibres, to focus near or distant objects on the retina. To aid focus of near objects, where light rays will be diverging as they enter the eye, the ciliary muscles contract causing the lens to become more convex. The more convex lens causes light rays to refract back towards each other to a greater extent than when the lens is less convex (a process known as accommodation; Tovee, 2008). Accommodation ensures that the image is precisely focused on the retina; without accommodation light rays from near objects would converge behind the retina causing a decrease in visual acuity (i.e., sharpness of the image; Tortora and Derrickson, 2009). A steady decline in accommodation, resulting in light rays converging behind the retina, is common with increasing age (Tovee, 2008). When viewing distant objects, light rays will be entering the eye nearer parallel to each other thus requiring less refraction to converge at the retina. Therefore, the ciliary muscles relax and result in the lens becoming less convex (alternatively more concave), thus light rays are not refracted to the same extent as a more convex lens (Tortora and Derrickson, 2009; Tovee, 2008). A more concave lens prevents the light rays converging before reaching the retina, which would result in reduced visual acuity (Tortora and Derrickson, 2009).

Having passed through the lens, light then passes through the vitreous chamber (containing a jelly-like substance known as the vitreous body) and is focused on the retina at the back of the eye. The retina contains photoreceptors that convert light energy into the neural signals that transmit information to the brain (Duchowski, 2007). Based upon their function, photoreceptors are classified as either rods or cones. Rods are the most numerous (~ 120 million) of the photoreceptors, and provide low visual acuity (i.e., low detail due to not being able to distinguish differences in the spatial distribution of light) monochrome vision (Tovee, 2008). Cones, of which there are ~ 7 million, provide high acuity colour vision, with the greatest density of cones found in an area of the retina known as the fovea (Figure 2.2; Duchowski, 2007). The area of the retina where neural information from the photoreceptors travels to the optic nerve is known as the optic disc (Tortora and Derrickson, 2009); as no photoreceptors are located at the optic disc this creates a blind spot (Tovee, 2008). If light rays reach the blind spot no image can be formed (Tortora and Derrickson, 2009).

The fovea subtends ~ 2° of visual angle (visual angle = 2arctan * (size of object/distance to the object)). As the human visual field extends to ~ 180° of visual angle horizontally, and ~ 120° of visual angle vertically, the acuity available from the fovea accounts for a small proportion of the available visual field (Duchowski, 2007; Tovee, 2008). High acuity is maintained up to ~ 5° of visual angle in an area known as the parafovea, however beyond ~ 5° of visual angle acuity decreases by ~ 50 %, with minimal useful acuity beyond ~ 30° of visual angle due to the low density of cones (Duchowski, 2007; Tovee, 2008). Away from the fovea (i.e., in peripheral regions of the retina) the density of cones decreases with increasing distance from the fovea, whilst the density of rods initially increases before gradually decreasing, although not to the same extent as cones (Tortora and Derrickson, 2009). Due to the density of cones in the fovea, visual acuity is greatest when light is focused on this area. Yet, whilst peripheral regions of the retina do not provide high visual acuity due to the lack of cones, the greater density of rods makes the periphery more sensitive to movement than the fovea (Duchowski, 2007).

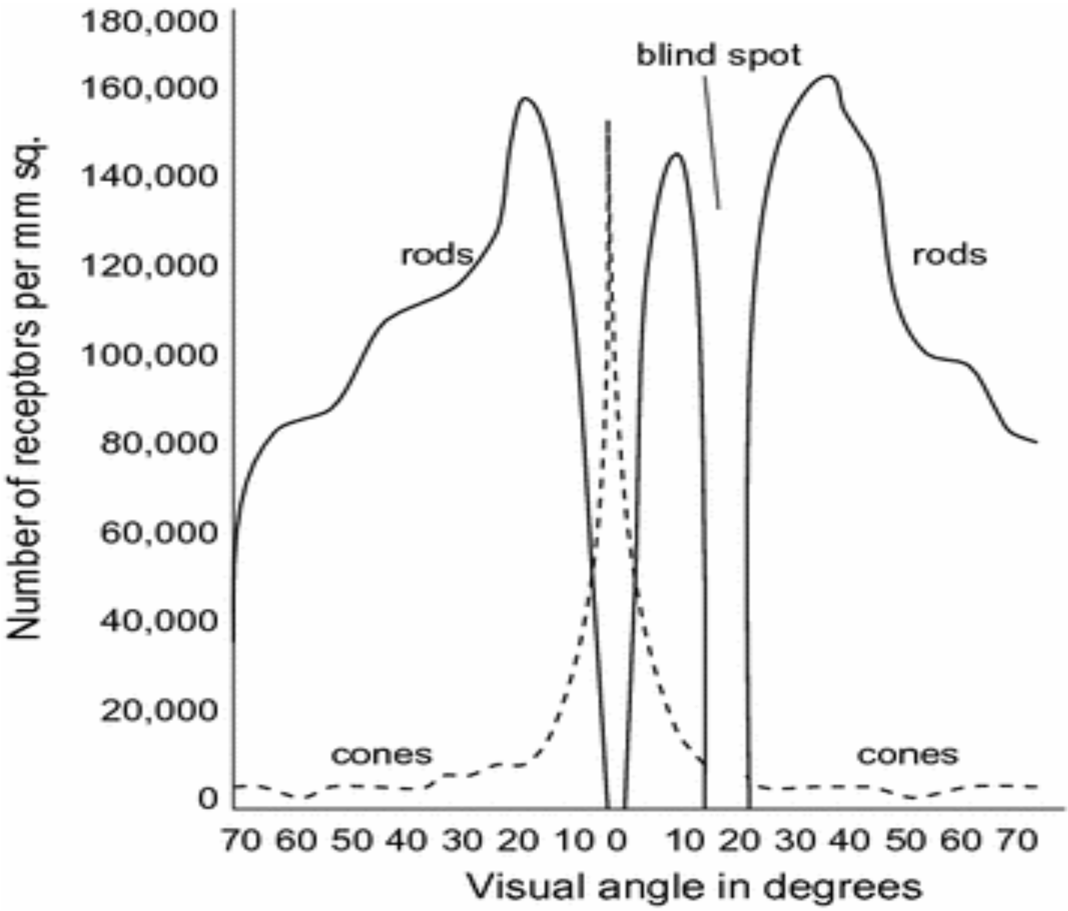


**Figure 2.2** Density of rods and cones across the retinal surface (Adapted from Pirenne, 1967, cited in Duchowski, 2007, p.32). Dashed line = cones; solid line = rods.

Such differences in acuity and sensitivity to movement across the retina can be explained by differences in the structure of rods and cones, and how neural signals from the photoreceptors travel to the brain via ganglion cells (Tovee, 2008). The photoreceptors are the outer layer of three retinal layers, and are located furthest away from light entering the eye via the pupil, meaning that light has to initially travel through the other two layers to reach the photoreceptors (Figure 2.3). Following the conversion of light energy into neural signals, the neural signals travel via the bipolar layer of the retina (i.e., the middle layer) to the ganglion cells (i.e., inner layer; Tortora and Derrickson, 2009). At the fovea (where visual acuity is greatest), ganglion cells converge (via bipolar and horizontal cells in the bipolar layer) with fewer cones than in the periphery (Tovee, 2008). This convergence of ganglion cells with fewer cones decreases the receptive field, thus improving spatial resolution of incoming light (i.e., visual acuity). In the periphery of the retina (where rods predominate) ganglion cells converge with a large number of rods, thus increasing the receptive field and decreasing visual acuity (Tovee, 2008). The increase in the receptive field increases the sensitivity of the periphery to incoming light due to multiple photoreceptors being available to detect light and stimulate the ganglion cell (Tovee, 2008).

Sensitivity of rods is further increased due to their larger diameter and greater length (Tovee, 2008). Respectively, these structural aspects increase the probability of a photon (a discrete package of light energy) passing through a rod, and the photon being absorbed (Tovee, 2008). Furthermore, the greater persistency of response (i.e., the ability of a photoreceptor to remain stimulated, even if the stimulation is not sufficient enough to stimulate the bipolar cell that links to the ganglion cell) of rods compared to cones can aid in increased sensitivity. If a photoreceptor can remain stimulated for longer, despite not stimulating the bipolar cell, the possibility of absorbing a second photon whilst stimulated is increased, and this second photon can contribute to augmenting the initial stimuli to an extent that ultimately stimulates the ganglion cells (Tovee, 2008).

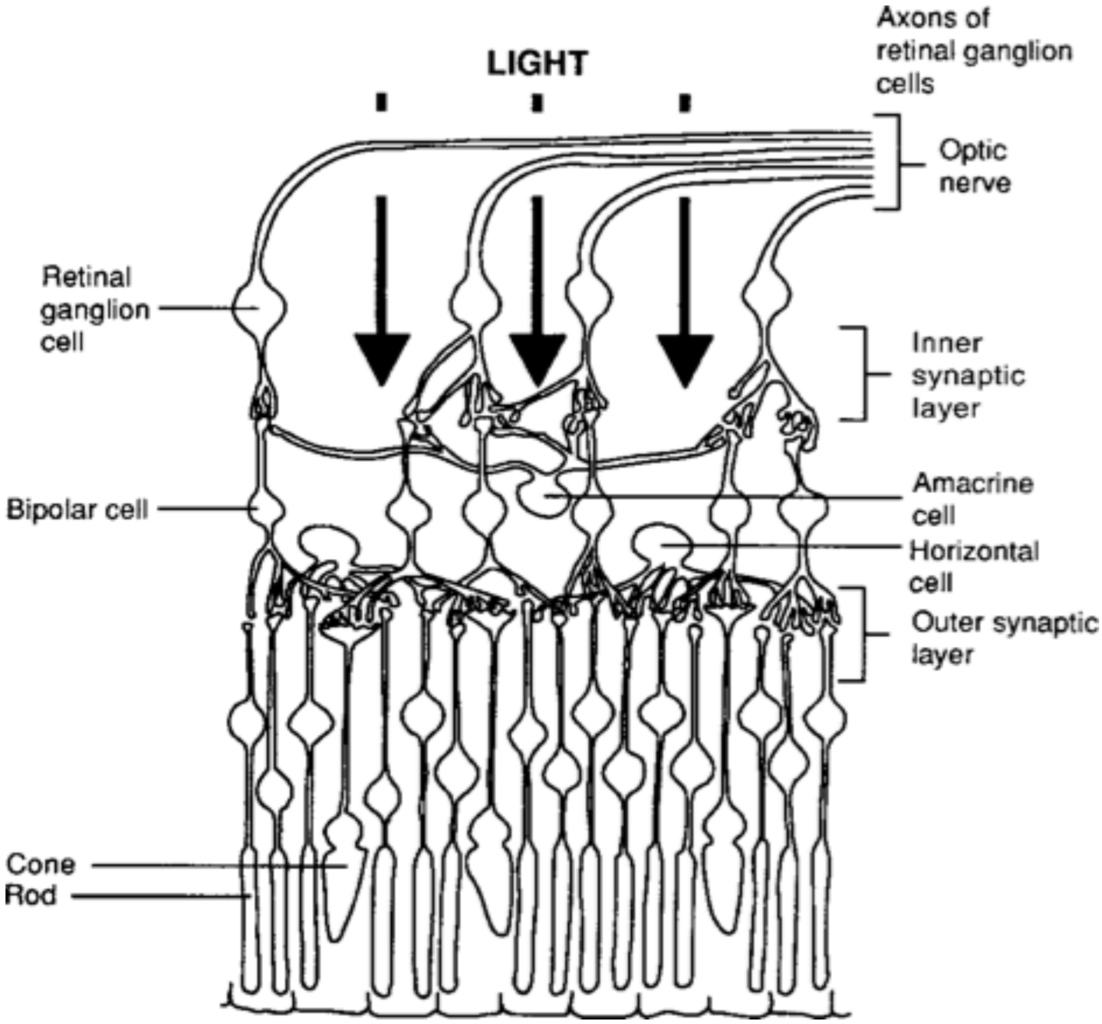


**Figure 2.3** The neural structure of the retina (Tovee, 2008, p.22).

The ganglion cells can be divided into α cells and β cells (alternatively M- and P-cells respectively; Tovee, 2008), with the larger α cells accounting for ~ 10 % of retinal ganglion cells, and the smaller β cells accounting for ~ 80 % of retinal ganglion cells (Duchowski, 2007). The remaining ~ 10 % comprises several other ganglion cell types (Tovee, 2008). The axons of all ganglion cells merge to form the optic nerve, which passes out of each eye via its optic disc (Tovee, 2008). The optic nerves from each join before primarily projecting to the lateral geniculate nucleus (LGN; Tortora and Derrickson, 2009), with the α cells projecting to the magnocellular layer of the LGN, and the β cells to the parvocellular layer of the LGN (Duchowski, 2007). Cells projecting to the parvocellular and magnocellular layer can respond to sustained stimuli, object location, and fine detail, whilst the magnocellular layer can also respond to transient stimuli, coarse features, and motion (Duchowski, 2007). In addition to projections to the LGN, some ganglion cells project to the superior colliculus, transmitting details regarding size, position, and movement of objects (Figure 2.4; Duchowski, 2007; Tovee, 2008).

From the LGN, neurons predominantly project to the primary visual cortex (or V1) where a range of stimuli can be detected (Duchowksi, 2007), and early processing of visual information can begin (e.g., processing edges and boundaries of objects; Tovee, 2008). From V1, neurons continue to visual area 2 (V2), where detection and processing of stimuli begin to increase in complexity (e.g., detection of colour and movement; Duchowski, 2007). In V2, three visual maps contain neurons that respond to orientation, colour, and retinal disparity (i.e., the difference in the relative position of an object in the visual field of each eye; Tovee, 2008). After V2, two separate streams emerge to allow further processing of visual information. The parvocellular pathway projects to visual area 4 (V4), and onwards to the inferotemporal cortex and the cortex of the inferior convexity to form the ventral stream (Figure 2.4). The magnocellular pathway projects to visual area 5 (V5 or middle temporal area; MT) and the middle superior temporal (MST), and onwards to the posterior parietal complex and dorsolateral prefrontal region to form the dorsal stream (Duchowski, 2007; Tovee, 2008).

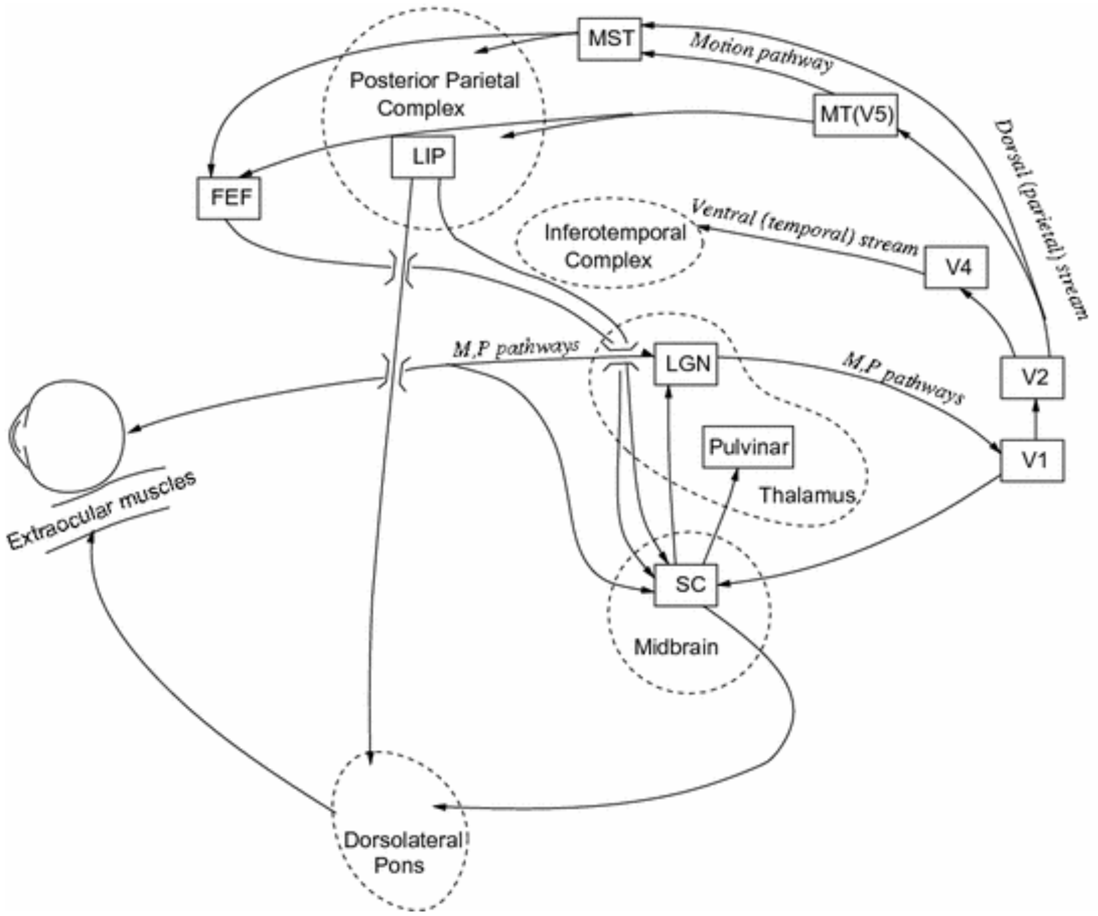


**Figure 2.4** Visual pathways of the brain relevant to eye movements and attention (Duchowski, 2007, p.17). FEF = frontal eye field; LGN = lateral geniculate nucleus; LIP = lateral intraparietal; MST = middle superior temporal; MT = middle temporal; SC = superior colliculus.

Functionally, the ventral and dorsal streams have been identified as the “what” and “where” attentional systems respectively (Duchowski, 2007; Tovee, 2008). The “what’ system (i.e., the ventral stream) is associated with cognitive processing (e.g., object identification), and the “where” system (i.e., the dorsal stream) is associated with sensorimotor processing (e.g., spatial positioning and motion of objects; Duchowski, 2007; Tovee, 2008). Additionally, the ventral stream has been denoted as providing vision for perception, and the dorsal stream as providing vision for action (de Wit, Masters and van der Kamp, 2012). Vision for perception is concerned with the perception of objects, and planning of future interactions with these objects, whereas vision for action is concerned with the provision of visuospatial information to the motor system to enable interactions with objects (de Wit, Masters and van der Kamp, 2012; Tovee, 2008).

**2.1.2 Eye movements.** Humans use eye movements, sometimes in combination with movement of the head and body, to locate an area of interest (AOI) in a visual scene (Geri, Martin and Wetzel, 2002; Solman, Foulsham and Kingstone, 2017), and to stabilise (or centrally fixate) the fovea on the desired AOI (Duchowski, 2007). Eye movements are achieved via the six extrinsic eye muscles: the medial and lateral recti (adduction and abduction respectively), the superior (elevation and adduction) and inferior recti (depression and abduction), and the superior (depression, abduction, and medial rotation) and inferior obliques (elevation, abduction, and lateral rotation; Duchowski, 2007; Tortora and Derrickson, 2009). These muscles receive signals from the brain (i.e., occipital cortex, superior colliculus, frontal eye field, supplementary eye field; Duchokwski, 2007; Hutton, 2008), and the semicircular canals (part of the vestibular apparatus located in the ear; Duchowski, 2007; Tortora and Derrickson, 2009). These signals can result in both voluntary and reflexive eye movements (Duchowski, 2007).

Moving the eyes to stabilise the fovea on an AOI provides an indication of how an individual is allocating their attention (i.e., attention is being allocated to the AOI), with movement of the eyes to stabilise another AOI on the fovea signifying a shift in attention (Carrasco, 2011). Such stabilisations of the fovea on AOIs provides an indication of overt attention; however, it is possible that an individual, whilst continually stabilising an AOI on their fovea (and therefore not moving their eyes), can covertly attend to other areas in the visual scene using peripheral vision (i.e., covert attention; Carrasco, 2011; Motter and Holsapple, 2007). It is possible that covert attention may be used to help search visual scenes, and plan subsequent overt shifts of attention (i.e., movement of the eyes to stabilise another AOI on the fovea; Carrasco, 2011; Motter and Holsapple, 2007).

Stabilising the fovea on an AOI is known as a dwell (van de Merwe, van Dijk and Zon, 2012). Alternatively, stabilising the fovea on an AOI may be termed a fixation if the stabilisation equals or exceeds a pre-determined duration (e.g., ≥ 120 ms; Williams et al., 1994), if eye movement velocity remains below a pre-determined threshold (e.g., < 30° per second; Beck, Lohrenz and Trafton, 2010), or if the magnitude of eye movements is minimal (e.g., < 1° of visual arc; e.g., van de Merwe, van Dijk and Zon, 2012). Once the fovea is stabilised on an AOI, the eye does not remain completely still. If the eye were to remain completely still, the visual system would become desensitised to the neural signals resulting from the AOI image, and the image would fade (Tovee, 2008). Therefore, small movements (1 – 2 minutes of arc), known as micro-saccades, occur to move the image on the fovea, ensuring that new neural signals continue to be sent and the image does not fade (Duchowski, 2007; Tovee, 2008).

Moving the eye to rapidly relocate the fovea from one AOI in the visual scene to another is known as a saccade (Tovee, 2008). Due to the rapidity (up to 800°/sec; Engelken, Stevens and Bell, 1994) and short duration (10 ms – 100 ms) of saccades visual information cannot be obtained and processed (i.e., saccadic suppression; Duchowski, 2007) whilst a saccade is occurring. However, whilst information cannot be obtained and processed during saccades, it is possible for the eye to stabilise a moving object on the fovea, and for the eye to match the object's velocity (up to ~ 100°/sec; Engelken, Stevens and Bell, 1994; Croft, Button and Dicks, 2010), thus tracking the object as it moves. Stabilising and tracking a moving object is known as smooth pursuit (Duchowski, 2007), and allows detailed information about an object to be obtained and processed as it moves. As object velocity increases (i.e., > 30°/sec), "catch-up" saccades may be used to compensate for the inability to track faster moving objects using smooth pursuit (Engelken, Stevens and Bell, 1994; Spering and Gegenfurtner, 2008). Furthermore, if a fast-moving object is to be intercepted or avoided, saccades may be made in advance of the object to an anticipated location of its trajectory (Croft, Button and Dicks, 2010). This combination of smooth pursuit and anticipatory saccades is termed optokinetic nystagmus (Duchowski, 2007).

As previously identified, movement of the eyes can be combined with movements of the head and body to locate objects of interest (Geri, Martin and Wetzel, 2002; Solman, Foulsham and Kingstone, 2017). Use of the head and body may occur when possible objects of interest are located at greater eccentricities (i.e., angular distances from the fovea). Saccades are typically < 20° in amplitude, with a maximum amplitude of 60° (Geri, Martin and Wetzel, 2002); therefore, if an AOI in located at an eccentricity of > 60°, head and body movements are utilised to move the eyes to the location where the AOI is located (Geri, Martin and Wetzel, 2002). As suggested by Solman, Foulsham and Kingstone (2017), saccades are seemingly used to search the current visual field (between 0° - 60° of eccentricity), with head and body movements used to move the eyes to an alternative visual field, where saccades are then used to search the novel visual field. Therefore, if the visual scene to be searched exceeds 60° of eccentricity, head and body movements may be used in conjunction with isolated eye movements.

Whilst the head and body can be used in conjunction with the eyes to locate AOIs for stabilisation on the fovea, movements of the head and body (e.g., up and down motions caused by locomotion, moving away from an AOI) can cause the AOI image to move from the fovea resulting in a loss of acuity (Liao et al., 2011). To account for this movement of the AOI image, reflexive eye movements occur due to the vestibulo-occular reflex. The vestibulo-occular reflex will cause eye movements that compensate for head and body movements (i.e., the eyes will move in the opposite direction of the head; Batuecas-Caletrio et al., 2013), thus enabling the AOI image to remain stabilised on the fovea. The movement of the eyes as a consequence of the vestibulo-occular reflex is termed vestibular nystagmus (Duchowksi, 2007).

The use of eye movements to search a visual scene for AOIs to be stabilised on the fovea is driven by a combination of bottom-up, stimulus-driven signals, and top-down, goal-directed signals (Lamy and Zoaris, 2009; Tovee, 2008). Bottom-up, stimulus-driven signals are a result of salient features in the visual scene such as movement, colour, size, and contrast (MacInnes et al., 2014; Wolfe and Horrowitz, 2004). In contrast, top-down, goal-directed signals are related to the task being carried out (Tovee, 2008), and are a consequence of the task requirements, and the individual's experience and memory of previously performing the task (Geyer, Muller and Krummenacher, 2008; MacInnes et al., 2014; Vine, Moore and Wilson, 2011). The dorsal component of the fronto-pareital network likely drives top-down, goal-directed visual search, whilst the ventral component of the fronto-parietal network responds to salient stimuli (Corbetta and Shulman, 2002; Madden et al., 2017). Furthermore, in visual search, top-down, goal-directed signals can suppress bottom-up, stimulus-driven signals (Geyer, Muller and Krummenacher, 2008; MacInnes et al., 2014; Vine, Moore and Wilson, 2011). Responses of cells in the inferior temporal cortex (a brain area involved in the later stages of visual processing and object recognition) to the salient stimuli may be suppressed, thus resulting in the receptive field shrinking around the AOI (Tovee, 2008). Consequently, there is less opportunity for signals resulting from the salient stimuli to excite the cells in the inferior temporal cortex.

**2.1.3 Measuring eye movements.** Eye-tracking equipment (i.e., eye trackers) provides a method of measuring eye movements (Hutton, 2008), and is used in a variety of disciplines (e.g., sport, medicine, aviation; Gegenfurtner, Lehiten and Saljo, 2011). The sensory dominance of vision, and links between vision, attention, and decision-making, mean that eye trackers provide a valuable indication of individuals' attention (as indicated by stabilsations of the fovea on AOIs) during visual search (Hutton, 2008; Spitz et al., 2016; van de Merwe, van Dijk and Zon, 2012). Furthermore, eye trackers can be used to identify the eye movements individuals use to search a visual scene (e.g., saccades, smooth pursuit), the sequencing of eye movements and stabilisations, and the extensiveness of individuals' search strategies (i.e., the frequency of saccades and stabilisations, and the number of AOIs stabilised on the fovea; Mann et al., 2009). However, it must be noted that whilst the use of eye trackers to identify eye movements in this manner provides an indication of overt attention, it does not provide an indication of covert attention. To investigate covert attention study designs typically involve participants maintaining a stabilisation of the fovea on a central point in the visual scene (i.e., to minimise eye movements), whilst attempting to identify when objects are presented in the periphery of their vision (Kulke, Atkinson and Braddick, 2016).

As eye movements are not restricted for those involved in sport (i.e., athletes, officials, coaches), covert attention study designs are not typically used to investigate visual search strategies during sporting situations. Consequently, investigations use eye tracking equipment to measure unrestricted eye movements, and infer overt attention from the data obtained. Despite covert attention not being measured, visually searching for, and overtly attending to, relevant information is an important early stage in decision-making for those involved in sport (Plessner and Haar, 2006; Raab and Helsen, 2015), and being able to measure the eye movements of athletes, officials, and coaches provides a valuable insight into their visual search behaviour. The emergence of mobile eye trackers (e.g., ASL Mobile Eye-XG; SMI Eye Tracking Glasses) has made investigating eye movements in the fast-paced, dynamic environment of sport increasingly feasible, whereas prior to the emergence of such equipment, investigations of visual search strategies in sport were typically restricted to the laboratory (Kredel et al., 2017). The following sections will review the literature that has investigated the visual search strategies (i.e., where they look) of athletes, sport officials, and sport coaches.

## 2.2 Visual search strategies in sport

**2.2.1 The visual search strategies of athletes.** For athletes, sport presents an expansive, fast-paced, and dynamic visual environment. Identifying and selecting relevant information at the appropriate time in such an environment is important for successful athletic performance (Mann et al., 2007). As such, due to eye movements providing an indication of where attention is allocated (Hutton, 2008; Spitz et al., 2016), athletes' eye movements have been investigated for over 40 years (Kredel et al., 2017). Furthermore, due to the possible relationship between the identification and selection of appropriate visual information and the execution of perceptual-cognitive skills (e.g., anticipation, decision-making, pattern recognition; Mann et al., 2007; Vilar et al., 2013; Williams, Davids and Williams, 1999), the measurement of athletes' eye movements have been used as a process tracing measure (i.e., adjunct measure to investigate mechanisms underpinning superior perceptual-cognitive ability; Hancock and Ste-Marie, 2013; Mann et al., 2007).

Investigations into athletes' eye movements, whether for solely investigating attention allocation or as a process tracing measure for perceptual-cognitive skills, typically use the expert-novice paradigm. This paradigm investigates eye movements as a function of the athletes' level of expertise, in an attempt to establish if expertise-based differences exist. Expertise has typically been established based upon level of involvement in the sport being investigated (e.g., non-player, recreational, sub-elite, and elite level involvement; e.g., Vaeyens et al., 2007a). However, when eye movements have been used as a process tracing measure, athletes have also been stratified based on the level of performance they demonstrate in the specific task (e.g., decision-making; e.g., Vaeyens et al., 2007b). Stratifying athletes based on performance in the task under investigation controls for athletes' competency in the different components of performance that can contribute to reaching higher levels (e.g., elite) of involvement in sport (Vaeyens et al., 2007b; Williams and Ericsson, 2005). For example, an athlete who competes at the elite level may have reached that level due to high levels of competency in components such as strength and speed, and competency in these components may have compensated for lower competency in perceptual-cognitive skills (Williams and Ericsson, 2005).

Using the expert-novice paradigm, the visual search strategies of athletes across the continuum of open and closed skills have been investigated. Investigations into the search strategies of athletes undertaking closed skills (i.e., self-paced skills in a stable environment where the objects to be interacted with do not alter) have identified a search strategy that appears to be characteristic of expert performers and successful performance outcomes (Martell and Vickers, 2004). In closed skill aiming tasks such as the basketball free throw (Vickers, 1996), rifle shooting (Janelle et al., 2000), golf putting (Vine et al., 2013; Walter-Symons, Wilson and Vine, 2017), and billiards (Williams, Singer and Frehlich, 2002), expert performers have demonstrated earlier and longer final fixations on the target prior to movement initiation compared to non-experts. This final fixation duration has been termed the "quiet eye" (QE) period (Vickers, 1996), with longer QE periods associated with improved performance outcomes (Lebeau et al., 2017; Timmis, Piras and van Paridon, 2018).

It has been suggested that longer QE periods provide greater time for preprogramming of movement, therefore accounting for improved performance

(Gonzalez et al., 2017; Vine et al., 2013). Findings from Williams, Singer and Frehlich (2002), where increased billiard task complexity, and thus greater processing demands, was associated with increased QE duration on successful attempts, provide some support for the need for the pre-programming hypothesis (Gonzalez et al., 2017). However, whilst Vine et al. (2013), found that reduced QE duration (< 2 s; a proposed minimum duration for successful performance in a golf putting task) was associated with decreased performance, they suggested that maintenance of QE on the target during movement execution, and not just prior to movement initiation, might also be important for successful performance by contributing to online control of movement. The decrease in QE during the execution of unsuccessful performances, and the consistency of QE duration prior to movement initiation during both successful and unsuccessful performances observed by Vine et al. (2013), supports their hypothesis that maintenance of the QE during movement execution is important for successful aiming performance. Further to the role of QE in golf putting performance, Dalton (2013) identified ocular dominance (the dominance of one eye over the other) as a component of vision that is important for golf putting performance due to its influence on fixation control during skill execution (i.e., facilitating longer QE durations). However, it does not appear that eye-hand dominance (e.g., uncrossed dominance: right eye dominance and right handedness; crossed dominance: right eye dominance and left handedness) is related to differences in golf putting skill (Dalton, Guillon and Naroo, 2015).

Longer QE periods have also been associated with improved performance outcomes in interceptive tasks (e.g., ice hockey goal-tending; Panchuk and Vickers, 2006; soccer goal-keeping; Piras and Vickers, 2011). Interceptive tasks are externally paced (i.e., dictated by the environment), and require athletes to intercept objects that are often fast moving, and with unpredictable flight paths (Martell and Vickers, 2014; Land and McLeod, 2000). Interceptive tasks are therefore more open (with regard to skill classification) compared to self-paced aiming tasks (Ives, 2014; Martell and Vickers, 2004).

The use of longer QE periods in interceptive tasks appear to utilise a final fixation on an area in the visual scene that provides information that allows athletes to predict the direction of the object to be intercepted (Panchuk and Vickers, 2006). For the ice-hockey goal-tenders in Panchuk and Vickers (2006) the final fixation was on the contact area between the puck and stick, whereas for the soccer goal-keepers in Piras and Vickers (2011) it was the area located between the ball and the kicking leg. Whilst the soccer goalkeepers did not fixate a specific location (i.e., either ball or player), by fixating between two areas it appeared that the athletes used peripheral vision to obtain information about both the ball and the kicking leg; this is likely due to both areas providing information that allows prediction of the ball's direction and flight (Piras and Vickers, 2011).

Once the object to be intercepted has been struck or released, athletes may use anticipatory saccades if the object to be intercepted is moving too fast for them to rely wholly on smooth pursuit to track the object (e.g., cricket and baseball batting; Bahill and Laritz, 1970; Croft, Button and Dicks, 2010; Land and McLeod, 2000; Mann, Spratford and Abernethy, 2013). For example, when facing a cricket bowler, batters appear to initially fixate the release of the ball and track its early movement (Croft, Button and Dicks, 2010; Land and McLeod, 2000). In elite batters, tracking of the ball is facilitated by coupling movement of the head with movement of the ball (Bahill and Laritz, 1970; Mann, Spratford and Abernethy, 2013). Following initial tracking of the ball, batters make an anticipatory saccade to the point where the ball will bounce, thus changing its velocity and trajectory (Croft, Button and Dicks, 2010; Land and McLeod, 2000). Additionally, elite batters may also use a second anticipatory saccade to the point of bat-ball contact (Mann, Spratford and Abernethy, 2013). Similar gaze behaviours (i.e., intial tracking and anticipatory saccades) have also been reported in activities where the object to be intercepted is moving slower than in baseball and cricket (e.g., table tennis; Rodrigues, Vickers and Williams, 2002). As suggested by McPherson and Vickers (2004), it appears that successful execution of interceptive tasks may require a combination of several gaze behaviours (e.g., obtaining early visual information, QE, fixating a location between several AOIs, object tracking, anticipatory saccades).

As with interceptive tasks (e.g., soccer goalkeeping; Piras and Vickers, 2011), fixating on an AOI and using peripheral vision to obtain information from other AOIs has been observed in other open-skill sports. In combat sports, the predominant fixation of a centrally located AOI (i.e., opponent's trunk), with few saccades to AOIs located in the periphery of the visual scene (e.g., limbs), has been observed in expert *karateka* (karate athletes; Williams and Elliot, 1999), fencers (Hagemann et al., 2010), and *judoka* (judo athletes; Piras et al., 2014). The central AOI that is fixated has been termed the visual anchor, and from this location it is possible that peripheral vision and covert shifts of attention are used to obtain information from AOIs in the periphery of the visual scene (Piras et al., 2014; Piras and Vickers, 2011).

The use of a visual anchor has also been observed in team-sports, with elite players predominantly fixating the ball and player in possession of the ball in 2 versus 1 attacking scenarios in soccer (Vaeyens et al., 2007a). Moreover, Vaeyens et al. (2007a), linked the elite soccer players use of a visual anchor to the efficiency of their visual search strategies. Efficient search strategies use fewer fixations of longer durations, hence requiring a reduced number of saccades between AOIs (Maan et al., 2007). The reduced number of saccades results in a reduction in saccadic suppression (i.e., time when visual information cannot be processed; Duchokwski, 2007). By fixating on a central area in the visual scene (i.e., the visual anchor) the need for saccades is reduced, as peripheral vision and covert shifts in attention can be used to obtain information from AOIs in the periphery of the visual scene (Motter and Holsapple, 2007; Williams and Davids, 1998).

Further to the reduced number of saccades, efficient search strategies selectively direct fixations to task-relevant information in the visual scene to reduce the amount of information (i.e., from task irrelevant information) that needs to be processed (Piras et al., 2014). The ability to select and direct the eyes to task-relevant information is likely a consequence of top-down, goal-directed visual search associated with experts' knowledge and experience of where relevant information will likely be located in the visual scene (Vine, Moore and Wilson, 2011). Moreover, it is potentially the top-down, goal-directed signals that suppress the drive to saccade to, and fixate irrelevant, salient stimuli (Geyer, Muller and Krummenacher, 2008).

Expert athletes use of an efficient search strategy that incorporates a visual anchor may be explained by an ability to use peripheral vision to obtain relational information (i.e., the position of limbs, objects or players relative to one another), and for this information to inform cognitive processes such as decision-making (North et al., 2009; Piras et al., 2011). In contrast, athletes with less expertise do not appear to be able to use relational information to the same extent, instead relying upon fixations (i.e., central vision) on surface features (e.g., distinct features of a player) to inform cognitive processes (North et al., 2009).

Whilst efficient search strategies using a visual anchor seem to be characteristic of expert athletes' visual search strategies, such a search strategy is likely task-specific (Mann et al., 2007). In situations involving multiple athletes (e.g., 11 versus 11; Williams et al., 1994), the use of more extensive search strategies (i.e., more fixations of shorter duration on a greater number of locations) by expert athletes has been observed (e.g., Afonso et al., 2012; Roca et al., 2013; Williams et al., 1994; Williams and Davids, 1998; Vaeyens et al., 2007a) in investigations with varying degrees of representativeness (e.g., large screen video footage with limited motor response; Williams and Davids, 1998; live situation with interceptive responses; Afonso et al., 2012). Furthermore, Vaeyens et al. (2007a) observed that as the number of athletes in soccer attacking scenarios increased (i.e., from 3 attackers versus 1 defender, to 3 attackers versus 2 defenders, and to 4 attackers versus 3 defenders), there was trend for search strategies becoming increasingly extensive. Whilst seemingly less efficient, such use of extensive search strategies by expert sport performers in multiple athlete situations may be a consequence of more potentially informative areas in the visual scene located at greater eccentricities from the fovea, and a greater number of potential responses compared to situations with fewer athletes (Vaeyens et al., 2007a).

Further to the more extensive search strategies used in multiple athlete situations, expert soccer players in Williams et al. (1994) alternated their fixations between the penalty box area of the pitch (where the player in possession of the ball was located) and other areas of the visual scene during their extensive search. The frequent re-fixations on the penalty box suggest that it is an informative, centrally located (in the visual scene) AOI (Williams et al., 1994). Moreover, whilst the frequent re-fixations on an informative, centrally located AOI could be considered a visual anchor, the extensive search of the visual scene suggests that the penalty box was acting as more of a visual pivot than a visual anchor (Piras et al., 2014). Unlike in 1 versus 1 situations, where fixating a centrally located AOI allows the majority of other relevant AOIs to be detected using peripheral vision, in multiple athlete situations the increased number of relevant AOIs and their eccentricity does not allow this, hence the use of an informative, centrally located AOI (i.e., the visual pivot) from which to explore the scene. However, whilst an extensive search strategy may use a visual pivot, it may also use gaze behaviours akin to a visual anchor. The highly skilled volleyball players in Afonso et al. (2012) used an extensive search strategy, and as part of this strategy fixated functional spaces (i.e., the space between two players) for longer than skilled players during live 6 versus 6 situations. Fixating between two players would have allowed information to be gathered from both players using peripheral vision (Afonso et al., 2012), in a manner similar to a visual anchor. Thus, it appears that in multiple athlete situations several gaze behaviours may comprise an athlete's search strategy.

Whilst efficient search strategies appear to be used in situations where athlete numbers are low (e.g., 1 versus 1), and more extensive search strategies appear to be used when athlete numbers increase, exceptions have been observed (e.g., Roca et al., 2013; Williams and Davids, 1998; Vaeyens et al., 2007a). Roca et al. (2013) found that in 11 versus 11 defensive soccer situations the extensiveness of skilled players' search strategies decreased when the ball was in their own team's half (near condition; where the player was located) compared to when the ball was in the opposition team's half (far condition; player located in own half) despite the number of players remaining constant. In the near condition the skilled players predominantly fixated the player in possession of the ball, whereas in the far condition, less time was spent fixating the player in possession, whilst the time spent fixating other AOIs (e.g., space). Roca et al. (2013) suggested that the decrease in extensiveness observed in the near condition was due to the possibility of an imminent defensive interaction with the ball and opponents. Yet, in 1 versus 1 soccer situations where interaction is imminent, Williams and Davids (1998) observed that experienced performers used a more extensive search strategy than those with less experience.

The more extensive search strategy used by experts in the 1 versus 1 soccer scenarios in Williams and Davids (1998) are in contrast with the efficient search strategies of experts (i.e., fewer fixations of greater duration) in other 1 versus 1 situations (e.g., combat sports; Piras et al., 2014; Williams and Elliot, 1999). The more extensive search strategies observed in Williams and Davids (1998) suggest that a visual anchor was not used, and that foveal vision was needed to gather information from several AOIs (i.e., opponent's hip, lower leg, and foot position in relation to the ball) to predict the opponent's direction. However, as the life-size video footage of the approaching opponent in Williams and Davids (1998) was projected onto a screen 5 m away from participants, it may have facilitated time for a more extensive search strategy (Roca et al., 2013). In contrast, the greater proximity of the opponent in Piras et al. (2014; live opponent immediately in front of participant) and Williams and Elliot (1999; life-size video projected on a screen 1.5 m away from participant), and the threat of an imminent interaction (grip; Piras et al., 2014; or strike; Williams and Elliot, 1999) with the opponent, may have placed greater temporal constraints on the participants' search strategies (Roca et al., 2013).

In such temporally constrained situations, fixating a centrally located AOI that allows information to be obtained from multiple areas (e.g., left and right hands) using peripheral vision is advantageous. For example, if combat sport athletes saccade away from a centrally located AOI (e.g., lapel, trunk) to fixate an opponent's right hand, they may miss information regarding an imminent left-handed attack during the period the eyes re-orientate towards the right hand (i.e., saccadic suppression). Thus, fixating a centrally located AOI potentially allows information from the periphery to be obtained, whilst reducing instances of saccadic suppression during which opponent's movements may not be seen. Moreover, by fixating a centrally located AOI, athletes are potentially fixating the most informative AOI regarding their opponent's intentions, and avoiding fixating irrelevant AOIs (e.g., opponent's lower limbs) that the opponent may move in an attempt to disguise their intentions and deceive their opponent (e.g., Brault et al., 2010; 2012). Indeed, whilst a *judoka's* stance can indicate their handedness (e.g., left foot and left hand forward indicates left handedness), and therefore their potential attacks, more experienced *judokas* adopt varied stances not necessarily related to their handedness (Collins and Challis, 2013). Such use of varied stances suggests an attempt to disguise attacking intentions; however, by fixating on the lapel (i.e., a centrally located AOI; Piras et al., 2014) expert *judokas* avoid fixating on irrelevant AOIs that potentially provide incorrect information about their opponents attacking intentions.

In addition to the potential effect of imminent interaction with an opponent on athletes' search strategies, Vaeyens et al. (2007a) found that despite an increase in the number of athletes from 3 attackers (including the participant) versus 2 defenders, to 5 attackers versus 3 defenders, search strategies became less extensive. Vaeyens et al. (2007a) suggested that the 3 versus 2 situation presented a more complex situation to participants compared to the 5 versus 3 scenario, due to a decreased ratio of attackers to defenders. Moreover, a more complex situation, despite fewer players, would provide more information to process (Vaeyens et al., 2007a), and therefore appears to have necessitated a more extensive search strategy. However, Vaeyens et al. (2007a) suggested that whilst more locations were fixated in complex scenarios, expert performers still appeared to predominantly fixate on the player in possession of the ball, and that this AOI could be considered a visual pivot. From this AOI players may have used peripheral vision to monitor movements of other players and inform subsequent saccades to, and fixations on, these players if more information is required (Vaeyens et al., 2007b).

Whilst task constraints such as the number of athletes in the visual scene, and temporal constraints (e.g., how imminent interaction with an opponent is) appear to influence athletes' visual search strategies, the perceptual-cognitive skill (e.g., anticipation, recognition) to be executed can also influence athletes' search strategies. For example, North et al., (2009) found that soccer players performing an anticipation task made more fixations, fixated more AOIs, demonstrated shorter fixation durations, and reduced relative viewing time of AOI categories (e.g., attacking team) compared to when performing a recognition task (i.e., reporting if a scene had previously been viewed). North and colleagues (2009) suggest that their results potentially indicate different underlying processes for recognition and anticipation, and that recognition of an evolving situation may not necessarily underpin anticipation. Consequently, the nature of the perceptual-cognitive skill to be executed may influence athletes' visual search strategies, thus providing a further indication of the task-specific nature of athletes' search strategies.

***2.2.1.1 Alternative approaches for analysing athletes' visual search strategies.*** Whilst investigations using summary fixation data have shown expertise-based differences and task-specificity in athletes' visual search strategies, it has been suggested that summary fixation data does not account for all aspects of athletes' search strategies, and that other approaches are required (Button et al., 2011; Manzanares et al., 2015). For example, whilst summary fixation data can indicate the efficiency or extensiveness of athletes' search strategies, it does not provide information regarding the sequencing of athletes' fixations on AOIs, or the probability of fixating on AOIs, during the execution of a task. Consequently, investigations have begun to give greater consideration to alternative approaches for analysing athletes' search strategies, such as the temporal sequencing, and entropy (predictability, or alternatively randomness of fixations) of athletes' search strategies (Dicks et al., 2017; Manzanares et al., 2015; Ryu et al., 2016).

Markov chain modelling, where the probability of fixating an AOI depends upon the previous fixation location (Allsop and Gray, 2014; Button et al., 2011; see chapter 9: Experiment 5 for further details), has been used to investigate the temporal sequencing (e.g., Button et al., 2011; Manzanares et al., 2015) and entropy (e.g., van Maarseveen et al., 2018; Ryu et al., 2016) of athletes' visual search strategies. Button et al. (2011) investigated the temporal sequencing of experienced soccer goalkeepers search strategies in video and live conditions. Using Markov chain modelling to estimate the relative likelihood of gaze being directed at a location at any moment, Button et al. (2011) identified that the goalkeepers fixated the penalty taker's head, prior to the ball being fixated. The findings support the earlier work of Dicks, Button and Davids (2010), who made initial attempts using summary fixation data to identify the sequence of fixations used by goalkeepers attempting to save penalties. Manzanares et al. (2015), also using Markov chain modelling, investigated the sequence of fixations used by top- and bottom-ranked youth sailors during a simulated Optimist class regatta pre-start period. The top-ranked sailors took less time to return and fixate (low recurrence time) on relevant areas in the visual scene compared to the time to return and fixate on less relevant areas (high recurrence time), whereas the bottom-ranked sailors had low recurrence time for both relevant and irrelevant areas (Manzanares et al., 2015).

In addition to temporal sequencing, Markov chain modelling has been used to investigate the entropy of athletes' visuals search strategies (e.g., van Maarseveen et al., 2018; Ryu et al., 2016). Investigating entropy allows an understanding of whether an athlete's visual search of a scene is executed in a structured and predictable manner (i.e., demonstrates lower entropy), or executed in a less structured and predictable manner (i.e., demonstrates higher entropy; Allsop and Gray, 2014; van Maarseveen et al., 2018). Such an understanding of visual search strategies cannot be obtained from summary fixation data, as summary fixation data typically only provides fixation locations, frequencies, and durations (Button et al., 2011; Manzanares et al., 2015), and not information about the structure and predictability of athletes' search strategies. By understanding the structure and predictability of athletes' search strategies further insight (i.e., beyond that provided by summary fixation data) may be gained into how athletes' search visual scenes.

Van Maarseveen and colleagues (2018) found that when undertaking a soccer-specific anticipation task, national level soccer players' demonstrated significantly greater predictability (i.e., lesser entropy) in their visual search strategies, compared to when undertaking a soccer-specific pattern recall task. It is possible that the differences in the predictability of the players' search strategies can be explained by the different gaze behaviours that comprised the players' visual search strategies during each task. During the anticipation task it appears that the players' adopted a more efficient search strategy (i.e., fewer fixations of longer duration; Mann et al., 2007; Piras et al., 2014). Additionally, the players' spent significantly longer fixating the attacker in possession of the ball during the anticipation task, compared to during the pattern recall task, suggesting that this AOI may have been used as a visual anchor (Piras et al., 2014; Vaeyens et al., 2007a). Furthermore, ~ 80% of the total viewing time was spent looking at the attacker in possession of the ball and the attacker without the ball during the anticipation task, and players returned to fixate the attacker in possession of ball following a fixation on another AOI more frequently during this task compared to during the pattern recall task.

Collectively the gaze behaviours comprising the players' search strategy during the anticipation task (i.e., fewer fixations of longer durations, the use of a visual anchor, and eye movements predominantly between two AOIs) may explain the greater predictability (i.e., lesser entropy) observed during the task, as there would likely have been a greater probability of fixating on the attacker in possession of ball following a fixation on the attacker without the ball (or vice versa), thus resulting in a more predictable search strategy.

In contrast to the anticipation task, the players' search strategy during the pattern recall task was characterised by a higher search rate (i.e., a higher number of fixations per second), and significantly shorter fixation durations. Additionally, the significantly shorter percentage viewing time spent looking at the attacker in possession of ball was accompanied by a decrease in the percentage viewing time spent looking at the attacked without the ball, increases in the percentage viewing time spent looking at several other AOIs, and fewer returns to the attacking player in possession of the ball from other AOIs. As suggested by van Maarseveen et al. (2018), players' may have used this search strategy in an attempt to scan and memorise the positions of multiple items (i.e., six players and the ball) for recall when required. By scanning multiple items in this manner, the probability of fixating an AOI would have been less dependent on the location of the previous fixation, consequently resulting in less predictable search strategy.

Ryu et al. (2016) investigated the entropy of recreational basketball players' visual search strategies with vision unrestricted, central vision restricted, and peripheral vision restricted, when observing video footage of 5 versus 5 situations on a small screen. The predictability of the players' search strategies was less (i.e., greater entropy) when vision was unrestricted compared to when either central or peripheral vision was restricted. Moreover, with vision unrestricted fixation duration was the shortest, and the breadth of search (relative to the player in possession of the ball) was the greatest, thus suggesting a more extensive search strategy. Together with the findings of van Maarseveen et al. (2018), the findings of Ryu et al. (2016) appear to suggest that greater entropy is associated with higher search rates and more extensive search strategies.

The use of analytical approaches, other than summary fixation data, has provided additional understanding of athletes' visual search strategies. In addition to expertise-based differences found using summary fixation data, the use of these alternative approaches has identified that expertise-based differences are present in temporal sequencing (e.g., Manzanares et al., 2015). Furthermore, analysis of entropy suggests that this aspect of athletes' visual search may be task-specific (e.g., van Maarseveen et al., 2018), in a manner similar to those aspects identified using summary fixation data (e.g., extensiveness).

**2.2.2 The visual search strategies of sport officials.** Sport officials (e.g., referees, umpires, assistant referees) are tasked with making decisions in the dynamic, temporally constrained sport environment. Like athletes, sport officials must obtain and interpret visual information from their environment to inform their decisions (Raab and Helsen, 2015; Spitz et al., 2016). Therefore, the visual search strategies of sport officials have been investigated using a similar approach (i.e., the expert-novice paradigm, summary fixation data) to that used to investigate athletes' visual search strategies. Whilst not receiving as much research attention as athletes' visual search strategies, investigations have provided an insight into the search strategies of sport officials. However, unlike the findings from investigations into athletes' search strategies, and with the exception of Millslagle, Smith and Hines (2013), findings from investigations into sport officials' search strategies have shown limited expertise-based differences (e.g., Catteeuw et al., 2010; Catteeuw et al., 2009; 2010; Hancock and Ste-Marie, 2013; Spitz et al., 2016). Yet, despite the lack of search strategy differences observed in these studies it has been found that expert sport officials make more accurate decisions (e.g., Cattueew et al., 2009; 2010; Hancock and Ste-Marie, 2013; Spitz et al., 2016).

Millslagle, Smith and Hines (2013) investigated the search strategies of near-expert (< 1 year experience at high school and university level), and expert (> 10 years experience at high school and university level) fast pitch softball umpires when calling pitches (i.e., identifying the pitch as a ball or strike). The expert umpires demonstrated a more efficient search strategy (i.e., fewer fixations), and a longer QE duration on the area of ball release compared to the near-expert umpires. Additionally, the expert umpires fixated the ball earlier during flight than the near-expert umpires, and were able to track it for a longer proportion of its flight. As suggested by the authors, the expert umpires' search strategy was similar to that of athletes engaged in interceptive tasks. That softball umpires have a similar view of the pitcher as batters (i.e., due to their position behind the batter), and the requirement for both batters and umpires to identify the trajectory of the ball may explain the similar search strategies. By effectively identifying the trajectory of the ball (by tracking it for longer), the expert umpires would have obtained more accurate information to inform their call (i.e., ball or strike). However, Millslagle, Smith and Hines (2013) did not analyse the accuracy of the umpires' calls, therefore links between search strategy and call accuracy cannot be made. Additionally, as with other investigations of officials' search strategies, the effect of previous motor experience of the sport (i.e., as an athlete) was not identified, despite the possibility that previous motor experience could influence officials' search strategies and decision-making (Pizzera, Moller and Plessner, 2018; Pizzera and Raab, 2012).

Cattueew et al. (2009) did investigate the links between search strategy and officiating decision accuracy when investigating the search strategies of international and national level soccer assistant referees tasked with making offside decisions. No expertise-based differences were observed for the fixation frequency, duration, and location of the assistant referees. However, the international level assistant referees were more accurate in their offside decision-making, and the national level assistant referees made more flag errors (i.e., raised their flag to indicate an offside player when no player was offside). In a subsequent study, Cattuew et al. (2010) divided elite soccer referees into two groups based upon the accuracy of their offside decisions using the median-split technique. As in Catteuw et al. (2009), no differences in visual search were observed, despite the differences in offside decision-making (Catteuw et al., 2010).

Further to Cattuew et al. (2009; 2010), no differences in the fixation frequency and duration of elite (Belgian top professional league experience) and sub-elite (no professional league experience) soccer referees when observing foul play situations have been observed (Spitz et al., 2016). Additionally, Hancock and Ste-Marie (2013) found no differences in the fixation frequency and duration of high- (Junior and Midget AAA leagues) and low-level (competitive youth league) ice hockey referees when observing penalty/no penalty situations on a small screen. Whilst no differences in fixation frequency and duration (i.e., search rate) were observed in either Spitz et al. (2016) or Hancock and Ste-Marie (2013), both the elite and high-level referees made more accurate decisions regarding the situations they were observing. Moreover, Spitz and colleagues (2016) found that despite the lack of differences in search rate (i.e., fixation frequency and duration) between the elite and sub-elite referees, the elite referees spent a greater amount of time fixating more informative AOIs (e.g., the contact zone between players). It is possible that the elite referees' greater experience and knowledge of foul play situations (i.e., domain-specific knowledge) allowed them to identify and interpret the most informative AOIs in the visual scene (Spitz et al., 2016). However, as Hancock and Ste-Marie (2013) did not analyse fixation location it is not known if expertise-based differences were present for this variable. Consequently, search rate alone may not be sufficient to identify expertise-based differences, and if possible fixation location should be analysed.

Officiating situations where expertise-based differences in search rate and fixation location are absent, and expertise-based differences in decision-making accuracy are present (e.g., Catteeuw et al., 2009), suggest that the same visual information is being interpreted differently (Cattuew et al., 2009; Hancock and Ste-Marie, 2013). The superior domain-specific knowledge of expert officials may account for their interpretation of the information and the subsequent accuracy of their decision-making (Catteuw et al., 2009; 2010). However, as Spitz et al. (2016) found that elite referees looked at different AOIs in soccer foul play situations, it is possible that the less accurate decision-making of the sub-elite referees was due to them not having access to the most relevant information, and attempting to make decisions based upon less informative AOIs (Spitz et al., 2016). Yet, whilst the findings of Spitz et al. (2016) differ to Catteuw et al. (2009; 2010), the officials were performing different soccer officiating tasks (i.e., offside decision-making; Cattuew et al., 2009; 2010; foul play decision-making; Spitz et al., 2016). Therefore it is possible that the two tasks require different visual search strategies, in a manner similar to the task specificity of visual search observed in athletes (e.g., Vaeyens et al., 2007a).

**2.2.3 The visual search strategies of sport coaches.** Sport coaches are required to observe their athletes' performance in training and competition. Where coaches look (i.e., their visual search strategy) when observing their athletes, and the visual information they obtain, may contribute to coaches' subsequent coaching decision-making (e.g., feedback; Moreno et al., 2006), and their manipulation of the training environment to facilitate learning (Davids, Button and Bennett, 2008). However, despite the apparent link between sport coaches' search strategies and their subsequent decision-making and behaviour, there have been few investigations into coaches' search strategies (e.g., Damas and Ferreira, 2013; Giblin et al., 2013; Moreno et al., 2002; 2006; Moreno Hernandez et al., 2006). This limited number of investigations of sport coaches' visual search strategies, as with investigations of athletes' and sport officials' visual search strategies, have used the expert-novice paradigm and summary fixation data (e.g., Giblin et al., 2013). In addition, how visual information is presented to coaches (e.g., video versus live; Moreno Hernandez et al., 2006) has been investigated.

Investigations into the visual search strategies of sport coaches have found both the presence, and absence, of expertise-based differences in coaches' search strategies. As with investigations of sport officials' search strategies, the influence of previous motor experience on coaches' search strategies has not been considered. Moreno et al. (2002) investigated the visual search strategies of expert and novice gymnastic coaches (how expertise was established was not stated) when observing video footage of gymnastic routines. The expert coaches exhibited fewer fixations of longer duration compared to the novice coaches. Such a search strategy is similar to the efficient search strategies (i.e., fewer fixations of longer duration to reduce the impact of saccadic suppression; Mann et al., 2007) observed in expert sport performers in scenarios with limited numbers of athletes (e.g., e.g., 1 versus 1; Piras et al., 2014). As Moreno et al. (2002) did not report screen size, or any other attempts to make the experimental setting representative of the gymnastics coaching environment (e.g., provide the coaches with a task), it is not known if the expert coaches' search strategy is what they would use in a live situation. However, coaching is not confined to live situations, and coaches may observe video as part of their coaching. Therefore, coaches search strategies when observing video footage may warrant investigation. Consideration should be given to providing a task for coaches (e.g., identify specific errors) to ensure that they engage with the visual information in a representative manner, and to allow investigation of the task specificity of coaches' search strategies.

Moreno and colleagues (2006) again used video footage to investigate the visual search strategies of expert and novice swimming coaches (as determined by underwater viewing experience). In this instance, a specific task was provided for the coaches to direct their attention (i.e., detect as many errors as possible when observing athletes perform the front crawl stroke), and the video footage was projected on a large screen. Additionally, coaches were required to view footage recorded from several positions (front overhead; side overhead; front underwater; side underwater) at normal and slow (33 % of normal) speeds. The inclusion of a task, and perspectives that a swimming coach may require to observe their athletes (e.g., underwater cameras) contributed to the representativeness of the experimental design. Additionally, by determining expert and novice groups based upon experience of the task being investigated (i.e., underwater viewing), Moreno et al. (2006) made some attempt to address concerns with how expert-novice groups are established (e.g., years spent coaching; Williams and Ericsson, 2005).

The swimming coaches in Moreno et al. (2006) demonstrated different visual search strategies with regard to the time different AOIs were fixated for when observing the swimmers from overhead compared to underwater, and when observing normal speed video compared to slow speed video. Additionally, expertise-based differences in fixation location were observed (Moreno et al., 2006). The authors attributed the expertise-based differences in the swimming coaches' search strategies to experience of underwater viewing (Moreno et al., 2006). Moreover, as suggested by the authors, the experienced swimming coaches may have adapted their search strategy based upon the nature of the task (i.e., perspective and speed of video footage; Moreno et al., 2006). Therefore, it appears that sport coaches' visual search strategies may be task specific, in a manner similar to that of athletes (e.g., Williams and Davids, 1998). However, whilst attempts to make the experimental-setting representative and establish groups based upon specific task experience, Moreno et al. (2006) defined fixation duration as ≥ 60 ms. This duration is less than those that have typically used (e.g., ≥ 99.99 ms) in investigations into athletes' and officials' search strategies. Whilst it may be possible to obtain and process visual information in less than 99.99 ms (e.g., Breitmeyer, Ogmen and Chen, 2004; Breitmeyer, Ro and Singhal, 2004; Kentridge, Nijboer and Heywood, 2008), Moreno et al. (2006) provide no explanation for their minimum duration, and their minimum duration does not facilitate further comparison of athletes', officials', and coaches' search strategies.

To further examine the possible task specificity of sport coaches' visual search strategies, Moreno Hernandez et al. (2006) investigated the differences between expert and novice tennis coaches' search strategies whilst observing tennis athletes performing top-spin second serves on video, then live, and then on video a second time. Fixation duration was defined as ≥ 60 ms. The tennis coaches observed the tennis serves on a small screen or live, and were required to detect errors and provide verbal feedback as if to the athletes. As in Moreno et al. (2006), the requirement to detect errors, and to verbalise feedback would have contributed to directing the coaches' attention, and increasing the representativeness of the experimental design. Expertise was established by how long the coaches had held the relevant coaching qualification and how long they had been coaching.

Across all conditions, the expert coaches made fewer fixations of longer duration compared to the novice coaches. Both groups fixated the upper body of the server most frequently (Moreno Hernandez et al., 2006). The total fixation frequency and duration were greater during the first video viewing compared to the live condition, with all AOIs fixated for longer and more frequently, with the exception of the server's lower body. During the second video viewing, the coaches demonstrated similar search strategies to the live situation. Whilst the authors attribute this to a possible decrease in attention in the later stages of the data collection period, it is not clear if the second viewing videos were the same as the first viewing videos. Prior exposure to relevant visual information (e.g., prior viewing of a visual scene, a cue to attend to a particular object) can influence subsequent visual search (e.g., Knapp and Abrams, 2012). Consequently, without information regarding the video footage used during each viewing, the potential role of familiarity with the servers, the influence of this on the coaches' search strategies during the second viewing cannot be established.

Further to concerns regarding the content of the video footage used by Moreno Hernandez et al. (2006), the authors reported fixation frequency and duration as absolute values. Clear criteria regarding what constituted the start and end of a trial was not reported, and in each of the three viewing conditions investigated (i.e., video, live, and repeated video) different total time of fixation was reported, with no explanation to account for this. These differences were reported as significant, with the differences between conditions ranging from ~ 0.41 secs to ~ 1.17 secs. Furthermore, in the condition with the longest total time of fixation, the time of fixation on specific AOIs (e.g., racquet arm) was greater than during the condition with the shortest total time of fixation. Consequently, it appears that there were feasibly differences in the length of trials in each condition; thus it is possible that the significant differences between conditions observed by Moreno Hernandez et al. (2006) were a result of the different trial durations and not the viewing conditions being investigated. For example, the significantly greater number of fixations, and significantly greater fixation time, on the racquet arm during the video condition compared to during the in-situ condition may have been due to the total time of fixation being ~ 1.17 secs longer in the video condition.

Whilst the reporting of absolute values is not a concern if trial duration is consistent, if trials of different durations are used, as appears to be the case in Moreno Hernandez et al. (2006), relative values for fixation frequency (i.e., number of fixations as a percentage of total fixations) and duration (i.e., duration of fixations as a percentage of trial duration) are needed to account for the difference in trial duration. For example, Vaeyans et al. (2007b) used video footage of soccer scenarios ranging from 3 – 9.7 secs and reported the percentage of total viewing time that participants spent fixating an AOI during the sequences, whilst Timmis et al. (2014) calculated total fixation duration on an AOI as a percentage of total trial length to account for any differences in the duration of an in-situ soccer penalty taking task. Furthermore, Vansteenskiste et al. (2014) reported the number of fixations on an AOI relative to the duration of the trial in an investigation of participants' gaze behaviour when cycling a set course at three different speeds. By using relative values participants' visual search strategies specific to completion of the trial can be established. In sport this is of interest, as the time to complete tasks is not necessarily fixed, due to factors such as the opposition and environmental conditions. Moreover, the use of relative values potentially allows for the comparison of variables such as level of expertise, viewing conditions, or task variations (e.g., power versus placement penalty kick; Timmis et al., 2014) despite differences in trial duration.

Giblin et al. (2013) also investigated the visual search strategies of expert and novice tennis coaches (and nationally ranked tennis players) when observing and evaluating video footage of tennis serves. Unlike Moreno Hernandez et al. (2006), Giblin et al. (2013) observed no expertise-based differences for the fixation frequency and duration of the coaches. Furthermore, they found no expertise-based differences for the number of locations fixated whilst observing the serve. However, the expert coaches and tennis players spent a greater amount of time viewing the trunk of the server, and shifted their gaze between the server's trunk and hips. This finding is similar to the finding of Moreno Hernandez et al. (2006), who found that all coaches fixated the upper body the most frequently. However, like Moreno Hernandez et al. (2006), there are limited details regarding the experimental design and statistical analysis used by Giblin et al. (2013). Therefore, conclusions regarding the visual search strategies of tennis coaches must be treated with caution.

Whilst caution is needed when interpreting the findings of Giblin et al. (2013), their findings are similar to those of Spitz et al. (2016) in their investigation of soccer referees' search strategies. In both instances, no expertise-based differences were found for search rate (as indicated by the frequency and duration of fixations), yet differences were observed for the AOIs fixated. As previously discussed (in section 2.2.2 The visual search strategies of sport officials), Spitz et al. (2016) found no expertise-based differences in the search rates of soccer referees (as indicated by the frequency and duration of fixations), but observed that expert referees spent more time fixating the contact zone between players in foul play situations. Moreover, Spitz et al. (2016) found that the expert referees made more accurate decisions regarding the foul play situations, and concluded that the expert referees attended to the contact zone due to the information it provided for informing their decision. For the tennis coaches in Giblin et al. (2013), despite the similarities in search rate, the greater amount of time spent fixating the trunk and hips by the expert coaches indicates an expertise-based difference in search strategy, and suggests that these AOIs provide relevant information when observing the serve. Additionally, it is feasible that the trunk acted as a visual pivot or anchor for the coaches' visual search, with peripheral vision used to monitor the athlete's limbs and the relative position of the limbs to each other and the trunk. However, unlike Spitz et al. (2016), no relevant task (e.g., a coaching decision-making task) was included in Giblin et al. (2013). Consequently, any associations between the AOIs fixated by the expert coaches (i.e., trunks and hips), the accuracy of decision-making, and whether the AOIs are important for accurate decision-making could not be investigated.

Whilst the previous studies investigated the visual search strategies of coaches involved in individual sports (e.g., tennis, gymnastics), Damas and Ferreira (2013) investigated the visual search strategies of expert and novice basketball coaches whilst observing live 5 versus 5 basketball games. Using a time series approach (rather than summary fixation data) that considered the recurrence of eye movements to areas in the visual scene, Damas and Ferreira (2013) identified that the expert coaches spent more time looking at areas of interpersonal space (i.e., space between two players). Such a search strategy may have allowed coaches to obtain information about two players and their positions relative to one another using peripheral vision (Damas and Ferreira, 2013), in a manner similar to that observed in athletes (e.g., Afonso et al., 2012). It is possible that the presence of multiple players required the coaches to use this approach, as fixating on a single player may not have provided sufficient information due to multiple athlete situations placing informative AOIs at greater eccentricities from the fovea. Additionally, the use of space in such a manner has not been observed in other investigations of coaches' visual search strategies, possibly due to the nature of the coaching activities (i.e., observing a single athlete). Consequently, it is feasible that coaches adopt task specific search strategies that are dependent on the number of athletes being observed.

**2.2.4 Task specificity of visual search strategies and representative design.** Task specificity has been observed in the visual search strategies of athletes, and to some extent in officials and coaches. The search strategy adopted appears to depend upon several aspects (e.g., number of athletes being observed, proximity of the opponent, perceptual-cognitive task to be performed), however, how visual information is presented, and the response required to this information, can also influence individuals' search strategies. Therefore, if the visual information and required response in an experimental setting differs from what participants would experience in the competitive or coaching environment, external validity is reduced, and findings cannot be generalised beyond the experimental setting (Dhami et al., 2004; Araujo, Davids and Passos, 2005; Dicks, Button and Davids, 2010). Additionally, the domain-specific nature of expertise (Bruce, Farrow and Raynor, 2012; Mann et al., 2009; Smeeton, Ward and Williams, 2004) means that for expert performers to be able to demonstrate their superior ability, the experimental setting and task must closely resemble their competitive or coaching environment (i.e., their domain; Araujo, Davids and Passos, 2005; Kurz and Munzert, 2018; Mann et al., 2007; Mann, Abernethy and Farrow, 2010; Persson and Wallin, 2012). Moreover, Dhami et al. (2004) suggest that if the experimental setting and task does not resemble the competitive or coaching environment expert performers may be aware that important cues are absent. Consequently, expert performers may then adopt different search strategies to those that they would use in the competitive or coaching environment in order to locate alternative visual information to help with completion of the task. Therefore, experimental settings and tasks should be as representative of the competitive and coaching environment (i.e., representative design) as possible.

Whilst representative designs are theoretically desirable, the challenges of achieving truly representative designs (e.g., equipment, access to athletes, repeatability, identifying effects) necessitate that hybrid designs may have to be used as an alternative (Dhami et al., 2004; Dicks, Button and Davids, 2010). Hybrid designs may incorporate aspects of systematic design (e.g., increased experimental control over conditions, control or removal of variables that are irrelevant, or that may mask effects; Dicks, Button and Davids, 2010; Pluijms et al., 2013), whilst attempting to be as representative as possible. For example, Dicks, Button and Davids (2010) and Timmis, Turner and van Paridon (2014) instructed penalty takers not to use deception (i.e., look one way and kick the other; cf. Wood and Wilson, 2010) when investigating the visual search strategies of soccer goalkeepers in order to attribute search strategy differences to the variables under investigation (i.e., live versus video conditions; Dicks, Button and Davids, 2010; live scenario power versus placement penalties; Timmis, Turner and van Paridon, 2014). Yet, in the competitive environment penalty takers would be able to use deception in their attempts to beat the goalkeeper. Nonetheless, carefully considered hybrid designs, that are a representative as possible, still have the potential to add to the understanding of visual search strategies in sport.

When investigating the visual search strategies of those involved in sport, and designing experimental settings and tasks to be representative as possible, the presentation of visual information is an important consideration. Such consideration is necessary to ensure that the properties of the visual information from the competitive or coaching environment are preserved in the experimental settings and tasks. Particular aspects for consideration include how the visual scene is presented (e.g., as a still image, on video, or as a live scenario; Afonso et al., 2014; Dicks, Button and Davids, 2010; Mann et al., 2007), the viewing perspective (e.g., aerial or first-person; Mann et al., 2009), the dimensionality (e.g., 2 or 3 dimensional; Pluijms et al., 2013), and (if presented as a still image or on video) screen size and visual angles (Al-Abood et al., 2002; Button et al., 2011; Spittle, Kremer and Hamilton, 2010). Findings from such previous investigations can inform future investigations into how visual information is presented when investigating the search strategies of those involved in sport.

In a meta-analysis conducted by Mann et al. (2007) it was found that expert athletes used fewer fixations of longer duration compared to non-expert athletes in studies where visual information was presented on film or as a live scenario. However, when visual information was presented statically (i.e., a still image) the non-expert athletes used longer fixations than the expert athletes. Therefore, it appears that the use of video may be acceptable, particularly in hybrid designs (Dharmi et al., 2004), as it preserves information regarding the opponent’s movements that are lost in a static image. The potential use of video is despite the loss of depth information that occurs due to video being 2-dimensional (versus the 3-dimensions of live situations; Pluijms et al., 2013).

If visual information is to be presented on video, screen size, the resulting visual angles (Al-Abood et al., 2002; Button et al., 2011; Spittle, Kremer and Hamilton, 2010), and viewing perspective (Mann et al., 2009) must be given consideration. Spittle, Kremer and Hamilton (2010) found that screen size (33.5 cm wide × 27 cm high, viewing distance ~ 1 m, vertical visual angle ~ 15°, versus 1.45 m wide × 1.8 m high, viewing distance ~ 5 m, vertical visual angle ~ 20°) had no affect on basketball athletes' performance in a basketball decision-making task. As identified by Spittle, Kremer and Hamilton (2010), the results suggest that screen size may not be a concern for representative design as key visual properties appear to be available on both small and large screens. However, as eye movements were not measured, it is possible that the athletes used alternative visual search strategies in each condition to obtain the required information to complete the task.

In an earlier study that did measure eye movements (Al-Abood et al., 2002), novice basketball players observed video footage of a skilled basketball athlete performing free throws (for the improvement of their own performance) on a small screen (23 cm wide × 29 cm high, viewing distance ~ 1m, estimated vertical visual angle ~ 17°), and on a large screen (1.5 m wide × 1.5 m high, viewing distance ~ 1.5 m, estimated vertical visual angle ~ 53°). Al-Abood et al. (2002) found that participants made fewer fixations of longer duration, and fixated the athlete's upper body for a longer duration, in the large screen condition. The fewer fixations in the large screen condition appears unexpected, as the larger visual angles would result in a smaller proportion of the image reaching the fovea compared to the small screen, thus requiring frequent saccades to bring different AOIs onto the fovea (Stelzer & Wickens, 2006). However, whilst Al-Abood et al. (2002) did not control for visual angle, the large screen may have increased feelings of immersion in the visual scene, and allowed participants to adopt an egocentric approach (i.e., imagine themselves within the scene; Tan et al., 2003). Consequently, the large screen condition in Al-Abood et al. (2002) may have been more representative of watching a live basketball player. Although, it must be recognised that the participants were not observing the free throws as if they were involved in a basketball game. Hence, the visual search strategies used may not be the same as in a competitive scenario.

In a study that did use competitive scenarios, Mann et al. (2009) projected video footage onto a large screen (2.45 m × 1.83 m, viewing distance ~ 3.7 m, visual angles ~ 34° × 27°) to investigate soccer players' visual search strategies when observing attacking scenarios from aerial and player perspectives (i.e., a stationary camera 1.5 m from ground level). Fewer fixation transitions were made between AOIs (i.e., a less extensive search strategy) when viewing scenarios from the player perspective compared to the aerial perspective. However, whilst the player perspective was more representative of a competitive scenario that a player would encounter during a soccer game, it was not a first-person perspective and the players were asked to make a decision about the best option for the player in possession of the ball. Accordingly, as they were not viewing the scenario from the perspective of the player in possession they may have not been able to see all the options available to that player (Mann et al., 2009). Nonetheless, the study does demonstrate that the perspective that video footage provides can influence visual search strategies, and should be considered when designing experimental tasks and settings.

More recently, Dicks, Button and Davids, (2010), Button et al. (2011), and Afonso et al. (2014) compared video and live presentation of visual information when investigating the search strategies of soccer and volleyball athletes' respectively. Dicks, Button and Davids (2010) compared the visual search strategies of soccer goalkeepers when presented with penalty takers in two, first-person perspective video conditions (verbal response and joystick response), and three live conditions (verbal response, joystick response, and interceptive motor response). Furthermore, Dicks, Button and Davids (2010) attempted to keep the visual angles similar in both the video and live conditions. No differences in fixation frequency or duration (i.e., search rate) were observed between the video and live conditions. However, a greater number of AOIs were fixated in the video conditions compared to the live interceptive response condition. It is possible that the loss of information regarding depth in the two-dimensional video conditions (Pluijms et al., 2013) may have caused the players to locate and fixate more AOIs in an attempt to obtain alternative visual information to compensate for the loss of depth-related information (Button et al., 2011).

In a follow-up study using a similar method to Dicks, Button and Davids (2010), Button and colleagues (2011) analysed when fixations occurred during the execution of the penalty. Similar to Dicks, Button and Davids (2010), Button et al. (2011) found that fewer locations were fixated in the live interceptive motor response condition, and additionally identified that in this condition the ball was fixated earlier and for longer compared to the other conditions (Button et al., 2011). Afonso and colleagues (2014) also found that the opportunity to respond in a representative manner influences live condition visual search strategies, with volleyball athletes demonstrating longer fixations, specifically on the attacker (i.e., opponent who will contact the ball), in a live volleyball condition compared to a video condition. Thus, whilst large screen, first-person perspective video conditions and live conditions subtending similar visual angles result in similar search rates, an increased representativeness of response (i.e., an interceptive motor response that is similar to that used in a game) does influence athletes' visual search strategies (i.e., number of AOIs fixated, when AOIs are fixated; Button et al., 2011; Dicks, Button and Davids, 2010). Furthermore, it is possible that the AOIs that were fixated for longer durations in the live interceptive motor response conditions provided the best visual information to inform the athletes motor responses (Afonso et al., 2014; Dicks, Button and Davids, 2010).

Due to the requirement in live conditions to execute interceptive motor responses (e.g., save a soccer penalty kick; Dicks, Button and Davids, 2010), it is probable that participants utilised an egocentric frame of reference (van Doorn et al., 2009). When utilising an egocentric frame of reference, visual information is encoded relative to one's own position via the dorsal stream (van Doorn et al., 2009). For example, for the soccer goalkeeper attempting to save a penalty kick, visual information about the ball's flight needs to be encoded relative to their own position if a successful save is to be made (Dicks, Button and Davids, 2010). Encoding visual information in this manner has been termed vision for action (van Doorn et al., 2009). However, when visual information is presented via video, and interceptive motor responses are not required (e.g., joystick or verbal response to indicate the direction of movement required to save a soccer penalty kick), it is probable that an allocentric frame of reference is used (Dicks, Button and Davids, 2010). An allocentric frame of reference refers to visual information regarding the position of objects/persons in the visual scene being encoded relative to one another, but not necessarily to one's own body and location (Columbo et al., 2017; van Doorn et al., 2009). Encoding of visual information in this manner is via the ventral stream, and has been termed vision for perception (van Doorn et al., 2009). Accordingly, if an individual is not directly involved in a situation (e.g., watching a video, not required to move in relation to objects/persons in the visual scene), and is required to only indicate a potential direction of movement through the use of a joystick or verbal response, visual information regarding the objects in the scene can be processed independent of the individual's position (Dicks, Button and Davids, 2010). The use of egocentric and allocentric frames of reference in live and video conditions respectively may provide an explanation for the different visual search strategies observed between these conditions (e.g., Afonso et al., 2014; Dicks, Button and Davids, 2010). Moreover, conditions that require the use of an egocentric frame of reference and motor responses are more representative of the competitive environment, and will more likely will result in visual search strategies being observed that are comparable to those used in competitive environments (Mann et al., 2007).

Whilst being able to execute a motor response in live experimental conditions adds to the representativeness of investigations, the performance of the motor response can be affected by the visual information available to the athletes. For example, Croft, Button and Dicks (2010) and Land and McLeod (2000) used bowling machines to deliver the ball to cricket batsmen. Whilst the use of bowling machines offers some experimental control regarding delivery speed and ball trajectory, it removes visual information regarding the possible trajectory of the ball that may be available from the bowler (e.g., bowling hand; Muller Abernethy and Farrow, 2006). Temporal occlusion studies (e.g., Causer, Smeeton and Williams, 2017; Muller, Abernethy and Farrow, 2006) have shown that highly skilled performers are able to use early visual cues to predict the direction of a ball thrown or struck by an opponent more successfully than lesser skilled performers. Consequently, if early visual cues are removed, then so are the cues that provide the advantage for highly skilled performers. Moreover, as successful execution of interceptive tasks likely requires several gaze behaviours (e.g., obtaining early visual information, object tracking, anticipatory saccades; McPherson and Vickers, 2004), and as athletes may use individualised search strategies that use these behaviours to differing extents (Croft, Button and Dicks, 2010), any restriction or removal of visual information may affect the success of athletes' task execution (Kredel et al., 2017).

Although it is apparent that when investigating athletes' visual search strategies live conditions that preserve visual information and allow motor responses from the competitive environment are desirable, there has been little attention given to the level of representativeness required in investigations of officials' and coaches' search strategies. The majority of investigations of officials' search strategies have used video footage presented on small screens and found limited expertise-based differences (e.g., Cattueew et al., 2009; Spitz et al., 2016), with the exception Millslagle, Smith and Hines (2013), who did find expertise-based differences in their investigation of softball umpires search strategies in live conditions. If representative design is as necessary when investigating officials' search strategies as it appears to be when investigating athletes' search strategies, then the limited expertise-based differences observed in the studies using video footage presented on small screens may be attributable to a lack of representativeness. However, as previously identified, the officiating task in Millslagle, Smith and Hines (2013) was similar to the batter's task (i.e., predict the trajectory of the ball), whereas the officiating tasks in the other studies (e.g., making a decision regarding foul play in soccer; Spitz et al., 2016) were dissimilar to tasks that present themselves to athletes in those sports.

As officials are predominantly involved in tasks dissimilar to those athletes undertake (i.e., not required to utilise complex motor skills to respond to visual information about the position of objects/persons in the visual scene) it is feasible that officials would utilise an allocentric frame of reference and encode visual information via the ventral stream (i.e., vision for perception). One could hypothesise that similar processing of visual information would be expected in coaches, as their tasks also differ to those of athletes, and they are not required to execute complex motor skills in response to visual information about the position of objects/persons in the visual scene. Furthermore, unlike officials who may have to respond immediately to visual information about the position of objects/persons in the visual scene (e.g., by signally a player is offside; Catteeuw et al., 2010), coaches' responses are not necessarily temporally constrained (e.g., their coaching decision does not have to immediately follow processing of the visual information).

Whilst investigations into the visual search strategies of officials and coaches are few, Dicks, Button and Davids' (2010) investigation of soccer goalkeepers gaze behaviours provides some basis for the possibility that officials and coaches may utilise vision for perception. Dicks and colleagues (2010) investigated soccer goalkeepers' gaze behaviours in video and live conditions combined with different response conditions (i.e., verbal, joystick, partial movement, full interceptive movement), and found that gaze behaviours during the video verbal, video joystick, and live verbal conditions differed to those during the live full interceptive movement condition. The authors suggested that the video verbal, video joystick, and live verbal conditions were likely to utilise vision for perception (i.e., the ventral stream), whilst the live full interceptive movement condition was likely to utilise vision for action (i.e., the dorsal stream), with the live partial movement condition representing an intermediate between the two (Dicks, Button and Davids, 2010). As coaches and officials are typically involved in scenarios similar to the video verbal and live verbal condition (e.g., observe a competitive situation and verbally respond with feedback or officiating decision) used in Dicks, Button and Davids (2010), it is feasible that they are utilising vision for perception.

If officials and coaches are using vision for perception, the use of fully representative experimental settings and tasks (e.g., live, in-situ tasks) may not be required, as video footage can provide sufficient visual information for vision for perception (Dicks, Button and Davids, 2010). Consequently, the use of video footage may be acceptable for investigations into the visual search strategies of sport officials and coaches, and if video footage can be used it would allow for greater experimental control (e.g., repeatable footage of competition scenarios; Dhami et al., 2004). If video footage is used to represent a live, in-situ officiating or coaching scenario (e.g., officiating or coaching during competition), attempts to make the visual information and environment as representative and immersive as possible (e.g., large screens, provision of a specific task) should be made. Yet, if the findings from investigations into coaches' search strategies using video are generalised to situations where coaches use video (e.g., to re-watch a competition), the experimental setting and task would be more representative.

## 2.3 Summary

The visual system allows humans to perceive and interact with their environment, and where individuals look (i.e., their visual search strategy) provides an indication of their overt attention. Eye trackers are used to measure eye movements, and have allowed researchers to investigate individuals' visual search strategies in a variety of settings, including sport. Investigations of athletes' visual search strategies have shown that expert athletes adopt different search strategies compared to athletes of lesser expertise, and that these search strategies are task specific. Such expertise-based differences have not been observed in sport officials. However, expert officials make more accurate decisions using the same visual information as officials of lesser expertise, suggesting a role for domain-specific experience when making officiating decisions. In sport coaches some expertise-based differences have been observed; however, methodological issues, a limited number of investigations, and no investigations of coaches' search strategies during competition mean that further investigations are warranted. Any future investigations of coaches' search strategies should consider the representativeness of the experimental setting and task.

# 3. Aim and objectives

## 3. 1 Aim

The aim of the series of experiments contained within this thesis is to investigate the visual search strategies of judo coaches when observing judo contests. Due to the limited number of investigations into the visual search strategies of sport coaches, and the absence of investigations into the visual search strategies of judo coaches, these studies are exploratory in nature and aim to generate hypotheses and areas for further investigation in future studies.

## 3.2 Objectives

1. To investigate if visual search strategies are different between level of judo coach.
2. To investigate if prior exposure to judo contest-specific information (i.e., from an earlier part of a judo contest) affects judo coaches' visual search strategies when observing a later part of the same contest.
3. To investigate the effect of previously viewing a judo contest on judo coaches' visual search strategies when observing a repeat viewing of the contest.
4. To investigate if level of coach and prior exposure to contest specific information affects the entropy of judo coaches' visual search strategies.

## 3.3 Hypotheses

As identified in section 3.1, the studies contained within this thesis are exploratory in nature, and aim to describe the visual search strategies of judo coaches of differing levels of expertise when observing judo contests. Descriptive and exploratory studies can serve the function of generating hypotheses for future research, and can be viewed as a precursor to future investigations that will test the hypotheses generated (Bernards et al., 2017; Bishop, 2008). At present, due to the limited number of investigations into coaches' search strategies, and the equivocal findings to date (e.g., Giblin et al., 2013; Moreno et al., 2002), it is difficult to generate informed hypotheses regarding judo coaches' search strategies. Expertise-based differences in coaches' search strategies may be expected based upon the findings of investigations into athletes' search strategies (e.g., Mann et al., 2007; Piras et al., 2014; Vaeyans et al., 2007). However, the task for the judo coach (i.e., vision for perception) differs to that of the athlete (i.e., vision for action), therefore different search strategies may be adopted due to these task differences (Dicks, Button and Davids, 2010). Investigations into officials' search strategies, due to greater task similarity, may provide a more suitable basis for formulating a hypothesis regarding judo coaches' search strategies; yet, there are fewer investigations of officials' search strategies' compared to investigations of athletes' search strategies, and the literature suggests both the presence (e.g., Sptiz et al., 2016) and absence (e.g., Hancock & Ste-Marie, 2013) of expertise-based differences in officials. Consequently, informed a priori hypotheses cannot be derived regarding the visual search strategies of judo coaches; therefore the thesis aims to generate hypotheses for future research into coaches' search strategies.

# 4. Methods

This chapter will provide details and rationale for the approaches used to investigate the visual search strategies of judo coaches. Due to the limited number of investigations into sport coaches' visual search strategies to inform the present investigation, the approaches used are additionally informed by investigations into athletes and sport officials' search strategies. It is the aim that the approaches used contribute to informing future investigations of coaches' visual search strategies.

## 4.1 Participants

Participants were recruited using a convenience sampling approach. It was expected that recruiting judo coaches of the required level (i.e., national and international levels) would be challenging due to their coaching commitments (e.g., travel to training camps and competitions). Therefore, judo coaches who were studying on judo-specific programmes at Anglia Ruskin University were approached for their participation. As the research was exploratory, the aim was to recruit as many participants as possible to carry out research into an area (i.e., the visual search strategies of judo coaches) that had yet to be investigated, and to provide a basis for any future investigations into judo coaches' visual search strategies.

Fifteen qualified judo coaches, and seven individuals with no experience of judo (participating or coaching), were recruited and took part in the study. The same participants were used for all experimental chapters in this thesis (with the exception of the preliminary analysis described in chapter 5: Experiment 1). Institutional ethical approval was obtained. All participants provided written informed consent, and completed a health questionnaire relating to their vision before participating (Appendix A: Figure A1). Participants reported normal, or corrected-to-normal (through wearing contact lenses) vision, and were able to view video footage without the aid of spectacles to correct vision. Individuals who wore spectacles were excluded from the study as spectacles affect the quality of eye tracking recording. All participants completed a judo experience questionnaire (Appendix A: Figure A2) to establish their level of coaching (for the coaching groups) and confirm that individuals in the non-judo group had no experience of judo. All coaches possessed, as a minimum, a British Judo Association (BJA)/United Kingdom Coaching Certificate (UKCC) level 2 judo coaching qualification (or equivalent for non-UK coaches), and a judo grade of 1st dan black belt. Non-UK coaches were enrolled on a UK-based degree programme and had demonstrated proficiency in English as a prerequisite for enrollment onto the degree programme. All coaches had previous competitive experience as a *judoka*, ranging from regional to international level.

As in previous investigations into the visual search strategies of athletes, officials, and coaches, the present series of studies adopted the expert-novice paradigm. Participants were divided into three groups based upon their responses to the judo experience questionnaire (Table 4.1). The judo coaches were divided into two groups based upon their experience of coaching at different competitive levels. The approach of dividing the judo coaches based upon experience was similar to that used in previous investigations of the visual search strategies of athletes (e.g., Roca et al., 2013), officials (e.g., Catteeuw et al., 2009), and coaches (e.g., Moreno et al., 2002). Coaches with regional to national level experience were placed into the national (NAT) group (n = 8), and coaches with international coaching experience were placed into the international (INT) group (n = 7). Group sizes were comparable to previous investigations into coaches' visual search strategies, where group sizes have ranged from three (Moreno et al., 2002) to 10 (Giblin et al., 2013) coaches per group. The coaches in the INT group demonstrated characteristics of elite coaches (i.e., minimum of 1st dan black belt, ≥ 10 years judo coaching experience, experience of international level coaching) as previously defined by Santos et al. (2015). Such use of composite criteria comprising aspects including qualifications, experience, and level to define coaching expertise are commonly used (Nash et al., 2012). The remaining seven participants with no experience of judo formed the non-judo (NJ) group.

**Table 4.1** Participant details.

| | N | Age (yrs ± SD) | Judo experience (yrs ± SD) | Coaching experience (yrs ± SD) |
|---|---|---|---|---|
| **NJ** | 7 | 26.14 ± 8.53 | NA | NA |
| **NAT** | 8 | 36.13 ± 12.60 | 24.75 ± 8.28 | 11.5 ± 7.58 |
| **INT** | 7 | 40.86 ± 8.78 | 31.57 ± 7.28 | 18.14 ± 8.15 |

NJ = non-judo; NAT = national; INT = international

## 4.2 Materials and apparatus

Video footage (including audio) of judo contests recorded by the Computer Aided Replay (CARE) system at an International Judo Federation (IJF) Grand Prix event was obtained. Grand Prix events form part of the IJF's annual schedule of international tournaments for elite *judoka*. At tournaments the CARE system is used to provide a panel of judo refereeing officials (situated at a table at the side of the contest area) with video replay footage of the contest from multiple viewing angles. In situations where it is unclear if a score (e.g., *ippon*) or penalty (e.g., *shido*) should be given to a *judoka*, the panel can use the CARE system to review the action from different viewing angles and at slower speeds. The contest referee (who wears an in-ear receiver) can then be informed of the correct decision via a radio communication system.

The CARE system contest footage used was recorded from a camera located in a position similar to that of coaches whilst observing their *judoka* compete (i.e. the judo coach sits mat side at the same level and approximate position as the CARE camera), and therefore presented a first-person perspective visual scene similar to that a coach would observe in-situ (Figure 4.1). The footage obtained from the CARE system consisted of male and female contests from multiple weight categories. Permission to use the footage was provided by the event organisers. The coaches who participated in this study were not present at the event where the contest footage was recorded. Coaches did not know the *judokas* in a coaching context.

Video footage from the CARE system was edited and clips of contests created (iMovie, Apple Inc., California; USA, ver. 10.0.5). Of the 158 contests recorded, 134 contests were excluded from the editing process as the view of the *judokas* was regularly obstructed (e.g., by the referee). Clips of contests were created from footage of each of the remaining 24 contests. Clips had a mean duration of 61 ± 14.93 s, and consisted of two consecutive periods of a contest separated by an 11 s pause. The pause represented the average contest *matte* period (Franchini, Artioli and Brito, 2013; Miarka et al., 2012). During the *matte* period a still image of the *judokas* was displayed (Figure 4.2). Audio was retained; however, on-screen text to indicate referee calls (i.e., *hajime*, *matte*, scores and *shidos*) was added to the footage, as calls were not consistently audible (e.g., due to crowd noise). If referee calls were audible the text was synchronized with the call. If calls were not audible and the referee's face was visible text was synchronized with the movement of the referee's mouth. If this was not possible text was synchronized with the referee's signal to the scoreboard operators. If a signal was not visible, text was synchronized with the change (e.g., timer starts) on the scoreboard.

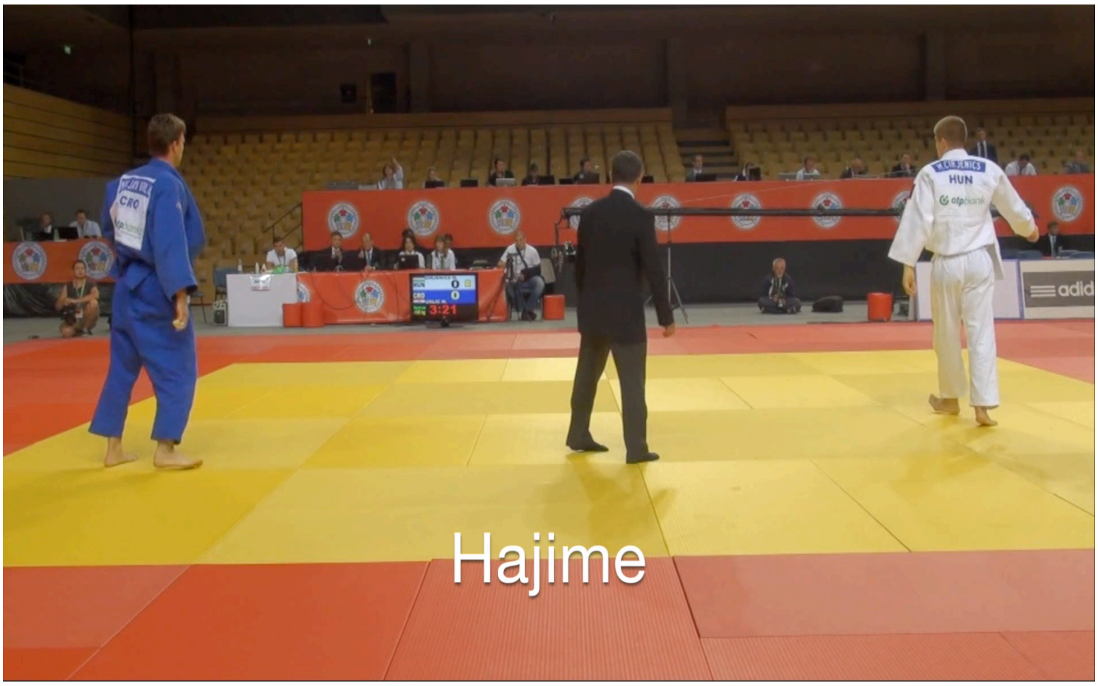


**Figure 4.1** Still image of the visual scene presented to participants with "Hajime" on-screen text added as described in section 4.2 Materials and apparatus

Prior to the start of data collection all participants were told that that they were going to watch a series of clips of elite level judo contests, during which they were to assume the role of coach for the *judoka* wearing white (in international judo contests one *judoka* wears white and the other blue). Participants were informed that on-screen text would indicate the referee's calls using the relevant Japanese judo terms. The meaning of the terms was explained to the participants with no judo experience (i.e., the NJ group). During each *matte* period participants were asked to provide verbal coaching instructions to improve the performance of the specified *judoka* (i.e., the *judoka* wearing white). The provision of feedback during the *matte* period followed IJF rules regarding when coaching instructions can be given to a *judoka* during a contest (IJF, 2014). Participants in the NJ group were encouraged to provide any feedback to the specified *judoka* that they felt appropriate (e.g., encouragement). On-screen text during the *matte* provided a prompt for participants to provide their feedback (Figure 4.2).

The instructions to assume the role of coach for the *judoka* in white, and to provide coaching instructions to this *judoka* during the *matte* period, provided a specific task for participants to undertake whilst viewing the contest video footage. The provision of a specific task (i.e., coach the specified *judoka* and provide feedback) was included to help ensure that participants' adopted the visual search strategy that they would use when coaching a *judoka* during a contest (Moreno et al., 2006; Moreno Hernandez et al., 2006). Furthermore, when investigating possible expertise-based differences in visual search strategies it is beneficial for the experimental setting and task to represent the natural setting and task (i.e., live contest coaching) as closely as possible in order to allow any expertise-based differences to be observed (Mann et al., 2007; Mann, Abernethy and Farrow, 2010). Clips were projected onto a large screen (height: 1.13 ± 0.27 m; width 1.92 ± 0.34 m) at a minimum resolution of 1024 × 640.

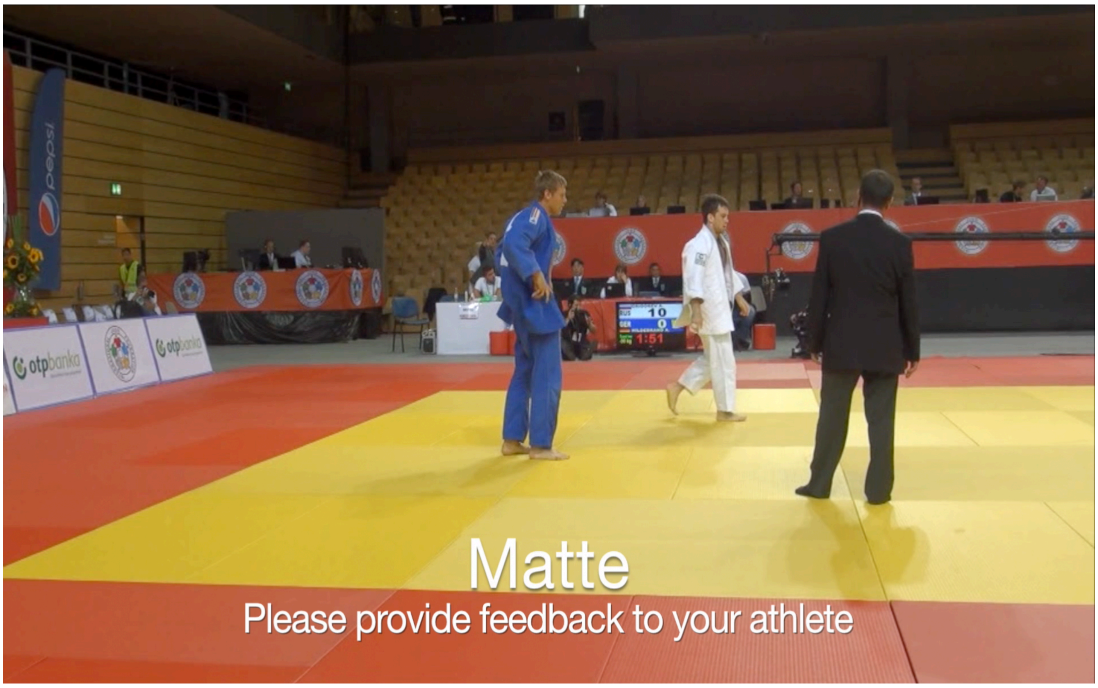


**Figure 4.2** Example of a *matte* period still image

Participants' eye movements were recorded using a SMI iViewETG head mounted mobile eye tracking glasses (SensoMotoric Instruments Inc, Warthestr; Germany, ver. 1.0; Figure 4.3) at 30 Hz. Mobile eye trackers allow researchers investigating eye movements in sport to use representative experimental settings (i.e., settings that match as closely as possible the participants' performance environment regarding stimuli and opportunities for movement responses) to achieve external validity (Kredel et al., 2017; Kurz and Munzert, 2018). The SMI mobile eye tracking glasses are a binocular system that consists of two infrared cameras (mounted in the lower frame of the glasses, inferior to each eye) used to establish eye position and movement, and a scene camera (mounted centrally in the frame of the glasses, and slightly superior to the eyes) to record what the wearer is viewing. The mobile eye tracking glasses use dark pupil and cornea reflection tracking to establish and track the position of the eye. The infrared cameras direct near-infrared light towards the eye to generate reflections (Purkinje images) in the cornea. The near-infrared light (700 nm to 1100 nm) is just beyond the visible spectrum of humans (~ 400 nm to 700 nm; Rojas and Gonzalez-Lima, 2011), and therefore cannot be seen by the wearer. The near-infrared light generates reflections from the cornea, and these sampled at 30 Hz by the infrared cameras, whilst the scene camera records at 24 Hz at a resolution of 1280 × 960 (Pfeiffer at al., 2014). The position of the eye, to an accuracy of ~ 0.5° (Pfeiffer at al., 2014), is established based upon the location of the corneal reflection relative to the pupil (Choo et al., 2012; Duchowski, 2007), and matched to the footage recorded by the scene camera. The inclusion of the cameras within the eye tracking glasses allows eye movements to be measured despite head movement, due to the cameras located below the eyes always being able to capture the static eye region (i.e., corneal reflection; Choo et al., 2012; Duchowski, 2007). Consequently, the use of mobile eye tracking glasses allowed participants to move their head in the same manner they would when coaching a *judoka* during a contest.


**Figure 4.3** Participant wearing SMI iViewETG head mounted mobile eye tracking glasses

**4.3 Procedure**

Participants were seated ≈ 2.8 m from the screen on a seat ≈ 0.75 m in height. When projected onto the screen the visual scene subtended a mean horizontal visual angle of 38 ± 6°, and a mean vertical visual angle of 23 ± 5°. The seating position, large screen, and audio were used to create an immersive experimental setting for participants (Rubio-Tamayo, Barrio and Garcia, 2017; Tan et al., 2003). Making the experimental setting as immersive as possible provided the sensory information (e.g., visual, auditory) participants would expect to experience when observing a live contest, and contributed to making the experimental setting representative of what coaches experience when coaching a *judoka* during a contest at an international level tournament (Figure 4.4). As discussed in section 2.2.4 of chapter 2, experimental settings and tasks need to be as representative of natural settings and tasks as possible for any expertise-based differences to be observed (Mann et al., 2007; Mann, Abernethy and Farrow, 2010).

**Figure 4.4** Experimental set-up

Whilst the use of video footage removed depth information from the visual scene, it is likely that judo coaches use the ventral stream (i.e., vision for perception) and require allocentric information (i.e., information about the position of the competing *judokas* relative to each other) when observing contests (e.g., van Doorn, van der Kamp and Savelsbergh, 2007). Additionally, judo coaches are not required to execute gross motor skills in response to visual information, and hence do not need the egocentric information (i.e., information about the position of the competing *judokas* relative to each other and the coach) that a live situation provides (e.g., Afonso et al., 2012). Therefore, the use of video footage projected on a large screen was deemed appropriate. Moreover, the use of video footage allowed identical contest footage to be viewed by all participants, and thus provided greater experimental control (e.g., Dhami et al., 2004).

Participants were fitted with the eye tracking glasses. Concerns regarding the susceptibility of mobile eye tracking glasses to moving when used in representative settings (Kurz and Munzert, 2018) were minimal, as participant movement was limited due to the nature of the study (i.e., coaching activities from a seated position rather than execution of motor skills). An initial three-point calibration was performed using a calibration image projected onto the screen (Appendix A: Figure A3). Following calibration participants were permitted to view up to five familiarisation clips, and to request clarification regarding the experimental procedures during the familiarisation period. Upon completion of the familiarisation period, accuracy of the eye tracking glasses calibration was confirmed. Adjustment of the eye tracking glasses, and a further three-point calibration was carried out if necessary. Participants then viewed the 24 clips, plus five repeated clips from the original 24. The same repeated clips were used for each participant. Participants viewed the total of 29 clips in blocks of no more than six clips. Clips were presented in random order (www.randomizer.org) for each participant. Repeated clips were separated from the original by at least one block. Between clips the screen went black for ~ 5 s. Participants were permitted a break of self-determined duration between blocks. Fitting and calibration of the eye tracking glasses was checked between blocks and if needed, adjustment and re-calibration occurred. The total time for data collection was ≈ 45 mins.

### 4.4 Data analysis

A single contest phase was chosen for analysis. Contest phases (i.e., preparation phase, *kumi-kata, tachi-waza*, *ne-waza*) present different visual information to coaches (e.g., *judokas* not in contact, *judokas* in contact, *judokas* standing, *judokas* on the ground), and may require different coaching decisions (e.g., techniques and tactics for *tachi-waza* are to those for *ne-waza*), and can therefore be considered as different tasks. Previous research has shown that task requirements determine the visual search strategy utilised (e.g., Vaeyens et al., 2007a). To ensure all participants were viewing the same task, only one contest phase (the preparation phase) was used. The preparation phase was selected for analysis, as it is an important tactical contest phase occurring at the beginning of the *hajime-matte* period (Miarka et al., 2012). The preparation phases occurring in the *hajime-matte* block prior to the *matte* period (i.e., the pre-*matte* preparation phase), and the preparation phase occurring in the *hajime*-matte block after the *matte* period (i.e., the post-*matte* preparation phase), were analysed.

From the original 24 clips presented to the participants, clips were reassessed regarding any obstruction of the view of the *judokas*. Clips that allowed a clear view of the *judokas*, and clips where *judokas* moved, but did not remain, behind an obstruction (e.g., the *judoka* continually moved from the left of the contest area, behind the referee, to reappear on the right of the contest area) were selected for tracking of eye movements. The included clips were tracked from the frame when *hajime* appeared on the screen, to the frame immediately before either *judoka* made contact with their opponent (i.e., the preparation phase). Visual search data recorded by the eye tracking glasses was analysed offline using SMI BeGaze (ver. 3.4) software. Data was manually mapped frame-by-frame (≈ 33,000 frames across all experiments) using an area of interest (AOI) image (Figure 4.5) uploaded to the BeGaze software (Figure 4.6).

Investigations into the visual search strategies of *judokas* in live 1 versus 1 contest situations have utilised precise AOIs (e.g., lapel, sleeve, wrist/hand; Piras et al., 2014). The use of precise AOIs was made possible, as the opposing *judoka* would have filled the majority of the visual scene (i.e., the opponent was standing close to the participant). In the present study, pilot testing indicated that the use of similar AOIs to Piras et al. (2014) would not be possible due to the visual scene encompassing a larger area (i.e., an ~ 10 m × 10 m contest area containing two *judokas* and the referee moving in multiple planes). Therefore, it was deemed more appropriate for broader AOIs to be used. Broad AOIs (e.g., attacker) have previously been used in studies that have presented visual scenes of larger areas (e.g., competitive situations containing several athletes; e.g., Damas and Ferreira, 2013; Vaeyens et al., 2007a; 2007b). Furthermore, in such visual scenes relational information (e.g., position of athletes in relation to one another) rather than specific feature level AOIs may be utilised (North et al., 2009). Consequently, six primary AOIs were identified based upon their potential to provide visual information regarding the *judokas* and the contest, given the visual scene (i.e., contest area containing several individuals). To account for eye movements within these broader

AOIs, a clear saccade from one region to another within the same AOI was mapped as a new gaze.

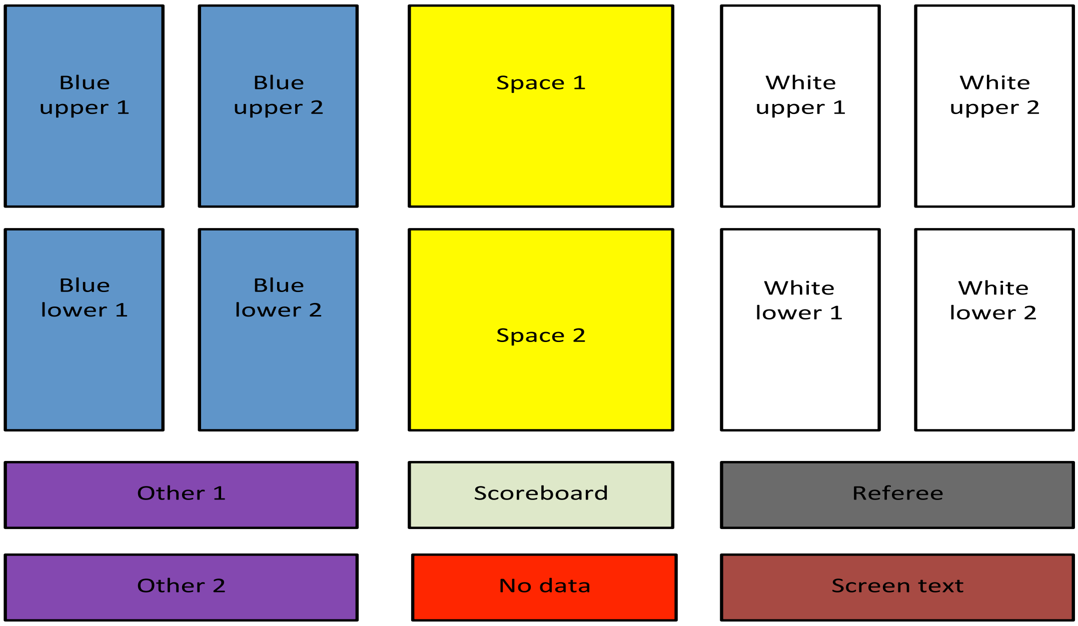


**Figure 4.5** Area of interest (AOI) image

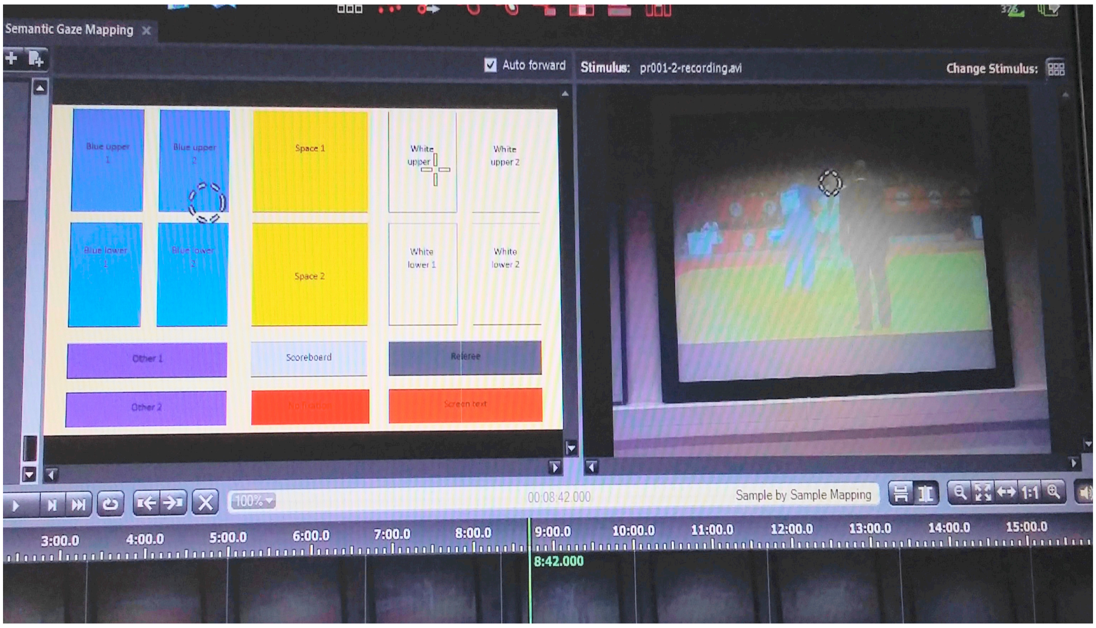


**Figure 4.6** Area of interest (AOI) image uploaded to BeGaze software

Previous research investigating *judokas'* visual search strategies has identified the importance of upper body areas for providing visual information in contest situations (Piras et al., 2014). Therefore, upper body areas (white upper, WU; blue upper, BU) were included as primary AOIs, with white and blue distinguishing the colour of the *judogi* (judo suit) worn by the *judoka*. The upper AOIs included the *judoka's* belt and any area above it. The belt was included in the upper body AOIs as *judoka* are permitted to grip the belt, and any area of the *judogi* above it, during *tachi-waza* (IJF, 2014) Lower body areas (white lower, WL; blue lower, BL) were also included as primary AOIs, similar to Piras et al. (2014), as a *judoka's* stance may provide information about their attacking intentions (Collins and Challis, 2013; Lee and Quan, n.d). A space (SP) AOI was included and defined as the area between the judokas when engaged in the contest. SP was included as it represented a central area in the visual scene. Previous research suggests that central areas may act as "visual pivots" for visual search (Piras et al., 2015; Vaeyens et al., 2007a). The sixth AOI was the scoreboard (SB). In judo contests the scoreboard provides the names and nationalities of the competing *judokas,* the remaining time of the contest, the score, and penalties conceded. SB was included as an AOI as it could provide participants with information about the context of the clip they were viewing.

Three secondary AOIs (referee, REF; on-screen text, TXT; other, OTH), that did not provide information about the contest or *judokas*, were identified to account for fixations on areas other than the primary AOIs. During the phase analysed REF did not provide any signals (e.g., awarding a score), and therefore did not provide information about the contest. TXT only indicated the beginning of the contest during the phase analysed, and was on the screen for the initial 1 sec of the clip.

Fixations on areas away from the contest area (e.g., crowd, advertising hoardings) were denoted by OTH. A tracking option to account for periods where gaze behaviour could not be recorded was included and termed NODATA (Vansteenkiste et al., 2014b). This allowed the tracking ratio to be calculated. The tracking ratio considers the number of frames recorded, and the number of frames where no data could be recorded. A higher tracking ratio means that more frames were recorded, and a tracking ratio of > 80 % has previously been identified as acceptable for use in gaze behavior studies (Vansteenkiste et al., 2014a). Tracking ratios in the present study exceeded 80 % for all participants.

### 4.5 Statistical analysis

***4.5.1 Reliability.*** A randomly selected sample of the clips included in the statistical analysis (n = 5; ≈ 11 %) was used to analyse the intra- and inter-rater reliability of frame-by-frame eye movement tracking. Intra-rater reliability interclass correlation coefficients (ICCs) > 0.9 were found for the frequency of tracking hits on WU (0.996), BU (0.996), and SP (0.979), the total number of fixations (0.952), and the number of fixations on WU (0.979), BU (0.947), and SP (0.962). Inter-rater reliability (conducted between PR and MT) ICCs > 0.9 were also observed for the frequency of tracking hits on WU (0.998), BU (0.999), and SP (0.906), the total number of fixations (0.952), and the number of fixations on WU (0.938), BU (0.974), and SP (0.962).

***4.5.2 Variables.*** Summary fixation data was initially used to analyse the visual search strategies of judo coaches when observing the preparation phase of judo contests (chapters 5 – 8: Experiments 1 - 4). Summary fixation data is typically used to investigate the search strategies of athletes (e.g., Piras et al., 2014), officials (e.g., Catteeuw et al., 2010), and coaches (e.g., Moreno et al., 2006). Additionally, as suggested by several authors (e.g., Dicks et al., 2017; Button et al., 2011; Manzanares et al., 2015), an alternative approach (i.e., transitions between AOIs and entropy) was used for further analysis of participants' search strategies as described in chapter 9: Experiment 5. Bespoke macro scripts (Appendix A: Figure A4) created using Excel Visual Basic for Applications (Excel 2010, Microsoft Corp., Washington, USA, ver. 14) were used to process the BeGaze software frame-by-frame tracking output and obtain the variables for analysis.

The dependent variables analysed in chapters 5 – 8 (Experiments 1 – 4) were (i) the total number of fixations during the entire trial, (ii) the relative number of fixations on an AOI, (iii) the relative total fixation duration on an AOI, and (iv) the average fixation duration on an AOI (chapter 6: Experiment 2 only). The relative number of fixations on an AOI was calculated as a percentage of the total number of fixations during the clip. Relative total fixation duration on an AOI was calculated as a percentage of clip duration (i.e., how much of the clip was spent fixating on an AOI). The average fixation duration on an AOI was the duration (in seconds) of a fixation on an AOI during a clip (i.e., how long was a fixation on an AOI). Relative values were used to account for differences in clip duration (Timmis, Turner and van Paridon, 2014). Fixations were defined as the gaze cursor remaining stationary for a minimum of four consecutive frames ($\geq$ 120 ms; Williams et al., 1994) relative to a location in the visual scene (i.e., on an AOI; Vickers and Adolphe, 1997). The use of such a minimum duration defining a fixation is typical in investigations of eye movements in sport, and is used to a greater extent than definitions using eye movement velocity and magnitude, possibly due to the equipment used (i.e., the equipment may not allow measurement of velocity or magnitude). Additionally, as some AOIs had the potential to move short distances at low velocities (e.g., a *judoka* may walk towards or away from their opponent), if the AOI moved and the gaze cursor tracked the AOI, it was deemed that the AOI was still being fixated (providing the minimum duration of ≥ 120 ms was achieved). Defining fixations by duration, in combination with the use of frame-by-frame tracking rather than an event detection algorithm, ensured that a single, slow moving fixation, rather than a series of several discrete fixations, was recorded in instances of an AOI moving and being tracked (Vansteenkiste et al., 2014a). For each variable, the mean value of group, and the mean value of the clips analysed were used.

In chapter 9: Experiment 5, the dependent variables analysed were (i) the total number of transitions between AOIs, (ii) the relative number of transitions from an AOI to another AOI (e.g., from WU to BU; calculated by the number of transitions from an AOI to another AOI/total number of transitions between AOIs), and (iii) entropy (i.e., predictability, or alternatively randomness). The use of relative values for the number of transitions between AOIs was used to account for differences in clip duration (Timmis, Turner and van Paridon, 2014). Entropy calculations used a dwell-based approach (i.e., a stabilisation of any duration by the fovea on an AOI). Entropy calculations are described in chapter 9: Experiment 5. As with the analysis of the summary fixation data, for each variable the mean value of group, and the mean value of the clips analysed were used.

***4.5.3 Analysis of summary fixation data.*** A single independent one-way ANOVA was used to analyse between-group differences for the total number of fixations during the entire trial. The relative number of fixations on the AOIs, the relative total fixation duration on the AOIs, and the average fixation duration on the AOIs were each initially analysed using a repeated measures 3 (coaching level) × 10 (AOI) ANOVA. The 3 × 10 ANOVAs were followed up with separate independent one-way ANOVAs for each AOI where appropriate. Effect size was calculated using partial eta squared ($\eta p^2$). Where appropriate, post-hoc pairwise comparisons using Fisher's least significant difference (LSD) were performed. Post-hoc effect sizes were calculated using Cohen's *d*.

Due to the exploratory nature of the present series of experiments, within-group differences for the relative number of fixations on AOIs, relative total fixation duration on AOIs, and average fixation duration on AOIs were analysed using a repeated-measures one-way ANOVA with the primary and secondary AOIs as the within-subject factor. Effect size was calculated using $\eta p^2$. Post-hoc pairwise comparisons using Fisher's LSD were performed where appropriate. Post-hoc effect sizes were calculated using Cohen's *d*. Further summary fixation data analysis during pre- versus post-*matte* preparation phases is described in chapter 7: Experiment 4, and further analysis of summary fixation data during repeated viewings is described in chapter 8: Experiment 4.

***4.5.4 Analysis of transition and entropy data.*** Data obtained using the NODATA tracking option (see section 4.4 for details of the NODATA tracking option) was excluded from the analysis of transition and entropy data, as NODATA did not represent a location in the visual scene, and therefore could not be transitioned from or to. Following the exclusion of NODATA, nine AOIs remained. An independent one-way ANOVA was used to analyse between-group differences for the total number of transitions between AOIs and entropy. For the analysis of the relative number of transitions from an AOI to another AOI, data from the nine AOIs provided 72 possible transitions between AOIs (i.e., from each AOI it was possible to transition to one of the eight other AOIs; see Appendix E: Figure E1 for possible transitions). Due to the high number of possible transitions, following descriptive identification of the most frequent transition combinations, it was decided to limit further statistical analysis to transitions between the AOIs most frequently utilised by participants (i.e., WU, BU, SP; as identified in chapter 6: Experiment 2 and chapter 7: Experiment 3). The selection of these three AOIs meant that six transitions from an AOI to another AOI were included in the analysis (i.e., (i) WU to BU, (ii) WU to SP, (iii) BU to WU, (iv) BU to SP, (v) SP to WU, (vi) SP to BU). To analyse the relative number of transitions from an AOI to another AOI, a 3 (coaching level) × 6 (transition) ANOVA was utilised. Effect size was calculated using eta squared ($\eta^2$) and partial eta squared ($\eta p^2$). Where appropriate, post-hoc pairwise comparisons using Fisher's least significant difference (LSD) were performed. Post-hoc effect sizes were calculated using Cohen's *d*.

As with the summary fixation data analysis, due to the exploratory nature of the present series of experiments, within-group differences for the relative number of transitions for the six transitions identified previously, were analysed using a repeated-measures one-way ANOVA with transitions as the within-subject factor. Effect size was calculated using $\eta p^2$. Post-hoc pairwise comparisons using Fisher's

LSD were performed where appropriate. Post-hoc effect sizes were calculated using Cohen's *d*. Further analysis of transition and entropy data during pre- versus post-*matte* preparation phases is described in chapter 9: Experiment 5.

# 5. Experiment 1: Dwells versus fixations: which approach is most appropriate for analysis of visual search data during the preparation phase of judo contests?

## 5.1 Introduction

The present chapter uses a sub-set of footage collected from the CARE system to inform the analysis of visual search in the subsequent experimental chapters. Visual search data is predominantly analysed using dwell- and fixation-based approaches for measuring eye movements, and in particular the stabilisation of the fovea on AOIs. Comparison of the two approaches is required, as the present series of experiments investigating the visual search strategies of judo coaches uses both a fixation-based approach (chapters 6 – 8: Experiments 2 – 4), and a dwell-based approach to calculate transitions between AOIs and entropy (chapter 9: Experiment 5).

Investigations into the search strategies of individuals involved in sport (e.g., athletes) typically use summary fixation data. The minimum fixation duration is often defined as ≥ 99.9 ms (e.g., Vickers, 1996) or ≥ 120 ms (e.g., Williams et al., 1994), with AOIs for each specific sporting context usually determined based upon previous research (e.g., Piras and Vickers, 2011). Based upon the selected minimum fixation duration, the majority of investigations then measure the number of AOIs fixated, and the frequency and duration of fixations on each AOI (i.e., search rate; Mann et al., 2007). These variables are typically averaged across trials and participants (Button et al., 2011; Dicks et al., 2017).

Whilst many studies cite early investigations when defining their minimum fixation durations of 99.99 ms (e.g., Vickers, 1996) and 120 ms (e.g., Williams et al., 1994), there appears to be no clear rationale for the durations typically used. Indeed, a recent review of eye tracking methods, whilst identifying the fixation-based approach, did not discuss any rationale for the duration of fixations (Panchuk, Vine and Vickers, 2015). It is possible that the minimum fixation durations used may have initially been selected based upon the capture rate of the available eye tracking technology used (e.g., at 30 Hz three frames results in a duration of 99.99ms). Alternatively, it is possible that the minimum fixation durations were selected in an attempt to ensure that participants had sufficient time to encode and process information about the location in the visual scene being fixated. As fixation duration increases more effective and detailed encoding and processing of information can occur (Li et al., 2007; Rayner et al., 2009), with average fixation durations of ≈ 330 ms during scene viewing (Henderson, 2003). However, Rayner and colleagues (2009) found that fixations of at least 150 ms were required for normal processing of information when viewing natural scenes (i.e., scenes experienced in everyday life) and undertaking visual search and scene recall tasks. Thus, it still remains unclear why the typical minimum fixation durations of 99.99 ms and 120 ms have been utilised in investigations of visual search in sport if 150 ms is required for normal processing. Nonetheless, of the two minimum fixation durations typically used in investigations of visual search in sport, 120 ms provides the greatest duration for encoding and processing information, and would appear to be the most appropriate to utilise.

Whilst there is some basis for the specification of a minimum fixation duration (i.e., to allow for encoding and processing of visual information), it does mean that any period of time where the fovea is stabilised on an AOI that falls below the specified duration will not be accounted for in any analysis of visual search data. As such, using minimum fixation durations suggests an assumption that visual information cannot be obtained and processed in less than the specified minimum fixation duration. Consequently, in the interpretation of any analysis it is possible that AOIs may be deemed of less relevance to the observer, and therefore do not influence subsequent responses, as the fovea was not stabilised on the AOIs sufficiently long enough to be deemed a fixation. For example, during a visual search task an individual may have regularly stabilised their fovea on an AOI for durations ranging from 33.33 ms (1 frame) to 99.99 ms (3 frames; as measured using eye tracking equipment with a capture rate of 30 Hz), yet if the minimum specified fixation duration was set as 120 ms, these stabilisations would not be accounted for in the analysis. If it was not possible for information to be effectively encoded in process during these stabilisations, then their exclusion from the analysis would be appropriate; however, there is evidence to suggest that visual information presented for durations less than the typical minimum fixation durations can possibly be processed and influence subsequent responses.

In the neuroscience literature it has been suggested that visual stimuli can be presented to participants for very brief durations (e.g., 20 secs) and have a subsequent influence on a response (e.g., reaction time; Breitmeyer, Ogmen and Chen, 2004; Breitmeyer, Ro and Singhal, 2004; Kentridge, Nijboer and Heywood, 2008). Moreover, participants deny seeing the stimulus, suggesting that visual attention (i.e., unconscious processing) can occur in the absence of visual awareness (i.e., conscious processing and perception; Breitmeyer, Ogmen & Chen, 2004; Kentridge, Nijboer and Heywood, 2008; Lamme, 2003). The dorsal stream's involvement in oculomotor behaviour that individuals are unaware of, may explain participants' lack of awareness regarding the stimulus (van Zoest & Donk, 2010). If visual stimuli can be processed (albeit unconsciously) from short exposures and influence subsequent responses, it is possible that stabilising the fovea on an AOI for less than the typical minimum fixation durations could provide useful visual information to individuals and influence their subsequent decisions, and therefore all stabilisations of the fovea on an AOI should be accounted for. However, the studies that have demonstrated the possible influence of brief stabilisations of the fovea utilised priming protocols with basic shapes, and not natural scene viewing; consequently their applicability to visual search in sport is limited.

Despite the limited applicability of priming studies using basic shapes as stimuli to investigations of visual search in sport, there is some additional evidence to suggest that visual information presented for durations less than the typical minimum fixation durations can be encoded, and subsequently processed. For example, the context (or gist) of a scene may guide subsequent visual search (Chun, 2000), and can be encoded following very brief presentations (26 ms) of a natural scene and in the absence of exploratory eye movements (Rousselet, Joubert and Fabre-Thorpe, 2005). Additionally, reading is not impaired when words disappear after 60 ms (Rayner, Liversedge and White, 2006), suggesting that 60 ms is sufficient for information to be encoded. It must be noted that processing of the information in both the scene gist and reading scenarios would continue to occur subsequent to the removal of stimulus (i.e., the scene or word; Rayner, Liversedge and White, 2006). With regard to investigations of visual search in sport, if stimuli can be presented for brief durations and encoded for subsequent processing, it is feasible that stabilising the fovea on an AOI for less than the typical minimum fixation durations could provide useful visual information to individuals. For instance, a participant may stabilise their fovea on an athlete for 60 ms before that athlete is obscured (e.g., by an opponent or official); yet, sufficient information about the athlete (e.g., postural cues) may have been encoded during the 60 secs of stabilisation for information about the athlete to be processed, and it is possible that this information may be used to inform subsequent decision-making. However, if a fixation-based approach is used, and therefore not all stabilisations of the fovea are accounted for, this aspect of a participant's visual search may be missed.

To account for aspects of participants' visual search that may not be accounted for using the fixation-based approach, a dwell-based approach can be used. In contrast to a fixation where there is a minimum duration, a dwell is any period of time that the fovea stabilises on an AOI; therefore a dwell-based approach will account for all stabilisations of the fovea on AOIs during a trial, thus providing an indication of the relative importance of areas in the visual scene (van de Merwe, Dijk and Zon, 2012). Several investigations of individuals' visual search strategies when controlling vehicles have used dwells to calculate dwell time (e.g., van de Merwe, van Dijk and Zon, 2012; Vansteenkiste et al., 2014b). Dwell time is defined as the total time the fovea is stabilised on an AOI for the duration of a trial, and is commonly reported as a percentage of trial time (i.e., dwell time/duration of trial x100; Vansteenkiste et al., 2014b). However, whilst dwells and dwell time have been used in previous studies, there does appear to be a lack of consistency regarding terminology and analytical approaches (Vansteenkiste et al., 2014a). For example, Hagemann et al., (2010) and Milazzo et al., (2015), when investigating the visual search strategies of combat sport athletes, analysed the number and duration of fixations, yet did not define a minimum fixation duration. Therefore, it is possible that these investigations of visual search in sport used a dwell-based approach rather than the fixation-based approach typically used.

The use of different minimum fixation durations (e.g., ≤ 99 ms; Vickers, 1996; ≤ 120 ms; Williams et al., 1994), and unclear usage of terminology (e.g., Hagemann et al., 2010; Milazzo et al., 2015), limits the potential for comparison of findings from investigations of visual search strategies (Vansteenkiste et al., 2014a). Additionally, the potential for brief presentations of visual stimuli (e.g., 20 – 60 ms) to influence subsequent responses (Breitmeyer, Ogmen and Chen, 2004; Breitmeyer, Ro and Singhal, 2004; Kentridge, Nijboer and Heywood, 2008), and allow encoding of information for subsequent processing (Rayner, Liversedge and White, 2006; Rayner et al., 2009; Rousselet et al., 2005), suggests that a fixation-based approach may not account for aspects of individuals' search strategies; hence, a dwell-based approach is a possible alternative. However, the extent of any differences between findings using dwell- versus fixation-based approaches is not known. Therefore, the aim of the present chapter is to explore how using the dwell- or fixation-based approach to analyse stabilisations of the fovea on AOIs affects the findings when investigating the visual search strategies of judo coaches during the preparation phase of judo contests.

As identified in chapter 4: Methods, the preparation phase is an important tactical contest phase (Miarka et al., 2012), and a single contest phase (i.e., the preparation phase) was selected for investigation to ensure all participants undertook the same task. Due to the dwell-based approach accounting for all stabilisations of the fovea (within the constraints of the eye tracking equipment used; i.e., minimum stabilisation duration = 33.33 ms), it is hypothesised that, compared to the fixation-based approach, the dwell-based approach will result in a greater total number of stabilisations during the preparation phase, a greater number of stabilisations on an AOI, and a longer total duration of stabilisations on an AOI (minimum fixation duration = 120 ms). The greater number of stabilisations and longer total duration of stabilisations expected using the dwell-based approach are due to all stabilisations being accounted for (i.e., stabilisations ≤ 33.33 ms), whereas using the fixation-based approach stabilisations < 120 ms will not be accounted for. Consequently, a greater number of stabilisations may suggest a more extensive search strategy, with the greater number of stabilisations and greater total duration of stabilisations on an AOI resulting from the dwell-based approach making the AOI appear to have more relevance in participants' visual search strategies (e.g., by accounting for a greater proportion of their viewing time and a greater number of their stabilisations compared to when using the fixation-based approach). However, as judo contests present a limited number of potentially relevant AOIs (i.e., two athletes) in close proximity to one another and moving at a slow pace (i.e., approaching opponent at approximately walking pace), judo coaches may not need an extensive search strategy with frequent saccades to multiple AOIs dispersed throughout the visual scene (as typically observed in situations with a greater number of athletes in a large area; Williams et al., 1994). Consequently, coaches may stabilise the fovea on a relevant AOI for prolonged periods, thus mitigating any differences between the dwell- and fixation-based approaches.

## 5.2 Method

**5.2.1 Participants and procedures.** Twenty qualified judo coaches observed video footage of elite level judo contests following the procedures described in chapter 4: Methods. Coaches possessed a current national governing body coaching qualification, and were 37.7 ± 10.67 years of age, with 13.45 ± 8.27 years of coaching experience from participation (i.e., "grassroots") level to international level. The shortest (1.09 s) and longest (7.69 s) pre-*matte* preparation phases from the 9 clips of judo contests where eye movements were tracked were selected for analysis. As fixations on an AOI are defined by a minimum duration (i.e., four consecutive frames; ≥ 120 ms), and as the duration of judo contest phases can vary due to the context of the contest (e.g., score, fatigue, time remaining, penalties), the shortest and longest preparation phases were selected to assess if any interaction was present between clip duration and the dwell and fixation approaches.

**5.2.2 Statistical analysis.** The dependent variables analysed were (i) the total number of fixations (on any AOI) during the entire trial, (ii) the relative number of fixations on an AOI, (iii) the relative total fixation duration on an AOI, (iv) the total number of dwells (on any AOI) during the entire trial, (v) the relative number of dwells on an AOI (as a percentage of the total number of dwells during the clip), and (vi) the relative total dwell duration on an AOI (as a percentage of total clip duration). All AOIs were included in the analysis of the total number of fixations and dwells during the entire trial. AOIs only related to the *judoka* wearing the white *judogi* (i.e., WU and WL) were included in the analysis of the relative number of dwells and fixations, and the relative total duration of dwells and fixations. AOIs related to the *judoka* wearing white were selected, as this was the *judoka* coaches were instructed to provide coaching instructions for during the *matte* period. It was anticipated that coaches would look at this *judoka* frequently during the preparation phases, thus facilitating the comparison of dwells and fixations as measures of stabilisations of the fovea on AOIs.

Separate 2 (short clip, long clip) × 2 (fixation, dwell) repeated measures ANOVAs were performed to compare the total number of fixations and dwells on WU, the relative number of fixations and dwells on WU, the relative number of fixations and dwells on WL, the relative total fixation and dwell duration on WU, and the relative total fixation and dwell duration on WL. Paired-samples t-tests were used where appropriate to follow-up the repeated measures ANOVAs.

### 5.3 Results

Table 5.1 presents the total number of fixations and total number of dwells made during the short and long clips. Table 5.2 presents the relative number of fixations, relative number of dwells, relative total fixation duration, and relative total dwell duration on white upper (WU) and white lower (WL) areas of interest (AOIs) during the short and long clips.

**Table 5.1** Total number of fixations and total number of dwells made during short and long clips (mean ± SD)

| Clip duration | Dwells | Fixations |
|---|---|---|
| **Short** | 4.7 ± 2.41 | 2.9 ± 1.17 |
| **Long** | 18.4 ± 10.31 | 11.25 ± 3.46 |

**Table 5.2** Relative number of fixations, relative number of dwells, relative total fixation duration, and relative total dwell duration on white upper (WU) and white lower (WL) areas of interest (AOIs) during short and long clips (mean ± SD)

| | Clip duration | WU (%) Dwells | WU (%) Fixations | WL (%) Dwells | WL (%) Fixations |
|---|---|---|---|---|---|
| **Relative number** | **Short** | 16.77 ± 24.53 | 22.25 ± 26.36 | 5.28 ± 10.39 | 7.92 ± 16.99 |
| | **Long** | 25.78 ± 10.1 | 34.75 ± 12.7 | 6.17 ± 6.57 | 3.76 ± 4.5 |
| **Relative total duration** | **Short** | 25.89 ± 29.55 | 25.89 ± 29.55 | 7.99 ± 17.35 | 7.85 ± 17.41 |
| | **Long** | 39.29 ± 17.89 | 38.9 ± 17.93 | 2.93 ± 3.9 | 2.46 ± 3.59 |

**5.3.1 Total number of fixations versus total number of dwells.** There was a significant main effect of approach, $F(1, 19) = 23.43$, $p < 0.001$, $\eta p^2 = 0.55$, and a significant effect of clip, $F(1, 19) = 69.02$, $p < 0.001$, $\eta p^2 = 0.78$. Additionally, there was a significant clip (short, long) × approach (fixation, dwell) interaction, $F(1, 19) = 12.94$, $p < 0.003$, $\eta p^2 = 0.41$. During the short clip, the total number of dwells (4.7 ± 2.41) was significantly greater than the total number of fixations (2.9 ± 1.17), $t(19) = 5.34$, p < 0.001, $d = 0.95$. The total number of dwells (18.4 ± 10.31) was also significantly greater than the total number of fixations (11.25 ± 3.46) during the long clip, $t(19) = 4.35$, $p < 0.05$, $d = 0.93$. Significantly more dwells, $t(19) = - 6.74$, $p <$

0.001, $d = -1.83$, and significantly more fixations, $t(19) = -11.79$, $p < 0.001$, $d = -3.24$, were observed during the long clips compared to during the short clips (Figure 5.1).

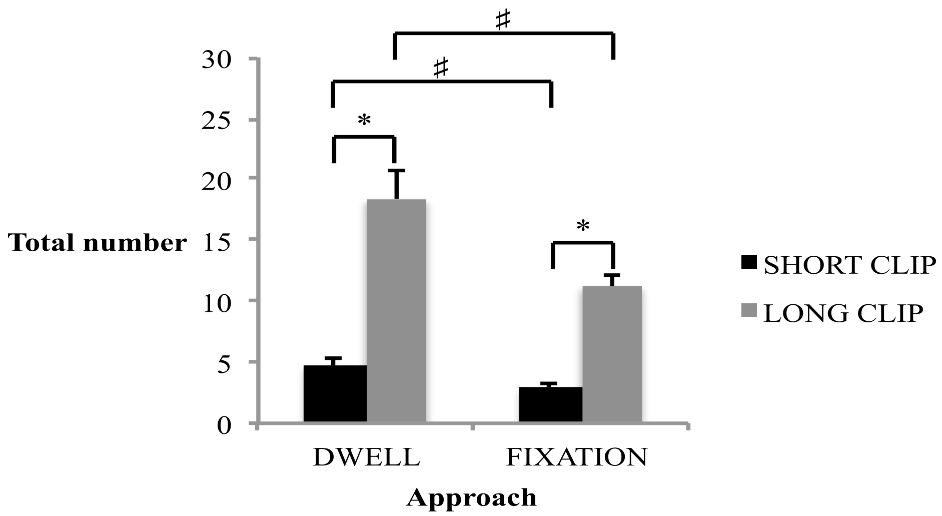


**Figure 5.1** Total number of stabilisations of the fovea using the dwell- and fixation-based approaches (mean ± SE)

* denotes significant difference (p < 0.05) between short and long clip; ♯ denotes significant difference (p < 0.05) between dwell and fixation during clips of the same duration

**5.3.2 Relative number of fixations versus relative number of dwells on an area of interest (AOI).** For WU there was a significant effect for approach, $F(1, 19) =$ $p < 0.001$, $\eta p^2 = 0.64$, with the relative number of fixations on WU collapsed across both clips (28.5 ± 21.41 %) significantly greater than the relative number of dwells on WU (21.28 ± 19.07 %; Figure 5.2a). There was a significant clip (short, long) × approach (fixation, dwell) interaction for WL, $F(1, 19) = 5.87$, $p < 0.03$, $\eta p^2 = 0.24$. During the long clip, the relative number of dwells on WL (6.17 ± 6.57) were significantly greater than the relative number of fixations on WL (3.76 ± 4.5), $t(19) = 2.69$, $p < 0.02$, $d = 0.43$ (Figure 5.2b).

**5.3.3 Relative total fixation duration versus relative total dwell time on an area of interest (AOI).** For WU there was a significant effect of approach, $F(1,19) = 5.31$, $p < 0.04$, $\eta p^2 = 0.22$. A significant clip (short, long) × approach (dwell, fixation) interaction for WU, $F(1, 19) = 5.31$, $p < 0.04$, $\eta p^2 = 0.22$, was observed. The relative total dwell duration on WU (39.29 ± 17.89 %) was significantly less than the relative total fixation duration on WU (38.9 ± 17.93 %), $t(19) = 2.3$, $p < 0.04$, $d = 0.02$ during the long clip (Figure 5.3a). For WL there was significant effect of approach, $F(1, 19) = 7.84$, $p < 0.02$, $\eta p^2 = 0.29$, with the relative total dwell duration on WL collapsed across both clips (5.46 ± 12.67; Figure 5.3b) greater than the relative total fixation duration on WL collapsed across both clips (5.15 ± 12.7).

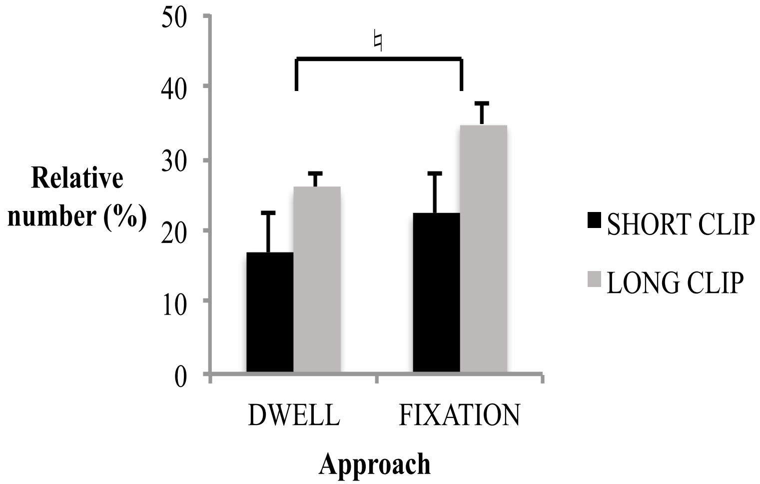


**Figure 5.2a** Relative number of stabilisations (%) of the fovea on white upper (WU) using the dwell- and fixation-based approaches during short and long clips (mean ± SE)

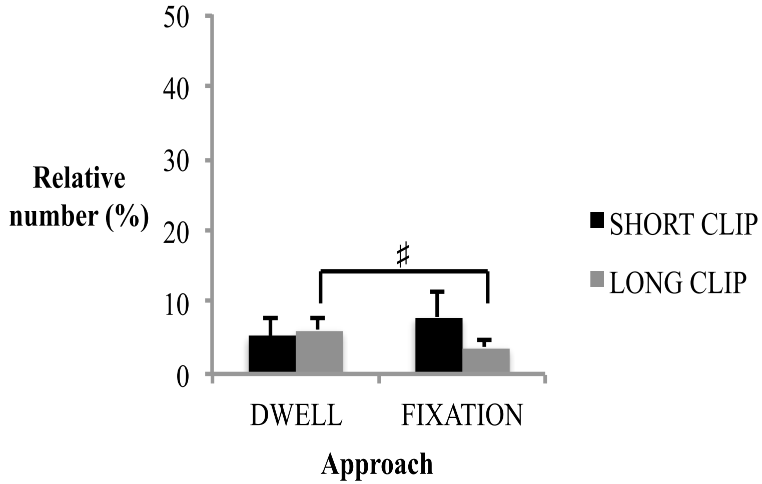


**Figure 5.2b** Relative number of stabilisations (%) of the fovea on white lower (WL) using the dwell- and fixation-based approaches during short and long clips (mean ± SE)

♯ denotes significant difference ($p < 0.05$) between dwell and fixation during clips of the same duration; ♮ denotes significant difference ($p < 0.05$) between dwell and fixation with clips collapsed

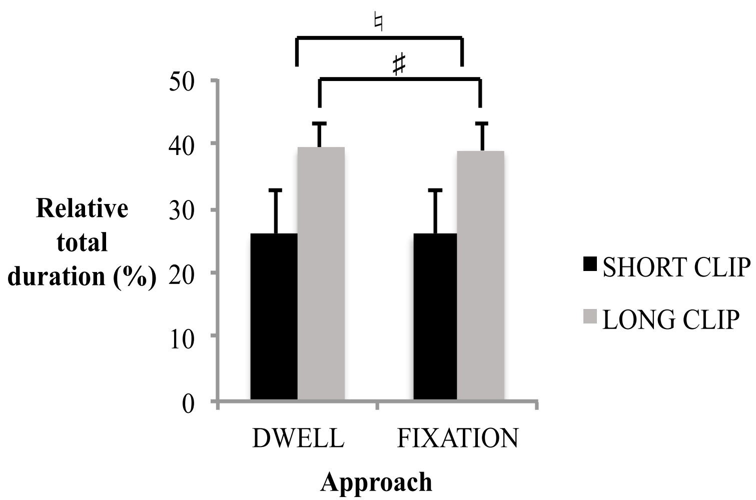


**Figure 5.3a** Relative total duration of stabilisations (%) of the fovea on white upper (WU) using the dwell- and fixation-based approaches during short and long clips (mean ± SE)

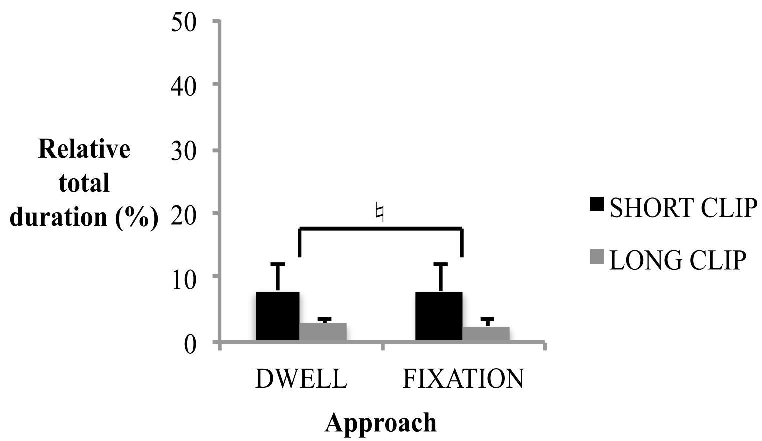


**Figure 5.3b** Relative total duration of stabilisations (%) of the fovea on white lower (WL) using the dwell- and fixation-based approaches during short and long clips (mean ± SE)

♯ denotes significant difference ($p < 0.05$) between dwell and fixation during clips of the same duration; ♮ denotes significant difference ($p < 0.05$) between dwell and fixation with clips collapsed

## 5.4 Discussion

The present chapter aimed to explore whether using a dwell- or fixation-based approach to analyse stabilisations of the fovea on AOIs affected the findings when investigating the visual search strategies of judo coaches when observing judo contest preparation phases. Whilst the dwell-based approach includes any stabilisation of the fovea on an AOI (within the constraints of the eye tracking equipment used), the fixation-based approach includes only those stabilisations that meet a specified minimum duration (e.g., 120 ms; Williams et al., 1994). Consequently, the two approaches may result in different findings with regard to participants' visual search strategies. Hence, the two approaches were used to analyse the visual search strategies of judo coaches during preparation phases to establish if they did result in different findings. The preparation phase was analysed as it is an important tactical contest phase (Miarka et al., 2012), and the analysis of a single contest phase ensured that participants were engaged in the same task. As contest phase duration can vary, a short and long preparation phase were analysed to investigate any interaction between the dwell- and fixation-based approaches and phase duration.

The judo coaches made a significantly greater total number of dwells (i.e., dwell-based approach; 11.55 ± 10.13) compared to the total number of fixations (i.e., fixation-based approach; 7.08 ± 4.94) with the data collapsed across both preparation phase clips. Additionally, the total number of dwells during the short clip (4.7 ± 2.41) was significantly greater than the total number of fixations (2.9 ± 1.17), as was the total number of dwells during the long clip (18.4 ± 10.31 versus 11.25 ± 3.46).

Furthermore, both the total number of dwells and fixations were significantly greater during the long clip compared to the short clip.

With regard to specific AOIs, with the data collapsed across both clips coaches made a significantly greater relative number of fixations on WU (28.5 ± 21.41 %) compared to the relative number of dwells (21.28 ± 19.07 %). However, the clip duration did not have a significant effect on the number of dwells or fixations. There was no significant difference between the relative number of dwells and the relative number of fixations on WL during the short clips, yet the relative number of dwells on WL (6.17 ± 6.57 %) was significantly greater than the relative number of fixations (3.76 ± 4.5 %) during the long clip.

When collapsed across both clips, the relative total dwell duration on WU (32.59 ± 25.05 %) was significantly greater than the relative total fixation duration (32.4 ± 25.01 %). During the short clip the relative total dwell and fixation durations were identical (25.89 ± 29.55 %), and during the long clip, despite a minimal actual difference (~ 0.4 %), the relative total dwell duration on WU (39.29 ± 17.89 %) was significantly greater than the relative total fixation duration (38.9 ± 17.93 %). There was no significant difference between the relative total dwell on WU during the short and long clips, or between the relative total fixation duration on WU during the short and long clips. However, the relative total dwell and fixation durations were both ~ 13 % greater in the long clip compared to the short clip. Despite a minimal actual difference (~ 0.3 %), when collapsed across both clips the relative total dwell duration on WL (5.46 ± 12.67 %) was significantly greater than the relative total fixation duration on WL (5.15 ± 12.7 %). There was no effect of clip duration on the relative total dwell and fixation durations on WL.

The greater total number of stabilisations of the fovea on AOIs observed when using the dwell-based approach compared to the fixation-based approach was as hypothesised, as this approach included all stabilisations (on relevant, irrelevant, and distracting AOIs) in the analysis, whereas the fixation-based analysis excluded stabilisations ≤ 3 frames. Consequently, the use of the dwell-based approach, in comparison to the fixation-based approach, suggests the coaches used a greater search rate (or alternatively a less efficient search strategy) during the preparation phase. The greater total number of both dwells and fixations observed during the long preparation phase clip is likely a consequence of the clips' longer duration allowing coaches more time to stabilise the fovea on AOIs. Furthermore, the greater absolute difference between the total number of dwells and fixations during the long clip (~ 7) compared to the short clip (~ 2), indicates that as clip duration increases the disparity between the dwell- and fixation-based approaches increases.

Whilst the total number of fixations was less than the total number of dwells, the relative number of fixations on WU was unexpectedly greater than the relative number of dwells on WU. Furthermore, whilst there was no effect of clip duration, both the relative number of dwells and relative number of fixations were ≥ 9 % greater during the long clip. The greater number of fixations on WU suggests that when using the fixation-based approach WU attracted the coaches' eye movements more frequently, and was therefore possibly more relevant to them, compared to when using the dwell-based approach. By accounting for all stabilisations of the fovea on AOIs, the dwell-based approach would have included brief stabilisations (i.e., 1 – 3 frames) on both potentially relevant AOIs (i.e., the *judokas*, scoreboard), and potentially irrelevant, distracting AOIs (e.g., movement in the crowd) that would not have been included using the fixation-based approach. These brief stabilisations would have contributed to the greater total number of dwells in comparison to fixations, and as a consequence the dwells on WU accounted for a lesser percentage of the total number of dwells.

Whilst the relative total dwell duration on WU was significantly greater than the relative total fixation duration on WU, the difference was minimal (~ 0.2 %). Furthermore, the relative total dwell and fixations durations on WU during the short clip were identical, and despite the relative total dwell on WU being greater than the relative total fixation, the difference was again minimal (~ 0.4 %). Therefore, it appears that using the dwell- and fixation-based approaches results in similar relative total durations for stabilisations of the fovea on WU. That the dwell-based approach did not result in a greater relative total duration than the fixation-based approach suggests that the majority of dwells must have been ≥ 4 frames (i.e., the same duration as fixations), as any dwells ≤ 3 frames would have contributed to making the relative total dwell duration greater than the relative total fixation duration. In addition, whilst not significant, the ~ 13% increase in the relative total dwell and fixation durations during the long clip, compared to during the short clip, indicates that the coaches stabilised the fovea on WU for longer during the long clip.

Unlike WU (i.e., a greater number of fixations versus dwells), the relative number of dwells on WL was significantly greater than the relative number of fixations.

Additionally, this difference between dwells and fixations was only observed during the long clip. The greater number of dwells on WL during the long clip is despite the potential for dwells on an AOI to account for a lesser percentage of the greater total number of dwells, as discussed with regards to WU. Thus, using the dwell-based approach suggests that during the long clip the coaches made brief stabilisations of the fovea on WL that were not identified using the fixation-based approach. However, despite a relative total dwell duration on WL that was significantly greater than the relative total fixation duration, the difference was minimal (~ 0.3 %), with no effect of clip duration. If coaches had made brief stabilisations of the fovea on WL, as indicated by the relative number of dwells on WL, it would be expected that the relative total dwell duration would be greater than the relative total fixation duration.

It is possible that the unclear findings regarding WL are a consequence of the large variances observed WL data (i.e., standard deviations > means). Furthermore, the relatively low number of dwells and fixations on WL (< 8 % of both total dwells and fixations), and the relatively short dwell and fixation durations on WL (< 8 % of trial time) suggest that WL may not be an important AOI for judo coaches during the preparation phase, and hence may not be the most appropriate AOI to compare the dwell- and fixation based approaches. In contrast, the frequency of dwells and fixations on WU, particularly in the long clip (> 25 % of both total dwells and fixations), and the dwell and fixation durations on WU, again particularly in the long clip (> 38 % of trial time), suggest that WU may be of greater importance to coaches than WL, and therefore a more appropriate AOI to compare the two approaches. The potentially greater importance of WU compared to WL in coaches' search strategies may be due to the contest phase being analysed and contest rules, as during the preparation phase *judokas* attempt to achieve their first grip (Miarka et al., 2012), and grips must be on or above the belt of their opponent (IJF, 2014), thus falling within the WU AOI. In addition to the potential importance of WU, the lesser variance in the WU data observed during the long clips (standard deviations < 50 % of means) compared to during the short clips (standard deviations > means) indicates that the WU data from the long clips may be the most suitable when comparing the dwell- and fixation-based approaches. It is possible that as the long clip duration (7.69 s) was more representative of competition preparation phase durations (6.56 ± 0.97 s; Miarka et al., 2016; Miarka et al., 2012), it allowed coaches to employ their preferred preparation phase search strategy (with regard to WU) to a greater extent than during the short clip.

The minimal differences observed between the dwell- and fixation-based approaches (particularly during the long clip) may be a consequence of the context of judo contests, and the visual scene presented to the coaches observing them. Due to the limited number of potentially relevant AOIs (i.e., the two *judokas*), and their proximity to one another (i.e., moving towards one another to try and take a grip), coaches may not need to adopt an extensive search strategy that requires frequent saccades to multiple AOIs dispersed around the visual scene. More extensive search strategies are typically observed in situations with multiple athletes spread across a large area (i.e., 11 versus 11 soccer scenarios spread across the width of the pitch; Williams et al., 1994), whereas less extensive search strategies (i.e., strategies using fewer saccades) are observed as athlete numbers decrease, and their proximity to one another increases (e.g., 2 versus 1 soccer scenarios; Vaeyens et al., 2007a). Thus, the visual scene presented to the judo coaches in the present experiment has greater similarity to scenarios with a fewer athletes in closer proximity to one another. If the coaches are making fewer saccades, and stabilising the fovea on the limited number of AOIs for longer durations, differences between the dwell- and fixation-based approaches would not be as apparent, as short dwells (i.e., those less than the minimum fixation threshold of ≤ 4 frames) would be less likely to occur.

### 5.5 Conclusion

As hypothesised, the dwell-based approach resulted in a greater total number of stabilisations of the fovea on AOIs compared to the fixation-based approach due to accounting for all stabilisations. Consequently, use of the dwell-based approach would be suggestive of a different search strategy (i.e., a less efficient search strategy) compared to use of the fixation-based approach. However, analysis of specific AOIs using relative measures suggested minimal difference (i.e., ≤ 7 % for all relative measures) in search strategy when using each of the two approaches, possibly due to the context of observing a judo contest (i.e., observing two athletes in close proximity).

Of the two AOIs selected for analysis, WU provided the most appropriate AOI for comparing the dwell- and fixation-based approaches, due to less variance in the WU data, and the greater use of WU by the coaches, compared to WL. Furthermore, WU data obtained during the long preparation phase clip was more suitable for comparing the two approaches due to less variance in the data compared to that obtained from the short clip, and the clip being more representative of completion preparation phase durations. Whilst the relative number of fixations on WU was greater than the relative number of dwells, the dwell-based approach accounted for all stabilisations of the fovea, and thus the dwells on WU accounted for a lesser percentage of the total number of dwells. Moreover, the minimal difference between the relative total dwell and fixation durations on WU suggests that the dwell- and fixation-based approaches both accounted for the majority of stabilisations on WU.

Whilst it appears that the dwell- and fixation-based approaches may both be used for investigating the AOIs that coaches use during the preparation phase of judo contests, the fixation-based approach should be used to enable comparisons between the present series of experiments and other investigations of visual search strategies in sport (which have all used fixation-based approaches). However, if an investigation is concerned with all stabilisations of the fovea on AOIs (e.g., the influence of distracting AOIs or the predictability of individuals' search strategies), the dwell-based approach is more appropriate. For example, whilst the fixation-based approach would not account for brief stabilisations (i.e., $\leq$ 3 frames) on distracting AOIs, the dwell-based approach would ensure that they are included in the analysis. Furthermore, by not accounting for all stabilisations of the fovea, the fixation-based approach has the potential to make search strategies appear more predictable than they may be. Use of the dwell-based approach in such instances would address this issue.

# 6. Experiment 2: Is visual search strategy different between level of judo coach when acquiring visual information from the preparation phase of judo contests?

The experiment presented in this chapter has been published as:

Robertson, P. J., Callan, M., Nevison, C. and Timmis, M. A., 2018. Is visual search strategy different between level of judo coach when acquiring information from the preparation phase of judo contests? *International Journal of Sports Science and Coaching*, 13(2), pp.186-200.

## 6.1 Introduction

Judo contests are complex situations due to the combination of physical, technical, tactical and psychological demands, and the multiple periods and phases that constitute a contest (Lahart and Robertson, 2009; Miarka et al., 2012; Santos et al., 2015). A contest consists of two recurring periods: the *hajime-matte* (begin-pause) period in which combat occurs, and the *matte* period where the contest is paused (Challis, 2010). The *hajime-matte* period can be sub-divided into two types of combat: standing combat (commonly referred to as *tachi-waza*), and ground combat (commonly referred to as *ne-waza*). In *tachi-waza judokas* (judo athletes) attempt to grip their opponent and throw them to the ground, and in *ne-waza judokas* attempt to immobilise their opponent or force them to submit. Contests (and resumption of contests) begin in *tachi-waza*. *Tachi-waza* can be sub-divided into several phases: the preparation phase, where *judokas* aim to control the space between themselves and their opponent, and attempt to establish their first grip on their opponent whilst avoiding their opponent's attempts to grip; the *kumi-kata* phase, where a *judoka* obtains a grip with one or both hands; an attack (i.e., attempt to throw); and a (possible) fall leading to *ne-waza* or a score that wins the contest (Calmet, Miarka and Franchini, 2010; Challis, 2010; Marcon et al., 2010; Miarka et al., 2012; Santos et al., 2015). Whilst the demands and structure of a judo contest present a complex situation for the competing *judoka*, they also present a complex situation for the coaches observing the contest (Santos et al., 2015).

Where judo coaches look when observing contests (i.e., their visual search strategy) may contribute to their subsequent decision-making (e.g., provision of feedback; Moreno et al., 2006), and knowing where experienced coaches look may aid in the identification of what visual information is relevant to them. However, whilst investigations into the visual search strategies of athletes (e.g., Bakker et al., 2006; Hagemann et al., 2010; Milazzo et al., 2015; Piras et al., 2016; Piras, Lobietti and Squatrito, 2014; Piras, Pierantozzi and Squatrito, 2014b; Piras et al., 2011; Savelsbergh et al., 2002; Vaeyens et al., 2007a; 2007b; Vickers, 1996; Williams et al., 1994; Williams and Davids, 1998; Williams and Elliot, 1999) and officials (e.g., Catteeuw et al., 2010; Catteeuw et al., 2009; Hancock and Ste-Marie, 2013; Spitz et al., 2016) have provided understanding of visual search strategies in sport, there are a limited number of investigations into coaches' search strategies (Damas and Ferreira, 2013; Giblin et al., 2013; Moreno et al., 2002; Moreno et al., 2006; Moreno-Hernanadez et al., 2006), and no published research investigating the visual search strategies of judo coaches.

Whilst there have been no investigations into the visual search strategies of judo coaches, high-level coaches (≥ 10 years coaching experience including international level coaching, minimum 1st dan black belt) have self-reported the grip and body position of both *judokas* as key areas to attend to when observing contests (Santos et al., 2015). However, in the absence of information about coaches' visual search strategies it is not known if and how coaches visually attend to these areas as part of their search strategy. Furthermore, it is not known which aspects of body position coaches attend to (e.g., upper body, lower body), if this depends upon the phase of the contest, or if expertise-based differences in search strategy exist. Additionally, coaches in the work of Santos et al. (2015) responded to questions about how they coach *judoka* with whom they are familiar (i.e., coach regularly at training and contests); yet coaches also observe contests where they are less familiar with the competing *judoka*. For example, coaches may coach a *judoka* at a contest for the first time (e.g., national squad coach coaching a new national squad member), or observe an unfamiliar *judoka* during a contest (live or on video) in preparation for their *judoka* competing against them.

Determining the visual search strategies used by different levels of judo coaches when observing contests can contribute to understanding which areas of the visual scene provide relevant information for coaches. In the absence of investigations into judo coaches' visual search strategies, the present study is an exploratory investigation of the effect of coaching experience on the visual search strategies of judo coaches when observing unfamiliar *judoka* during a contest phase. A single contest phase was chosen as phases present different visual stimuli to coaches (e.g., *judokas* not in contact, *judokas* in contact, *judokas* standing, *judokas* on the ground) and can therefore be considered as different visual search tasks. Previous research has shown that task requirements determine the visual search strategy utilised

(Vaeyens et al., 2007a; 2007b). To ensure all participants were viewing the same task only one phase of the judo contest was used. The preparation phase was selected for the study, as it is an important tactical contest phase occurring at the beginning of the *hajime-matte* period (Miarka et al., 2012). As an exploratory investigation, the findings of the present study have the potential to inform the development of hypotheses for future studies of judo coaches' visual search strategies.

## 6.2 Method

**6.2.1 Participants.** Fifteen qualified judo coaches and seven individuals with no experience of judo (participating or coaching) took part in the study. Participant grouping and details can be found in chapter 4: Methods.

**6.2.2 Materials and apparatus.** Video footage was obtained, edited, and viewed by participants as per the details in chapter 4: Methods. Instructions to participants regarding coaching and when to provide feedback were as described in chapter 4: Methods.

**6.2.3 Procedure.** The data collection procedure was as described in chapter 4: Methods.

**6.2.4 Data analysis.** Data analysis was carried out as described in chapter 4: Methods. Of the 9 clips tracked, 7 had a preparation phase $\leq$ 2.8 s, with the remaining 2 clips having preparation phases of $\approx$ 7 s and $\approx$ 8 s. In international competition preparation phases are longer than in lower levels of competition (Calmet, Miarka and Franchini, 2010), with a total mean duration from previous studies of 6.56 ± 0.97 s (Miarka et al., 2016; Miarka et al., 2012). Therefore, the 7 clips with preparation phase durations of ≤ 2.8 s were excluded, and the two clips with preparation phase durations of ≈ 7 s and ≈ 8 s used for further analysis. This ensured that the phases analysed replicated as closely as possible the duration of those previously reported.

**6.2.5 Statistical analysis.** Statistical analysis was carried out as described in chapter 4: Methods. Main effects and interactions reported in the present chapter refer to primary and secondary AOIs. Post-hoc analyses of differences between all AOIs are located in Appendix B. Within-group post-hoc analyses of primary AOIs only are reported within the manuscript. Within-group post-hoc analyses of secondary AOIs can be found in Appendix B.

## 6.3 Results

Table 6.1 presents the relative number of fixations, relative total fixation duration, and average fixation duration on the primary AOIs. The total number of fixations made by each group is presented in text in section 6.3.1.

**6.3.1 Total number of fixations.** The total number of fixations for the NJ, NAT, and INT groups were 30.57 ± 6.59, 28.88 ± 4.32, and 30.14 ± 4.79 respectively. There was no significant between-group difference for the mean total number of fixations, $F(2, 19) = 0.21$, $p > 0.05$, $\eta p^2 = 0.02$.

**Table 6.1** Relative number of fixations, relative total fixation duration, and average fixation duration on primary AOIs (mean ± SD)

| | Group | WU | WL | BU | BL | SP | SB |
|---|---|---|---|---|---|---|---|
| **Relative number of fixations (%)** | **NJ** | 43.67 ± 22.46 | 3.72 ± 3.19 | 28.66 ± 11.49 | 4.44 ± 4.15 | 11.08 ± 14.51 | 2.54 ± 4.67 |
| | **NAT** | 37.49 ± 9.57 | 2.45 ± 3.62 | 26.59 ± 14.04 | 7.05 ± 7.81 | 13.13 ± 6.15 | 6.97 ± 4.69 |
| | **INT** | 51.55 ± 14.60 | 1.40 ± 1.76 | 23.24 ± 8.47 | 2.49 ± 4.64 | 9.37 ± 7.04 | 7.12 ± 4.58 |
| **Relative total fixation duration (%)** | **NJ** | 40.08 ± 24.02 | 3.01 ± 2.97 | 27.13 ± 12.35 | 4.35 ± 3.86 | 11.02 ± 18.49 | 3.27 ± 5.89 |
| | **NAT** | 35.38 ± 13.24 | 1.55 ± 2.03 | 27.44 ± 15.39 | 5.25 ± 6.46 | 9.12 ± 5.99 | 12.68 ± 8.88 |
| | **INT** | 49.64 ± 10.09 | 1.42 ± 2.21 | 22.54 ± 9.67 | 1.99 ± 3.51 | 5.76 ± 4.46 | 9.07 ± 7.02 |
| **Average fixation duration (secs)** | **NJ** | 0.74 ± 0.45 | 0.31 ± 0.29 | 0.78 ± 0.45 | 0.41 ± 0.33 | 0.53 ± 0.58 | 0.17 ± 0.28 |
| | **NAT** | 0.83 ± 0.22 | 0.19 ± 0.25 | 0.94 ± 0.55 | 0.28 ± 0.30 | 0.51 ± 0.31 | 0.94 ± 0.78 |
| | **INT** | 0.99 ± 0.26 | 0.22 ± 0.34 | 0.69 ± 0.18 | 0.18 ± 0.34 | 0.35 ± 0.21 | 0.51 ± 0.37 |

AOI = area of interest; NJ = non-judo; NAT = national; INT = international; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard

**6.3.2 Relative number of fixations on the areas of interest (AOIs).** There was no significant coaching level × AOI interaction for the relative number of fixations on the AOIs, $F(18, 171) = 0.96$, $p > 0.05$, $\eta p^2 = 0.092$. The relative number of fixations was significantly affected by the AOI, $F(9, 171) = 70.66$, $p < 0.001$, $\eta p^2 = 0.79$. Within-group analysis indicated that the AOI had a significant effect on the relative number of fixations for the NJ group, $F(8, 48) = 13.88$, $p < 0.001$, $\eta p^2 = 0.7$.; NAT group, $F(8, 56) = 29.93$, $p < 0.001$, $\eta p^2 = 0.77$; and INT group, $F(9,54) = 41.86$, $p < 0.001$, $\eta p^2 = 0.88$.

***6.3.2.1 Non judo (NJ) group.*** Post-hoc analysis indicated no significant difference between the relative number of fixations on WU (43.67 ± 22.46 %) and BU (28.66 ± 11.49 %). The relative number of fixations on WU and BU were both significantly greater than on all other AOIs ($p < 0.05$, minimum mean difference = 32.59 %, $d$ = 0.93 to 2.75 and $p < 0.02$, minimum mean difference = 17.58 %, $d$ = 1.34 to 3.53 respectively; Figure 6.1a)

***6.3.2.2 National (NAT) coaches.*** There were no significant differences between the relative number of fixations on WU (37.49 ± 9.57 %) and BU (26.59 ± 14.04 %). The relative number of fixations on WU was significantly greater than on all other AOIs ($p < 0.002$, minimum mean difference = 24.35 %, $d$ = 1.25 to 5.54). The relative number of fixations on BU was significantly greater than on all other AOIs ($p < 0.03$, minimum mean difference = 19.54 %, $d$ = 1.72 to 2.68) except SP (13.13 ± 6.15 %; Figure 6.1b). The relative number of fixations on SP was significantly greater ($p < 0.04$, $d$ = 0.86 to 2.12) than on SB (6.97 ± 4.69 %), WL (2.45 ± 3.62 %) and BL (7.05 ± 7.81 %; Figure 6.1b).

***6.3.2.3 International (INT) coaches.*** The relative number of fixations on WU (51.55 ± 14.60 %) was significantly greater compared to all AOIs ($p < 0.02$, minimum mean difference = 28.32 %, $d = 2.37$ to 4.89). The relative number of fixations on BU was significantly greater ($p < 0.02$, minimum mean difference = 13.88 %, $d = 1.78$ to 3.68) than on all other AOIs (Figure 6.1c). The relative number of fixations on SP (9.37 ± 7.04) was significantly greater ($p < 0.03$, $d = 1.15$ to 1.55) than on WL (1.40 ± 1.76) and BL (2.49 ± 4.64), and the relative number of fixations on SB (7.12 ± 4.58) was significantly greater ($p = 0.032$, $d = 0.81$) than on WL (Figure 6.1c).

**6.3.3 Relative total fixation duration on the areas of interest (AOIs)**. There was no significant coaching level × AOI interaction for the relative total fixation duration on the AOIs, $F(18, 171) = 1.04$, $p > 0.05$, $\eta p^2 = 0.01$. The relative total fixation duration was significantly affected by the AOI, $F(9, 171) = 55.803$, $p < 0.001$, $\eta p^2 = 0.75$. Within-group analysis indicated that the AOI had a significant effect on the relative total fixation duration for the NJ group, $F(8, 48) = 9.60$, $p < 0.001$, $\eta p^2 = 0.62$, the NAT group, $F(9, 63) = 19.11$, $p < 0.001$, $\eta p^2 = 0.73$, and the INT group, $F(9, 54) = 53.87$, $p < 0.001$, $\eta p^2 = 0.9$.

***6.3.3.1 Non judo (NJ) group.*** Post-hoc analysis indicated no significant differences between the relative fixation duration on WU (40.08 ± 24.02 %), BU (27.13 ± 12.35 %) and SP (11.02 ± 18.49 %). The relative fixation duration on WU was significantly longer than on all other AOIs ($p < 0.02$, minimum mean difference = 35.37 %, $d = 2.08$ to 2.36). The relative total fixation duration on BU was significantly longer ($p < 0.02$, minimum mean difference = 22.79 %, $d = 2.47$ to 3.11) than all other AOIs except SP (Figure 6.2a).

***6.3.3.2 National (NAT) coaches.*** There was no significant difference between the relative total fixation duration on WU (35.38 ± 13.24 %) and BU (27.44 ± 15.39 %). The relative total fixation duration on WU was significantly longer than all other AOIs ($p < 0.02$, minimum mean difference = 22.7 %, $d = 2.15$ to 4.01). The relative total fixation duration on BU was significantly greater compared to all other AOIs ($p < 0.05$, minimum mean difference = 18.32 %, $d = 1.68$ to 2.67) except SB (12.68 ± 8.88 %). The relative total fixation duration on SB was significantly longer ($p < 0.03$, $d = 1.02$ to 1.85) than WL (1.55 ± 1.89 %) and BL (5.25 ± 6.04 %). The relative total fixation duration on SP (9.12 ± 5.60 %) was significantly longer ($p = 0.011$, $d = 1.81$) than WL (Figure 6.2b).

***6.3.3.3 International (INT) coaches.*** The relative total fixation duration on WU (49.64 ± 10.09 %) was significantly longer compared to all AOIs ($p < 0.007$, minimum mean difference = 27.06 %, $d = 2.74$ to 6.89). The relative total fixation duration on BU was significantly longer than on all other AOIs ($p < 0.03$, minimum mean difference = 13.47 %, $d = 1.59$ to 3.23). The relative total fixation duration on SB (9.07 ± 7.02 %) was significantly longer ($p = 0.24$, $d = 1.47$) than on WL (1.42 ± 2.21 %). The relative total fixation duration on SP (5.76 ± 4.46 %) was significantly longer ($p = 0.038$, $d = 0.94$) than on BL (1.99 ± 3.51 %; Figure 6.2c).

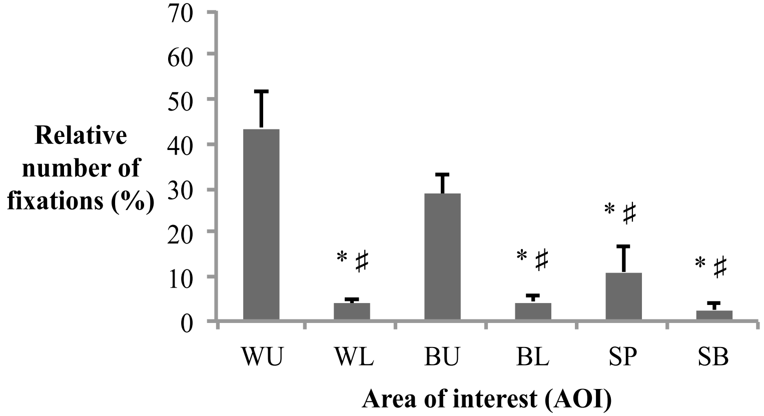


**Figure 6.1a** Relative number of fixations (%) NJ group (mean + SE)

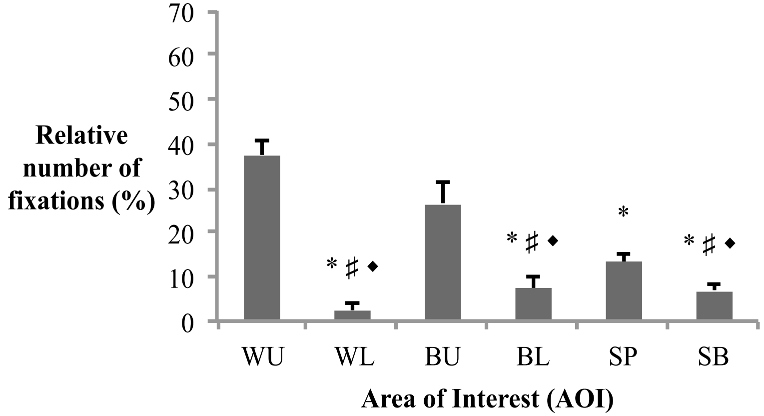


**Figure 6.1b** Relative number of fixations (%) NAT coaches (mean + SE)

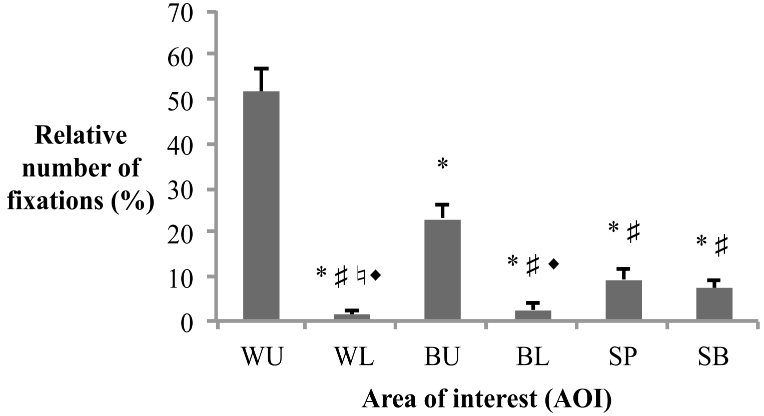


**Figure 6.1c** Relative number of fixations (%) INT coaches (mean + SE)

NJ = non-judo; NAT = national; INT = international; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard; * denotes significantly different ($p < 0.05$) from WU; ♯ denotes significantly different ($p < 0.05$) from BU; ♮ denotes significantly different ($p < 0.05$) from SB; ◆ denotes significantly different ($p < 0.05$) from SP

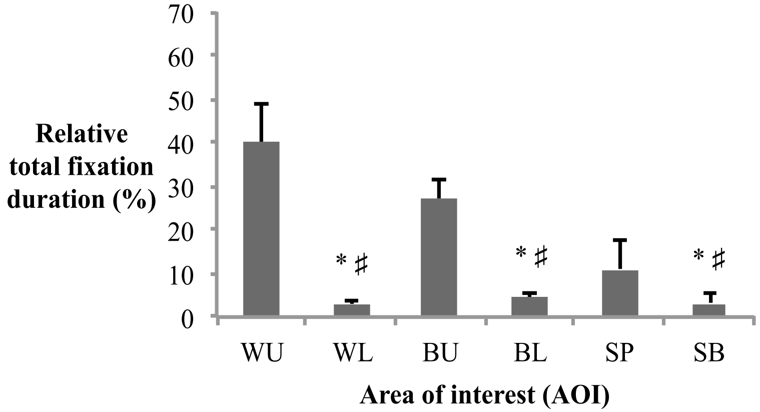


**Figure 6.2a** Relative total fixation duration (%) NJ group (mean + SE)

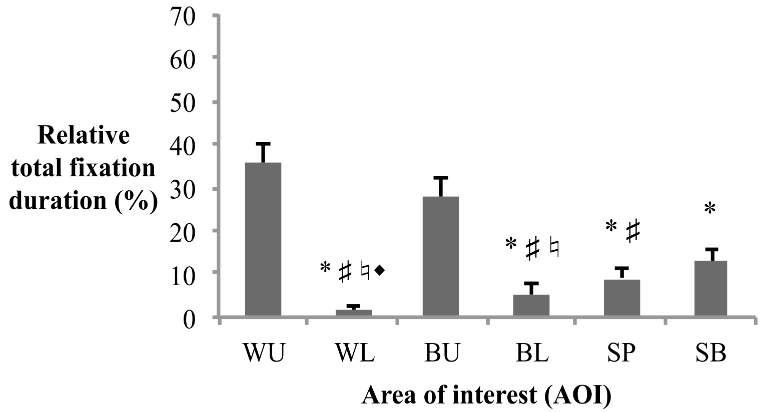


**Figure 6.2b** Relative total fixation duration (%) NAT coaches (mean + SE)

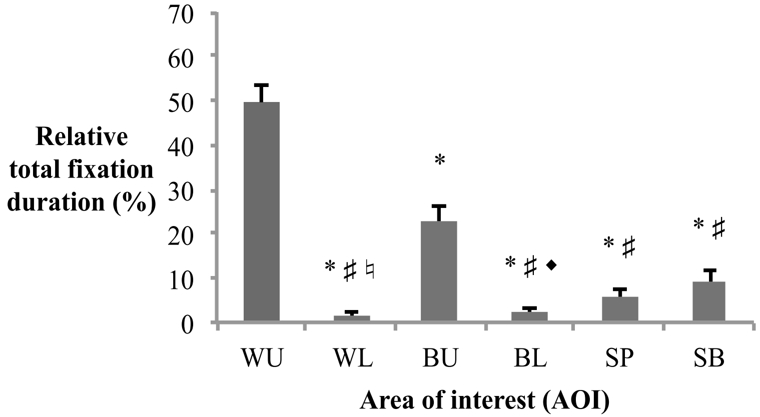


**Figure 6.2c** Relative total fixation duration (%) INT coaches (mean + SE)

NJ = non-judo; NAT = national; INT = international; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard; * denotes significantly different ($p < 0.05$) from WU; ♯ denotes significantly different ($p < 0.05$) from BU; ♮ denotes significantly different ($p < 0.05$) from SB; ◆ denotes significantly different ($p < 0.05$) from SP

**6.3.4 Average fixation duration on the areas of interest (AOIs)**. There was a significant coaching level × AOI interaction for the average fixation duration on the AOIs, $F(18,171) = 1.67$, $p < 0.05$, $\eta p^2 = 0.15$. Follow-up separate independent one-way ANOVAs for each AOI revealed a significant between-group effect for the average fixation duration on SB $F(2, 19) = 3.80$, $p < 0.05$, $\eta p^2 = 0.29$. Post-hoc analysis found that the NAT group fixated for significantly longer ($p < 0.02$, $d$ = 1.28) on SB (0.94 ± 0.78 s) in comparison to the NJ group (0.17 ± 0.28 s). No significant between-group effects were observed for the other AOIs ($p < 0.05$, $\eta p^2$ = 0.03 to 0.1).

The average fixation duration was significantly affected by the AOI, $F(9, 171) = 19.47$, $p < 0.001$, $\eta p^2 = 0.51$. Within-group analyses indicated that AOI had a significant effect on the average fixation duration on an AOI within the NJ group, $F(9, 54) = 4.24$, $p < 0.001$, $\eta p^2 = 0.41$, NAT group, $F(9, 63) = 9.07$, $p < 0.001$, $\eta p^2 = 0.56$, and INT group, $F(9, 54) = 13.15$, $p < 0.001$, $\eta p^2 = 0.69$.

***6.3.4.1 Non judo (NJ) group.*** There were no significant differences between the average fixation duration on WU (0.74 ± 0.45s), BU (0.78 ± 0.45s), SP (0.53 ± 0.58s), and BL (0.41 ± 0.33s). WU was fixated for a significantly longer average duration compared to all other AOIs ($p < 0.05$, minimum mean difference = 0.44s, $d$ = 1.17 to 2.28). The average fixation duration on BU was significantly longer ($p < 0.05$, minimum mean difference = 0.47s, $d$ = 1.26 to 2.40) than all other AOIs except SP (0.53 ± 0.58s), and BL (0.41 ± 0.33s; Figure 6.3a).

***6.3.4.2 National (NAT) coaches.*** The average fixation duration on WU (0.83 ± 0.22s) was not significantly different to BU (0.94 ± 0.55s), SP (0.94 ± 0.78s), and SB (0.51 ± 0.31s). WU was fixated for significantly longer average duration compared to all other AOIs ($p < 0.02$, minimum mean difference = 0.54s, $d = 2.06$ to 4.75). The average fixation duration on BU was significantly longer than on all other AOIs except SP and SB (p < 0.03, minimum mean difference = 0.66s, $d = 1.50$ to 2.31). The average fixation duration on SB was significantly longer ($p < 0.04$, $d = 1.10$ to 1.28) than on WL (0.19 ± 0.25) and BL (0.28 ± 0.30). The average fixation duration on SP was significantly longer than BL ($p = 0.12$, $d = 0.72$; Figure 6.3b).

***6.3.4.3 International (INT) coaches.*** There was no significant difference in the average fixation duration on WU (0.99 ± 0.26s) and BU (0.69 ± 0.18s). The average fixation duration on WU was significantly longer than on all other AOIs ($p < 0.02$, minimum mean difference = 0.47s, $d = 1.47$ to 4.54). The average fixation duration on BU was significantly longer ($p < 0.02$, mean minimum difference = 0.34s, $d =$ 1.74 to 4.15) compared to all other AOIs except SB (0.51 ± 0.37s; Figure 6.3c).

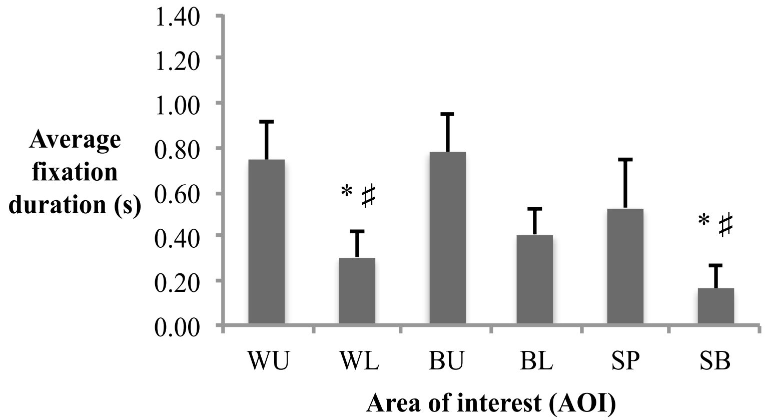


**Figure 6.3a** Average fixation duration (s) NJ group (mean + SE)

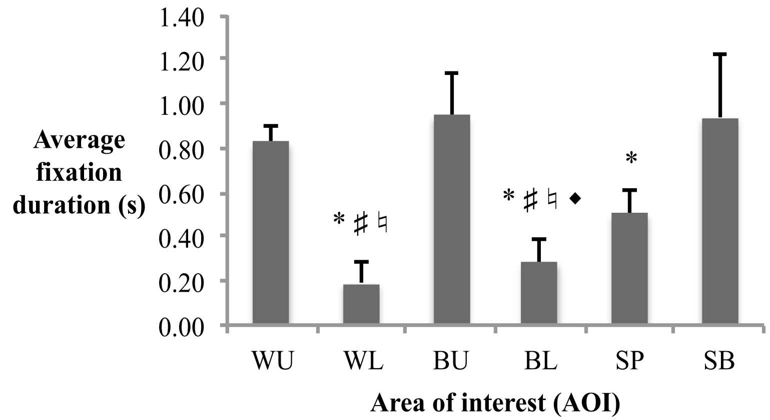


**Figure 6.3b** Average fixation duration (s) NAT coaches (mean + SE)

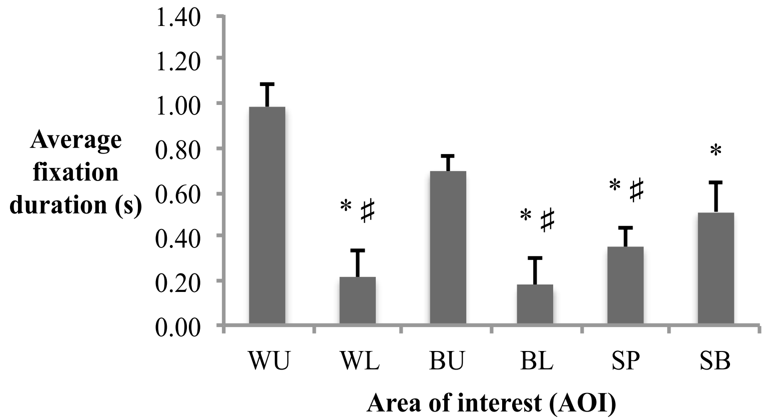


**Figure 6.3c** Average fixation duration (s) INT coaches (mean + SE)

NJ = non-judo; NAT = national; INT = international; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard; * denotes significantly different ($p < 0.05$) from WU; ♯ denotes significantly different ($p < 0.05$) from BU; ♮ denotes significantly different ($p < 0.05$) from SB; ◆ denotes significantly different ($p < 0.05$) from SP

### 6.4 Discussion

Judo contests are complex situations, in which judo coaches may observe unfamiliar *judokas* (e.g., coaching a *judoka* new to the squad, or observing *judokas* their athlete may face in future contests). Judo coaches have self-reported that grip and body position are key areas to observe during contests (Santos et al., 2015); however, there have been no investigations into the visual search strategies of judo coaches. Therefore, the aim of the present study was to investigate the effect of coaching experience on the visual search strategies of elite (INT) and sub-elite (NAT) judo coaches, and those with no experience (either coaching or playing) of judo (NJ), when observing unfamiliar *judokas* during the preparation phase of contests. As an exploratory study, the present study can also inform further investigations into judo coaches' visual search strategies.

Findings from the present study did not reveal any expertise-based between-group differences of significance for the relative number of fixations and relative total fixation duration. Within-group differences concerning upper body AOIs were found; these differences varied across groups and suggest that the INT coaches may have adopted an alternative visual search strategy to the NJ and NAT groups. However, due to the lack of between-group differences for the upper body AOIs some caution is warranted, with further investigations required to develop greater understanding of judo coaches' visual search strategies.

The INT coaches fixated more frequently on WU (52 % ± 15 %) compared to all other AOIs (Figure 6.1c). If, as suggested by Santos and colleagues (2015) grip and body position are key areas attended to by elite coaches, the results of this study show that this information appears to be gathered from the upper body. There was no significant difference between the INT coaches average fixation duration on WU (0.99 ± 0.26 s) and BU (0.69 ± 0.18 s), which in combination with the increased fixation frequency on WU, resulted in increased relative total fixation duration at WU (50 ± 10 %) versus BU (23 ± 10 %), and versus all other AOIs (Figure 6.2c). Similar to the INT, the NJ and NAT groups fixated more frequently on WU; however, there were no significant within-group differences between WU (NJ: 44 ± 22 %; NAT: 37 ± 10 %) and BU (NJ: 29 ± 11 %; NAT: 27 ± 14 %). Similarly, there were no significant differences between the relative total fixation duration on WU (NJ: 40% ± 24 %; NAT: 35% ± 12 %) and BU (NJ: 27 % ± 12 %; NAT: 27 % ± 14 %) within the NJ and NAT groups. These findings suggest that INT coaches employed a strategy whereby they frequently returned to fixate the upper part of the *judoka* they had been instructed to observe, whilst maintaining a similar average viewing time looking at both *judokas*. However, this strategy was not observed within the NAT or NJ group.

Whilst all groups fixated on WU and BU most frequently and for prolonged periods, the drive to look at these areas would have differed. Visual search is driven by the salience of features in the visual scene (stimulus driven, bottom-up signals), and the requirements of the visual search task (goal-directed, top-down signals; Lamy and Zoaris, 2009). The greater familiarity of the NAT and INT groups with the visual scene and instructions (i.e., provide coaching points for the *judoka* wearing white) would have resulted in goal-directed, top-down signals to obtain contest-specific information. The preparation phase of the contest, as analysed in this study, is a tactical phase where *judokas* aim to control the space between themselves and their opponent, and attempt to establish their first grip whilst avoiding their opponent's attempts to grip them (Miarka et al., 2012). Gripping of the opponent's *judogi* is essential for the execution of judo techniques (Collins and Challis, 2013), and achieving a favourable first grip is important, with the lapel the most common first grip location (Pierantozzi et al., 2009). Attempts to grip must be made on or above the belt of the opponent; attempts to grip or make contact below the belt are penalised (IJF, 2014). Gripping has previously been identified as a key aspect to observe when coaching during contests (Santos et al., 2015), and fixating on WU and BU would have provided the NAT and INT groups with information about gripping strategies as key grip locations (i.e., lapel) and the rules locate information about grips in the upper body AOIs. Fixating on these areas appears to have been a purposeful strategy driven by prior knowledge regarding the requirements of the task. That all other AOIs each accounted for ≤ 13 % of fixations, and were each fixated for < 13 % of clip duration in the NAT and INT groups, indicates the importance of the upper body AOIs to the judo coaches. Furthermore, it is feasible that the NAT and INT coaches would have been looking at specific regions within the upper body AOIs (e.g., lapel as a possible grip location; Pierantozzi et al., 2009). However, in the present study it was not possible to identify fixations on such specific regions. Future investigations should consider approaches that allow identification of specific upper body regions, and the use of adjunct measures such as verbal self-reports of thinking (e.g., Afonso et al., 2012) to aid in the identification of where coaches are looking.

In contrast to the NAT and INT coaches, salient features and attempts to understand an unfamiliar scene would likely have driven the visual search strategy of the NJ group. Movement is a salient feature and can strongly guide visual search and attentional deployment (MacInnes et al., 2014; Wolfe and Horowitz, 2004). Both *judoka* were engaged in attempts to grip resulting in large amounts of upper limb movement in WU and BU, thus providing similar salient features in the visual scene. In addition to movement, colour, contrast, and size are salient features (MacInnes et al., 2014; Wolfe and Horowitz, 2004), and the two *judokas* presented such features. The white and blue *judogi* worn by the *judokas* contrasted strongly with the *tatami* (red and yellow matted contest area) and the background (i.e., unlit seating area), and the *judoka* were the largest moving features in the visual scene (the referee was of a similar size but was largely static). As such, the combination of movement located in the upper body AOIs, and the colour, contrast, and size of the *judokas* in the visual scene provided strong salient stimuli to the NJ group. Goal-directed, top-down signals can suppress stimulus-driven, bottom-up signals (Geyer, Muller and Krummenacher, 2008; Vickers, 2007; Vine, Moore and Wilson, 2011); however, unlike the NAT and INT groups, it is likely that the NJ group's unfamiliarity with the visual scene meant that contest-specific goal-directed, top-down signals were not present and therefore could not suppress the influence of the salient features.

Whereas contest-specific goal-directed, top-down stimuli (e.g., obtain information about gripping) were likely to be absent in the NJ group, the instruction (i.e., provide coaching points for the *judoka* in white) and attempts to understand an unfamiliar visual scene may have resulted in some goal-directed, top-down stimuli being present. It is probable that the pre-task instruction guided eye movements to the specified *judoka*. Pre-task instructions can attract eye movements to the specified area (Bakker et al., 2006), and may do so due to the information provided being held in working memory, before subsequently guiding eye movements to the area (Dowd and Mitroff, 2013). Furthermore, it is plausible that fixating on the upper body AOIs was an attempt to gain some understanding of the unfamiliar visual scene. When presented with visual scenes containing several people and objects, peoples' eyes and heads are the most frequently fixated areas (Birmingham, Bichof and Kingstone, 2008). In particular, fixating on the eyes of a person in the visual scene allows the observer to establish the attention and intentions of that person (e.g., where they are looking and possible future movements; Birmingham, Bichof and Kingstone, 2009). In the absence of information from the eyes, the head and body orientation of a person can provide such information (Iteir and Batty, 2009). Whilst the head and eyes were not specified as AOIs in the present study due to tracking limitations, the head and eyes were contained within the upper body AOIs. Consequently, the NJ group may have been looking at these regions within the upper body AOIs in an attempt to gain visual information about the *judokas'* intentions.

Whilst the upper body AOIs provided contest-specific information to the NAT and INT coaches, the INT coaches fixated on WU compared to other AOIs significantly more frequently and for a significantly longer proportion of the clips. However, in the NAT coaches no significant differences between WU and BU for the relative number of fixations and relative total fixation duration. The greater experience of the INT coaches may account for their alternative search strategy. In addition to gripping, establishing the handedness of *judokas* in a contest is important, as handedness can indicate attacking intentions (Lee and Quan, n.d). A *judoka's* stance can indicate their handedness (e.g., left foot and left hand forward indicates left handedness); however, at higher competitive levels, *judoka* adopt varied stances not consistently related to their handedness (Collins and Challis, 2013). The use of varied stances may help a *judoka* disguise their attacking intentions by reducing the number of familiar postural cues available to their opponent (Harris, 2010; Loffing, Solter and Hagemann, 2014; Tirp et al., 2014), and well-trained *judoka* have the ability to attack in multiple directions (Mikheev et al., 2002). As the INT coaches had greater experience of observing *judoka* in international competition, it is possible that they are more aware of attempts by high-level *judoka* to disguise their handedness and attacking intentions during contests. The contests observed in this study were from an elite-level tournament; as such, the *judokas'* are likely to have utilised varied stances as described. In addition, the coaches were unfamiliar with the *judokas* they were tasked with coaching (i.e., the *judokas* wearing white), and the contest phase analysed (i.e., the preparation phase) was the first phase of a *hajime-matte* block and thus the coaches' first opportunity to observe the *judokas*. Therefore, the INT coaches' eye movements may have frequently returned to WU (i.e., the upper body of the *judoka* they were tasked with coaching) to ameliorate any attempt from the *judoka* to disguise handedness and attacking intentions, and ensure that they accurately established the handedness of their *judoka*. Furthermore, the drive to establish accurate information about the *judoka* in white could have suppressed the stimulus-driven, bottom-up signals from movement from BU (Geyer, Muller and Krummenacher, 2008; Vickers, 2007; Vine, Moore and Wilson, 2011), suggesting fixations on BU were part of a purposeful strategy, and made only when more detailed information that could not be picked up using peripheral vision was required. However, whether specific regions within the white upper body AOI were used to establish handedness could not be established in the present study. As previously mentioned, methods to identify specific regions within the upper body AOIs should be considered in future investigations.

The INT coaches's strategy of frequently returning to fixate WU could indicate that WU acted as a visual pivot for their visual search. Athletes appear to use visual pivots in a range of sports (e.g., soccer: Piras and Vickers, 2011; Vaeyens et al., 2007a; volleyball: Piras, Lobietti & Squatrito, 2014; table tennis: Piras et al., 2016; Piras et al., 2015; combat sports: Hagemann et al., 2010; Piras, Pierantozzi and Squatrito, 2014; Williams and Elliot, 1999). The visual pivot allows athletes to utilise central vision to obtain information from the area selected as the pivot, and peripheral vision to gather information from other areas of the visual scene (e.g., other players: Damas and Ferreira, 2013; distal parts of an opponent's body: Piras, Pierantozzi and Squatrito, 2014). Information gained from the visual pivot may underpin decision-making (Vaeyens et al., 2007a; 2007b) and facilitate anticipation (Piras et al., 2016; Piras, Lobietti and Squatrito, 2014). If necessary, athletes can saccade from the visual pivot to other areas to acquire more detailed information, before making a saccade back to the visual pivot (Vaeyens et al., 2007a).

Whilst the use of a visual pivot has been observed in combat sport athletes (Hagemann et al., 2010; Williams and Elliot, 1999), including *judoka* (Piras, Pierantozzi and Squatrito, 2014), how a visual pivot is used by a judo coach observing a contest may differ. Similarities between the visual search strategies of athletes and coaches from the same sport have been highlighted (Moreno-Hernandez et al., 2006), and it would seem feasible that judo coaches may adopt similar search strategies to *judokas*. Yet the visual scene presented to the judo coach is dissimilar to the scene presented to the *judoka*. Investigations into the visual search strategies of combat sport athletes typically involve the participant viewing one person (i.e., their opponent) who is in close proximity and fills the majority of the visual scene. In this instance it is likely that athletes attempt to gather the majority of their information from the opponent's postural cues to anticipate their movements (Williams and Elliot, 1999). In contrast, a combat sport coach viewing a contest, as in the present study, observes two athletes moving in a larger area. When viewing multiple athletes in larger areas, relative information (e.g., relative position of athletes to one another) also informs viewers' decisions (North et al., 2009). For the elite judo coaches observing the preparation phase, where *judokas* attempt to control the space between them and their opponent, relative information would have been important. Therefore, it is feasible that WU acted as a visual pivot that allowed them to obtain information about the handedness and attacking intentions of their *judoka*, whilst using peripheral vision to gather information about how the space between the *judokas* was being controlled.

Whilst the within-group analysis suggests that the INT coaches utilised an alternative visual search strategy to the NJ group and NAT coaches, the lack of between-group differences indicates similarities in search strategy across the groups. Previous research has found no expertise-based differences in the visual search strategies of coaches (Giblin et al., 2013) and officials (Catteeuw et al., 2009; Hancock and Ste-Marie, 2013). However, the investigations into officials' search strategies found that despite the lack of expertise-based differences, more experienced officials made more accurate decisions (Catteeuw et al., 2009; Hancock and Ste-Marie, 2013). The greater accuracy of the experienced officials can be attributed to more effective processing of visual information (Catteeuw et al., 2009) and use of prior knowledge of similar situations (Plessner and Haar, 2006; Raab and Helsen, 2015) to inform their decision-making. Consequently, it is possible that judo coaches, regardless of level, whilst visually attending to similar areas would make different coaching decisions. However, in the present study coaching decision data was not analysed, therefore conclusions about the relationships between decision-making and visual search were not possible. Additionally, it is highly probable that coaching decisions will be informed by visual information obtained from multiple phases, therefore any analysis of visual search strategy and coaching decisions should incorporate data from all contest phases, and not solely the preparation phase.

### 6.5 Conclusion

The present study was the first to investigate the visual search strategies of elite and sub-elite judo coaches, and participants with no experience of judo, whilst observing an unfamiliar *judoka* during the preparation phase of judo contests. By investigating coaches' visual search strategies, this study adds to previous work that has utilised self-report methods to identify what judo coaches attend to when observing contests (Santos et al., 2015) and provides information to inform the development of hypotheses for future investigations into the visual search strategies of judo coaches.

Sub-elite (NAT coaches) and elite (INT coaches) judo coaches looked at the upper bodies of the competing *judokas* more frequently and for greater proportions of the total fixation duration compared to other AOIs, suggesting that the upper body provides important information to coaches during the preparation phase of contests. Grip, body position, and handedness have been previously reported as important aspects during a judo contest (Collins and Challis, 2013; Pierantozzi et al., 2009; Santos et al., 2015) and it appears that judo coaches attempt to obtain information about these aspects from the *judokas'* upper bodies. It is not known if differences in where the groups looked within the upper body AOIs were present. Future investigations should consider adopting methods (e.g., more specific AOIs, verbal reports of thinking) to establish if such differences exist.

It is possible that elite coaches adopted an alternative visual search strategy to sub-elite coaches (and NJ group), whereby they looked at the upper body of the *judoka* they had been instructed to provide coaching points more frequently and for longer than the upper body of the opposing *judoka*. Awareness of elite *judokas* attempts to disguise handedness and attacking intentions provides an explanation for the INT coaches' search strategy. By fixating frequently on the specified *judoka* the elite coaches would have been able to obtain and update visual information to help them decipher any attempts at disguising attacking intentions. The specific regions that allowed them to do this were not identified in this study. Additionally, the upper body of the *judoka* they had been instructed to provide coaching points for may have acted as a visual pivot for elite coaches' visual search, allowing them to obtain information about the space between the *judokas*.

The visual search strategy adopted by elite coaches suggests that the upper body of the *judoka* being coached may be of greater importance to them compared to that of the opponent's. Previous research highlights that elite performers in sport attend to more relevant information compared to sub-elite performers (Spitz et al., 2016). Therefore, it is feasible that the upper body of the *judoka* being coached is of greater importance (due to the need to decipher attacking intentions and provide a visual pivot) than the upper body of the opposing *judoka*. If this is the case then sub-elite coaches should be directed to attend to the upper body of the *judoka* being coached to a greater extent. However, the lack of between-group differences necessitates caution. It is feasible that expertise-based differences in visual search strategy do not exist. Yet, similar visual search strategies do not necessarily result in similar decision-making accuracy (Catteeuw et al., 2009; Hancock and Ste-Marie, 2013); and therefore future studies should consider the interaction between visual search strategy, establishing handedness and attacking intentions, prior knowledge, and decision-making in judo coaches of different levels. Additionally, researchers should investigate if judo coaches adopt similar search strategies when observing familiar *judokas* during contests.

## 7. Experiment 3: Does prior exposure to contest-specific information affect judo coaches' visual search strategies during the preparation phase of judo contests?

### 7.1 Introduction

In chapter 6: Experiment 2 the visual search strategies of judo coaches (and participants with no judo experience) whilst observing the preparation phase of judo contests were investigated. The findings from Experiment 2 show that elite judo coaches (INT coaches) fixated more frequently and for a longer total duration on the upper body of the *judoka* they were instructed to provide coaching points for (i.e., WU) compared to other AOIs. This visual search strategy was not observed in the sub-elite coaches (NAT coaches), or in the participants with no judo experience (the NJ group).

Whilst the results from Experiment 2 indicate that INT coaches appeared to primarily utilise WU in their visual search strategy, both the NJ group's and NAT coaches' fixation frequency and total fixation duration on WU was similar to the fixation frequency and total fixation duration on the opponent's upper body (i.e., BU). It is possible that INT coaches' greater experience of coaching at elite level competitions, compared to that of the NJ group and NAT coaches, could account for their increased utilisation of WU. Elite *judokas* attempt to disguise their handedness (Collins and Challis, 2013), and the INT coaches' greater experience of coaching at elite level competitions could make them more aware of this strategy. Thus, it is possible that the INT coaches' greater fixation frequency and total fixation duration on WU was an attempt to obtain accurate information about the *judoka* they had been instructed to coach (i.e., the *judoka* wearing white) by deciphering the *judoka's* attempts to disguise handedness. The need to decipher the handedness of the *judoka* wearing white would have been necessary due to the coaches' unfamiliarity with the *judoka.* However, as identified in Experiment 2, it is not uncommon for judo coaches to coach athletes with whom they are unfamiliar at tournaments (e.g., national squad coach coaching a new national squad member). Further to establishing handedness the INT coaches also may have utilised WU as a visual pivot for their visual search strategy. Using WU as a visual pivot would have allowed the INT coaches to use the greater acuity of central vision to obtain information about the *judoka* they had been instructed to coach, and peripheral vision to monitor the opponent's movements and position relative to their *judoka.*

Whilst the findings from Experiment 2 are the first contribution to the understanding of judo coaches' visual search strategies when observing contests, the findings are from the first preparation phase (and first contest phase) the participants observed. Thus, the phase was the first opportunity for coaches to search the visual scene and obtain information about the contest and *judokas*. Although the first preparation phase of a judo contest does provide an opportunity for judo coaches to obtain information about the competing *judokas* (e.g., handedness, potential gripping strategies etc.), it is not the only opportunity for coaches to obtain information about the *judokas*. The preparation phase is the first phase of a *hajime-matte* block, and judo coaches have the subsequent phases of the block (e.g., *kumi-kata* phase, *tachi-waza* phase etc.) to obtain information. During these subsequent phases, coaches can obtain further information about their *judoka* (e.g., handedness, gripping strategies, fighting style, and their *tokui-waza*; favoured techniques). Furthermore, *hajime-matte* blocks can be repeated numerous times throughout a contest, giving coaches the opportunity to observe the phases of a *hajime-matte* block several times, and to therefore continually gather information about the *judokas*. By being able to continually gather information, the coaches will be able to obtain additional information to assist them in generating a more accurate assessment of unfamiliar aspects of the situation (i.e., the *judokas*; Phillips, Klein and Sieck, 2004). It is possible that the elite coaches will possess superior perceptual skills and domain-specific knowledge that will allow them to use the additional information more effectively (Nash et al., 2012; Phillips, Klein and Sieck, 2004). Furthermore, as the contest progresses and the coaches observe several *hajime-matte* blocks, the context of the contest will change, with scores and penalties being accumulated by the *judokas*, and the available contest time decreasing.

With ongoing opportunities to gather information available to coaches as contests move through the phases of each *hajime-matte* block, it is feasible that once information is obtained (e.g., handedness), coaches will aim to obtain additional information about the *judokas* and contest. Obtaining additional information may require the coaches to alter their visual search strategy to get this information from other areas in the visual scene. The information obtained by judo coaches when observing the phases of a contest is likely to be stored in working memory. Working memory is the short-term storage of small amounts of information for use in ongoing tasks (Furley and Wood, 2016; Woodman and Chun, 2006), and such information can potentially influence attention and the visual search of a scene (e.g., Vo et al., 2015; Wood, Vine and Wilson, 2016; Woodman and Chun, 2006). Hence, it is feasible that the information obtained and stored by judo coaches when observing early phases of a contest could influence their visual search strategy during later phases of the contest.

Observations of earlier contest phases may be considered a form of prior exposure to a visual scene, as they enable judo coaches to obtain contest-specific information (i.e., information about the *judokas* and the context of the contest) that may influence their search strategy during subsequent phases. In the absence of investigations into prior exposure on coaches' visual search strategies, research from the areas of vision and perception science suggests that prior exposure to a visual scene facilitates subsequent visual search of the same or similar visual scene (e.g., Hollingworth, 2009; Kit et al., 2014; Li et al., 2016). Brief previews of a visual scene (≤ 10 s) have been shown to reduce the time required to fixate a target object in a subsequent visual search task occurring ~ 2.5 s after the preview (Hollingworth, 2009). It is possible that brief previews provide information about target location that can be stored in working memory, with this information guiding attention and subsequent visual search (Dowd and Mitroff, 2013; Hollingworth, 2009; Wood, Vine and Wilson, 2016). In addition to brief previews, repeated viewings of a visual scene have been found to alter visual search strategies, with participants using fewer fixations to locate a target (Kit et al., 2014), and fixating task irrelevant areas less frequently (Li et al., 2016), in later compared to earlier viewings. Repeated viewings of a visual scene may allow individuals to become more familiar with where objects in the scene are typically located in relation to one another, therefore aiding the location of target objects, and areas of the scene relevant to the task (Kit et al., 2014; Li et al., 2016; Vo and Wolfe, 2015).

Whilst the vision and perception science literature suggests that prior exposure can influence subsequent visual search strategies, compared to the dynamic nature and changing context of a judo contest, the scenes used are generally static (e.g., a kitchen; Kit et al., 2014), the tasks typically involve the location of a single, immobile target object (e.g., coffee maker; Kit et al., 2014), and multiple viewings of the same scene are often used (e.g., Kit et al., 2014; Li et al., 2016). Therefore, prior exposure in the context of a judo contest differs to that referred to in the vision and perception science literature, in that prior exposure refers to exposure to contest-specific information rather than repeated viewings of a visual scene. Additionally, this context-specific information is constantly developing (e.g., available contest time decreases, scores and penalties are conceded), and therefore cannot be viewed multiple times (in the context of live judo contest coaching). Moreover, judo coaches are required to not only locate relevant areas, but to also process the information available from these areas, and to use the information to inform coaching decisions. Consequently, it is possible that the task of observing judo contests and providing coaching points to a *judoka*, places a greater cognitive demand on coaches compared to that placed on participants engaging in visual search and target location tasks of static scenes. As a more cognitively demanding task, greater demands will be placed on coaches' cognitive resources. A greater working memory capacity (Wood, Vine and Wilson, 2016), or the ability to utilise information stored in long-term memory to supplement working memory (Piras, Lobietti and Squatrito, 2014), are possible mechanisms to preserve cognitive resources.

Further to working memory capacity, it has been suggested that a consistent visual search strategy may be an additional method to preserve cognitive resources (e.g., Dickinson and Zelinsky, 2007). A consistent visual search strategy, developed through task experience, may reduce cognitive demand as searchers use the same strategy for every search, and therefore do not have to use cognitive resources to recall previously searched areas of the visual scene (Biggs et al., 2013; Dickinson and Zelinsky, 2007). However, what constitutes a consistent search strategy varies. Whilst Biggs et al. (2013) defined consistency with regard to the time taken to complete search tasks (i.e., similar times to complete the task were deemed consistent); Dickinson and Zelinsky (2007) refer to consistency in terms of a consistent search path (i.e., searching a visual scene left-to-right, and then top-to-bottom on every occasion). Furthermore, Carter and Luke (2018) identified consistency was evident for several measures of eye movements associated with first pass reading (e.g., gaze duration on a word), but not for measures associated with re-reading (e.g., probability of returning to re-read a word).

Whilst Biggs et al. (2013) found that experienced professional visual searchers (security officers with > 6 yrs experience of airport x-ray search tasks) took a consistent amount of time to complete similar search tasks compared to early-career professional visual searchers (security officers with < 3 yrs experience of airport x-ray search tasks) and non-professionals, it is not known if consistency was evident for other measures of the participants' visual search strategy. Moreover, Carter and Luke (2018) suggest that whilst basic perceptual processes (e.g., those associated with first pass reading) may be consistent, an individual's comprehension of what is being viewed may affect their search strategy, with unfamiliar or complex information requiring re-fixations, and consequently greater total fixation durations to process the information. Therefore, the level of consistency in measures of visual search strategy may vary, with the level of consistency in these measures potentially associated with how complex the visual scene is to the viewer.

Although consistency has been observed in some measures of visual search (e.g., Biggs et al., 2013; Carter and Luke, 2018), these studies have presented participants with static scenes. For example, Biggs et al. (2013) presented participants with a static scene and the task of locating a stationary target object within this scene. Such a task would have required participants to search the whole scene, as there would have been no prior information regarding the potential location of the target object. Additionally, the task differs to the dynamism and changing context of a judo contest, where coaches will know the probable location of key areas in the visual scene (e.g., scoreboard, starting position of *judokas*) and therefore will not need to search the whole scene, and where coaches may need to return to previously searched locations due to changes in the context of the contest. Nonetheless, Damas and Ferreira (2013) did observe that more experienced basketball coaches, when observing 5 mins of a basketball game, adopted a more consistent visual search strategy than less experienced coaches with regard to areas of the visual scene looked at. The more experienced coaches consistently looked at the space between players during each of the three selected phases of the 5 min period, whereas such consistency was not observed in the less experienced coaches. As suggested by the authors, the consistent use of the space between the players may have represented an area in the visual scene that allowed coaches to gather information about multiple players using their peripheral vision in a manner similar to a visual pivot (Damas and Ferreira, 2013). Additionally, it is possible that the coaches consistently used the space between players to obtain relational information (i.e., information about the players' positions relative to one another) in a similar manner to skilled athletes when observing a dynamic scene (e.g., North et al., 2009).

The findings from Experiment 2 provided an indication of the visual search strategies used by sub-elite and elite judo coaches (and participants with no judo experience) during the first preparation phase. However, it is not known if these search strategies are used at later stages of contests following opportunities to obtain further information about the contest and *judokas*. Therefore, the aim of the present experiment is to investigate the visual search strategies of sub-elite and elite judo coaches (and participants with no judo experience) following prior exposure to opportunities to obtain further information about the contest and *judokas*, and the consistency of participants' search strategies as contests progress. To achieve this aim the current experimental chapter is divided into two studies. Study 1 will explore the effect of coaching experience on participants' visual search strategies whilst viewing preparation phases that follow a *matte* (pause) in the contest (i.e., the post-*matte* preparation phase). Investigating participants' visual search strategies during the post-*matte* preparation phase allows participants' to have observed a complete *hajime-matte* block containing several contest phases, and therefore to have received prior exposure to information about the contest and *judokas*. Study 2 of the present chapter will compare the data collected in Experiment 2 (i.e., during the pre- *matte* preparation phase before any contest specific information is available) to the data collected during the post-*matte* preparation phase (i.e., in study 1 of the present chapter). Comparing the data collected during the pre- and post-*matte* preparation phases can identify the consistency of participants' visual search strategies (with regard to the variables measured) as the contest progresses.

Based upon the findings from Experiment 2, and the literature regarding visual search strategy consistency in more experienced participants (e.g., Biggs et al., 2013; Damas and Ferreira, 2013), it is hypothesised that the elite coaches (INT coaches) will use a search strategy during the post-*matte* preparation phase that predominately fixates the upper body of the *judoka* they are instructed to provide coaching points for (i.e., WU), and that this strategy will not differ from that used during the pre-*matte* preparation phase. It is suggested that the INT coaches will use the same search strategy during the pre- and post-*matte* preparation phase, as through their greater experience of coaching at international level, the INT coaches would have developed a consistent, top-down driven search strategy to help them preserve cognitive resources (e.g., Biggs et al., 2013; Dickinson and Zelinsky, 2007) during the cognitively demanding task of observing a judo contest and coaching a *judoka*. In addition, WU is an AOI that will continue to provide relevant information to coaches (i.e., gripping, options re: attack and defence) during the post-*matte* preparation phase, and a top-down driven search strategy will contribute to suppressing stimulus-driven signals from salient (and potentially irrelevant) features in the visual scene (Geyer, Muller and Krummenacher, 2008; Vickers, 2007; Vine, Moore and Wilson, 2011).

Due to less experience of international level coaching, it is hypothesised that the sub-elite coaches (NAT coaches) will use a strategy that predominantly relies upon obtaining information from relevant areas using central vision during the post-*matte* preparation phase, and that this strategy may differ to that used during the pre-*matte* preparation. In the participants with no judo experience, it is expected that salient features and attempts to locate and fixate areas that can aid interpretation of an unfamiliar visual scene will drive their post-*matte* preparation phase search strategy. It is hypothesised that this strategy will differ from their pre-*matte* preparation phase search strategy, and the strategies of both the NAT and INT coaches.

## 7.2 Study 1: Method

**7.2.1 Participants.** Fifteen qualified judo coaches and seven individuals with no experience of judo (participating or coaching) took part in the study. Participant grouping and details can be found in chapter 4: Methods.

**7.2.2 Materials and apparatus.** Video footage was obtained, edited, and viewed by participants as per the details in chapter 4: Methods. Instructions to participants regarding coaching and when to provide feedback were as described in chapter 4: Methods.

**7.2.3 Procedure**. The data collection procedure was as described in chapter 4: Methods.

**7.2.4 Data analysis.** Eye movements during the post-*matte* preparation phases of the two clips selected for analysis in experimental chapter 1 were tracked. Due to a corrupted file post-*matte* preparation phase eye movements for a participant from the INT coaches could not be tracked, resulting in the INT group consisting of 6 coaches for analysis. The duration of the post-*matte* preparation phases were ≈ 4 s. The duration of the post-*matte* preparation phases were shorter than the average preparation phase length (6.56 s ± 0.97 s; Miarka et al., 2012; 2016), and the duration of the preparation phases (i.e., the pre-*matte* preparation phases) used in chapter 6: Experiment 2 (≈ 7 s and ≈ 8 s). However, to gain an understanding of the consistency of coaches' visual search strategies as contests progress, clips from the same contest were required despite the differences in duration. The use of relative measures as described in chapter 4: Methods was used to account for the differences in preparation phase duration. Eye movements were tracked using the AOI image and process described in chapter 4: Methods.

**7.2.5 Statistical analysis.** The intra- and inter-rater reliability of frame-by-frame eye movement tracking is reported in chapter 4: Methods. The dependent variables analysed were (i) the total number of fixations during the entire trial, (ii) the relative number of fixations on an AOI, and (iii) the relative total fixation duration on an AOI. For each variable, the mean value of the two clips was used. Between- and within-group analysis for each post-*matte* preparation phase variable was carried out in the same manner as analysis of the pre-*matte* preparation phase data as described in chapter 4: Methods.

Main effects and interactions reported in the study 1 results section of the present chapter refer to primary and secondary AOIs. Post-hoc analyses of differences between all AOIs are located in Appendix C. Within-group post-hoc analyses of primary AOIs only are reported within the study 1 results section of the present chapter. Within-group post-hoc analyses of secondary AOIs can be found in Appendix C.

### 7.3 Study 1: Results

**7.3.1 Total number of fixations.** The total number of fixations for the NJ group, NAT coaches, and INT coaches were 15.57 ± 5.24, 16.31 ± 4.14, and 14.75 ± 4.58 respectively. There was no significant between-group difference for the mean total number of fixations, $F(2, 18) = 0.194$, $p > 0.05$, $\eta^2 = 0.02$.

**7.3.2 Relative number of fixations on the areas of interest (AOIs)**. There was no significant coaching level × AOI interaction for the relative number of fixations on the AOIs, $F(18, 162) = 1.52.$, $p > 0.05$, $\eta p^2 = 0.14$ The relative number of fixations was significantly affected by the AOI, $F(9, 162) = 67.35$, $p < 0.001$, $\eta p^2 = 0.79$. Within-group analysis indicated that the AOI had a significant effect on the relative number of fixations for the NJ group, $F(9, 54) = 49.08$, $p < 0.001$, $\eta p^2 = 0.89$; NAT group, $F(9, 63) = 13.58$, $p < 0.01$, $\eta p^2 = 0.66$; and INT group, $F(9,45) = 23.06$, $p < 0.01$, $\eta p^2 = 0.82$.

***7.3.2.1 Non-judo (NJ) group.*** Post-hoc analysis indicated that the relative number of fixations on WU (61.63 ± 12.99 %) was significantly greater than on all other AOIs ($p < 0.01$, minimum mean difference = 39.26 %, $d$ = 3.22 – 6.71). The relative number of fixations on BU (22.38 ± 11.32 %) was significantly greater than on all other AOIs ($p < 0.01$, minimum mean difference = 18.85 %, $d$ = 2.25 – 2.8) except OTH (3.97 ± 10.50 %). The relative number of fixations on BL (3.53 ± 3.49 %) were significantly greater ($p = 0.037$, mean difference = 3.53 %, $d = 1.43$) compared to SB (00.00 ± 00.00 %; Figure 7.1a).

***7.3.2.2 National (NAT) coaches.*** There was no significant difference between the relative number of fixations on WU (41.13 ± 20.67 %) and BU (30.69 ± 17.94 %). The relative number of fixations on WU was significantly greater than on all other AOIs ($p < 0.02$, minimum mean difference = 32.47 %, $d = 1.98 – 2.7$). The relative number of fixations on BU was significantly greater than on all other AOIs ($p < 0.03$, minimum mean difference = 22.04 %, $d = 1.5 - 2.3$; Figure 7.2b).

***7.3.2.3 International (INT) coaches.*** The relative number of fixations on WU (50.81 ± 17.06 %) was significantly greater compared to all AOIs ($p < 0.01$, minimum mean difference = 23.66 %, $d = 1.65 – 4.21$). The relative number of fixations on BU was significantly greater ($p < 0.03$, minimum mean difference = 21.78 %, $d = 2.15 – 3.5$) than on all other AOIs (Figure 7.1c).

**7.3.3 Relative total fixation duration on the areas of interest (AOIs).** There was no significant coaching level × AOI interaction for the relative total fixation duration on the AOIs, $F(18, 162) = 1.79$, $p > 0.05$, $\eta p^2 = 0.17$. The relative total fixation duration was significantly affected by the AOI, $F(9, 171) = 75.46$, $p < 0.001$, $\eta p^2 = 0.81$. Within-group analysis indicated that the AOI had a significant effect on the relative total fixation duration for the NJ group, $F(9, 54) = 43.76$, $p < 0.02$, $\eta p^2 = 0.88$, the NAT coaches, $F(9, 63) = 16.76$, $p < 0.01$, $\eta p^2 = 0.71$, and the INT coaches, $F(9, 45) = 28.65$, $p < 0.02$, $\eta p^2 = 0.85$.

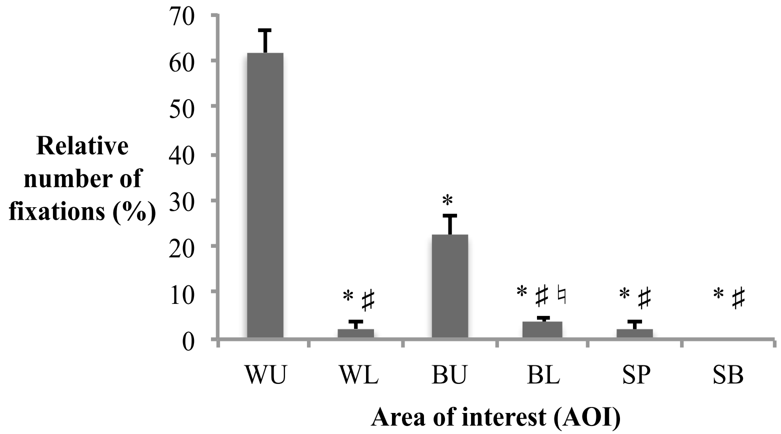


**Figure 7.1a** Post-*matte* relative number of fixations (%) NJ group (mean + SE)

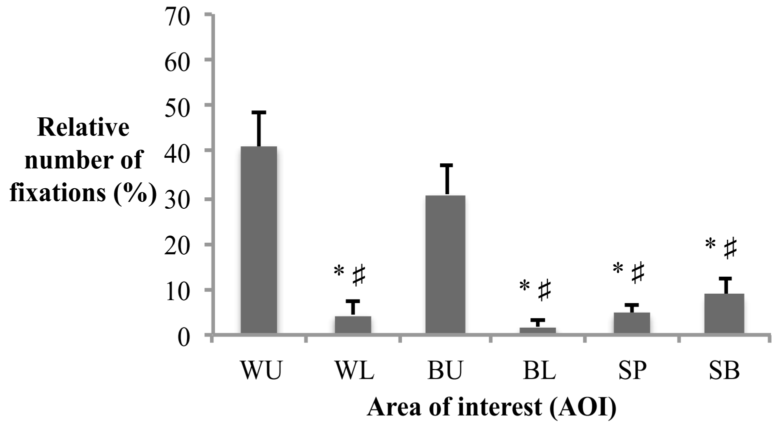


**Figure 7.1b** Post-*matte* relative number of fixations (%) NAT coaches (mean + SE)

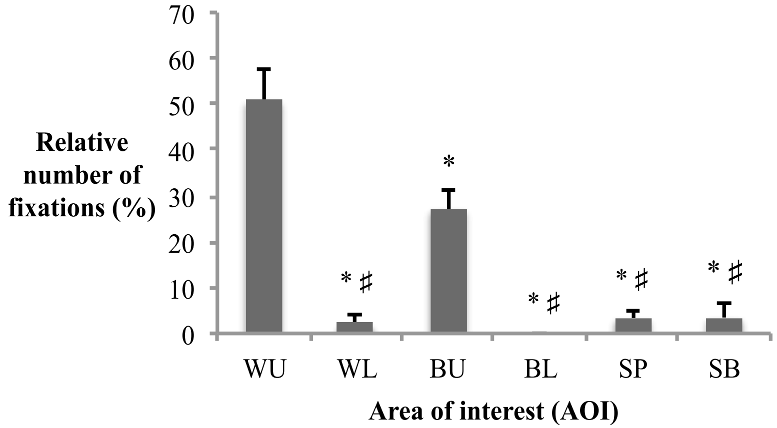


**Figure 7.1c** Post-*matte* relative number of fixations (%) INT coaches (mean + SE)

NJ = non-judo; NAT = national; INT = international; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard; * denotes significantly different ($p < 0.05$) from WU; ♯ denotes significantly different ($p < 0.05$) from BU; ♮ denotes significantly different ($p < 0.05$) from SB

***7.3.3.1 Non-judo (NJ) group.*** The relative total fixation duration on WU (60.06 ± 14.66 %) was significantly longer compared to all other AOIs ($p < 0.01$, minimum mean difference = 37.79 %, $d = 2.61 – 5.79$). The relative total fixation duration on BU (22.27 ± 14.26 %) was significantly longer than on all other AOIs ($p < 0.05$, minimum mean difference = 19.2 %, $d = 1.89 – 2.21$). The relative total fixation duration on BL (2.01 ± 2.13 %) was significantly longer ($p = 0.047$, minimum mean difference = 2.01 %, $d = 1.33$) compared to SB (00.00 ± 00.00 %; Figure 7.2a).

***7.3.3.2 National (NAT) coaches.*** There was no significant difference between the relative total fixation duration on WU (42.26 ± 16.53 %) and BU (32.45 ± 22.1 %). The relative total fixation duration on WU was significantly longer than all other AOIs ($p < 0.02$, minimum mean difference = 34.5 %, $d = 2.58 – 3.55$). The relative total fixation duration on BU was significantly longer compared to all other AOIs ($p < 0.03$, minimum mean difference = 24.68 %, $d = 1.46 – 2.03$; Figure 7.2b).

***7.3.3.3 International (INT) coaches.*** The relative total fixation duration on WU (58.59 ± 14.66 %) was significantly longer compared to all AOIs ($p < 0.004$, minimum mean difference = 40.79 %, $d = 2.62 – 4.04$). The relative total fixation duration on BU was significantly longer than on all other AOIs ($p < 0.03$, minimum mean difference = 13.59 %, $d = 1.78 – 3.15$; Figure 7.2c).

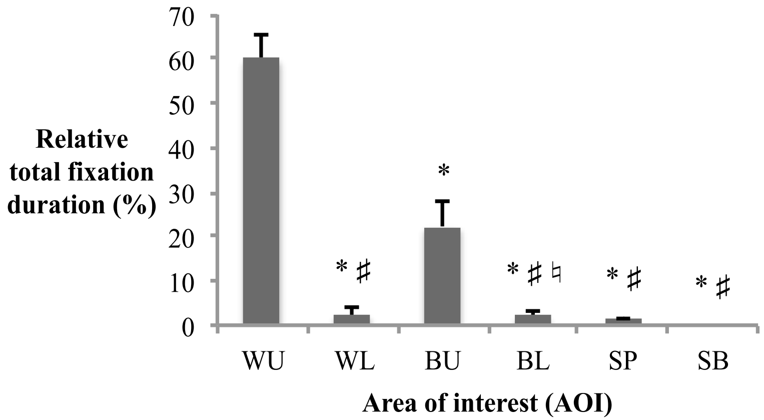


**Figure 7.2a** Post-*matte* relative total fixation duration (%) NJ group (mean + SE)

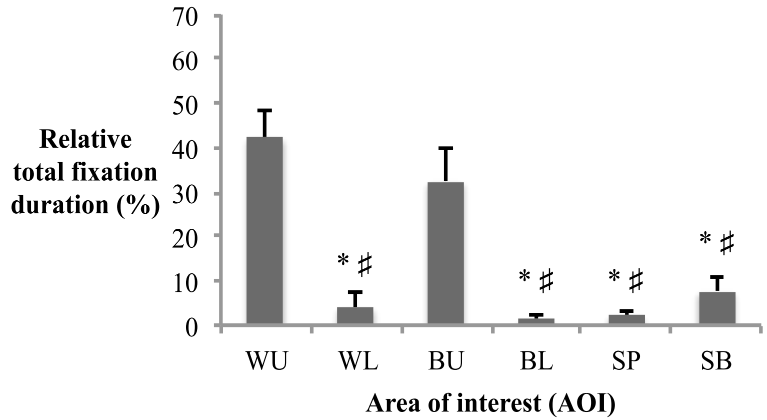


**Figure 7.2b** Post-*matte* relative total fixation duration (%) NAT coaches (mean + SE)

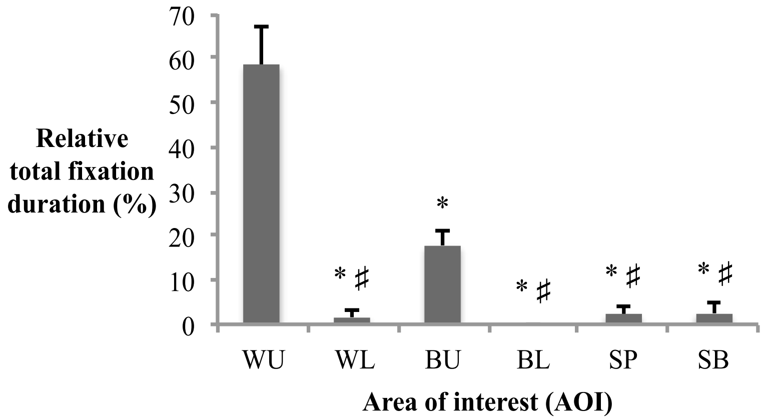


**Figure 7.2c** Post-*matte* relative total fixation duration (%) INT coaches (mean + SE)

NJ = non-judo; NAT = national; INT = international; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard; * denotes significantly different ($p < 0.05$) from WU; ♯ denotes significantly different ($p < 0.05$) from BU; ♮ denotes significantly different ($p < 0.05$) from SB

### 7.4 Study 1: Discussion

Prior exposure to visual information has the potential to influence subsequent visual search strategies (Vo et al., 2015; Wood, Vine and Wilson, 2016; Woodman and Chun, 2006), thus the information obtained by a judo coach during an early contest phase or *hajime-matte* block (i.e., contest-specific information) could influence their search strategy during a later phase or block. Therefore, study 1 of the present experimental chapter aimed to investigate the effect of coaching experience on the search strategies of sub-elite (NAT) and elite (INT) judo coaches, and participants with no judo experience (NJ), during post-*matte* preparation phases following exposure to the prior *hajime-matte* block.

Findings from study 1 of the present experimental chapter did not show any expertise-based between-group differences for the total number of fixations, relative number of fixations on the AOIs, and relative total fixation duration on the AOIs during the post-*matte* preparation phase. However, within-group differences were observed. These within-group differences varied across the groups, suggesting that the NJ group and INT coaches may have adopted an alternative visual search strategy during the post-*matte* preparation phase compared to the NAT coaches. Whilst all groups fixated on the upper body AOIs the most frequently and for the longest total durations compared to all other AOIs, the NJ group and INT coaches fixated significantly more frequently and for longer on WU compared to BU, yet the NAT coaches fixated on WU and BU in a comparable manner. The search strategies used by the NAT and INT coaches appear similar to those used by these coaches during the pre-*matte* preparation phase (as reported in chapter 6. Experiment 2) despite prior exposure to contest-specific information, whereas the search strategy used by the NJ group to differ to that used during the pre-*matte* preparation phase.

The INT coaches' greater fixation frequency and longer total fixation duration on WU (compared to BU) suggests that WU continued to be a source of relevant information to them during the post-*matte* preparation phase, despite prior exposure to contest-specific information. It is feasible that having possibly established the handedness of the *judoka* they had been instructed to coach (i.e., the *judoka* wearing white) from WU during the pre-*matte* preparation phase, that the INT coaches were trying to obtain further information from WU (e.g., gripping, body position; Santos et al., 2015) during the post-*matte* preparation phase. Additionally, it is possible that the INT coaches continued to use WU as a visual pivot, allowing them to use central vision to obtain information about their *judoka*, and peripheral vision to monitor the position of the opponent relative to their *judoka* (i.e., relational information; e.g., North et al., 2009). Whilst the NAT coaches appeared to use an alternative search strategy compared to the INT coaches (i.e., comparable use of WU and BU), they too used a similar search strategy post-*matte* compared to pre-*matte*. The NAT coaches lesser experience of elite level competition may account for their comparable use of WU and BU post-*matte* despite prior exposure to contest-specific information. Due to lesser domain-specific knowledge (compared to the INT coaches), the NAT coaches may have had to fixate on surface features (i.e., isolated actions from each *judoka*) to obtain information, rather than being able to obtain the information from a visual pivot (i.e., WU; North et al., 2009; Piras, Pierantozzi and Squatrito, 2014). Thus, it appears that judo coaches may utilise a consistent search strategy during the preparation phase of contests regardless of the availability of additional information, and that the search strategy used may be based on their level of expertise.

Unlike the NAT and INT coaches, the NJ group appeared to adopt a different search strategy during the post-*matte* preparation phase compared to during the pre-*matte* preparation phase. The NJ group's lack of judo coaching experience may account for the absence of a consistent search strategy during contest preparation phases, with information obtained following the pre-*matte* preparation phase, and prior to viewing the post-*matte* preparation phase, possibly contributing to their apparent change in search strategy. It is feasible that the on-screen instructions during the *matte* period (prior to the post-*matte* preparation phase) reiterated the requirement to provide coaching instructions to the *judoka* wearing white, therefore providing a cue for the NJ group's subsequent search (Knapp and Abrams, 2012; Kugler et al., 2015; Wood, Vine and Wilson, 2016). In the absence of judo coaching experience and a search strategy developed as a consequence of such experience, such a cue could account for the NJ group's greater fixation frequency and duration on WU compared to the other AOIs during the post-*matte* preparation phase.

In conclusion, whilst the NAT and INT coaches appeared to adopt alternative visual search strategies during the post-*matte* preparation phase, both groups seemed to use a similar strategy post-*matte* compared to that used pre-*matte* despite prior exposure to contest-specific information. While differences in international coaching experience may account for the alternative search strategies used by the coaching groups, it is possible that the NAT and INT coaches both use a pre-determined search strategy for contest preparation phases. Unlike the NAT and INT coaches, the

NJ group's post-*matte* search strategy appeared to differ from their pre-*matte* search strategy. It is possible that the apparent absence of a consistent search strategy resulted from a lack of judo coaching experience, and that information available between the pre- and post-*matte* preparation phases influenced the NJ group's post-*matte* search strategy. To further investigate if judo coaches use a consistent search strategy during contest preparation phases, pre- and post-*matte* preparation phase search strategies were directly compared in study 2 of the present experimental chapter.

## 7.5 Study 2: Methods

**7.5.1 Participants.** Fifteen qualified judo coaches and seven individuals with no experience of judo (participating or coaching) took part in the study. Participant grouping and details can be found in chapter 4: Methods.

**7.5.2 Materials and apparatus.** Video footage was obtained, edited, and viewed by participants as per the details in chapter 4: Methods. Instructions to participants regarding coaching and when to provide feedback were as described in chapter 4: Methods.

**7.5.3 Procedure.** The data collection procedure was as described in chapter 4: Methods.

**7.5.4 Data analysis.** Eye movement data obtained from chapter 6: Experiment 2 (i.e., eye movements during observation of pre-*matte* preparation phases), and study

1 of the present chapter (i.e., eye movements during observation of post-*matte* preparation phases) was used in the analysis.

**7.5.5 Statistical analysis.** Due to the loss of post-*matte* preparation phase data for an INT group participant, the INT coaches' group mean for each variable was used to account for the missing data and allow pairwise comparison of means between the pre- and post-*matte* preparation phases. The total number of fixations during the pre- and post-*matte* preparation phases were compared using a repeated measures 2 (phase) × 3 (level) ANOVA. The relative number of fixations on the AOIs and the relative total fixation durations on the AOIs during the pre- and post-*matte* preparation phases were compared using a repeated measures 2 (phase) × 3 (level) × 10 (AOI) ANOVA. Effect size was calculated using eta squared ($\eta^2$) and partial eta squared ($\eta p^2$). Where appropriate, post-hoc pairwise comparisons using Fisher's least significant difference (LSD) were performed. Post-hoc effect sizes were calculated using Cohen's *d*.

To establish pre- versus post-*matte* preparation phase differences in each group, within-group analysis for each variable was carried out. Within-group differences for the total number of fixations were analysed using a paired samples T-test for each group. Within-group differences for the relative number of fixations and the relative total fixation duration were analysed using a repeated measures 2 (phase) × 10 (AOI) ANOVA. Post-hoc pairwise comparisons using Fisher's LSD were performed where appropriate. For each group, paired samples T-tests were used to compare the relative number of fixations and relative total fixation duration on individual AOIs during the pre- and post-*matte* preparation phases. Post-hoc effect sizes were calculated using Cohen's *d*.

**7.6 Study 2: Results**

**7.6.1 Total number of fixations.** There was no significant phase × level interaction for the total number of fixations, $F(2, 19) = 1.23$, $p > 0.05$, $\eta p^2 = 0.12$. The total number of fixations was affected by phase $F(1, 19) = 309.33$, $p < 0.001$, $\eta p^2 = 0.94$, with significantly fewer fixations during the post-*matte* preparation phase (15.54 ± 0.78) compared to the pre-*matte* preparation phase (29.86 ± 0.88 ; $p < 0.001$, mean difference = 14.32, $d = 17.22$).

Within-group analysis identified that all groups made significantly fewer fixations during the post-*matte* preparation phase compared to during the pre-*matte* preparation phase. The NJ group made 15.57 ± 5.24 fixations post-*matte* compared to 30.57 ± 6.59 fixations pre-*matte*, $t(6) = 7.13$, $p < 0.001$, $d = 2.52$. The NAT coaches made 16.31 ± 4.14 fixations post-*matte,* and 28.88 ± 4.32 fixations pre-*matte*, $t(7) = 13.47$, $p < 0.001$, $d = 2.97$, and the INT coaches made 14.75 ± 4.18 fixations post-*matte* versus 30.14 ± 4.79 fixations pre-*matte,* $t(6) = 15.54$, $p < 0.001$, $d = 3.42$.

**7.6.2 Relative number of fixations on the areas of interest (AOIs).** There was no significant phase × level × AOI ($F(18, 171) = 1.07$, $p > 0.05$, $\eta p^2 = 0.102$) interaction. A significant phase × AOI interaction was observed with group data collapsed together, $F(9, 171) = 2.92$, $p < 0.05$, $\eta p^2 = 0.13$. The relative number of fixations on BL, $t(21) = 2.59$, $p < 0.02$, $d = 0.63$, was significantly less during the post-*matte* preparation phase (1.77 ± 3.17 %) compared to during the pre-*matte* preparation phase (4.77 ± 5.93 %). The relative number of fixations on SP was also significantly less, $t(21) = 3.47$, $p < 0.01$, $d = 1.06$, post-*matte* (3.48 ± 4.24) compared to pre-*matte* (11.28 ± 9.46 %), whilst the relative number of fixations on TXT was significantly greater, $t(21) = -4.28$, $p < 0.001$, $d = -1.26$, post-*matte* (4.21 ± 4.32 %) compared to pre-*matte* (0.27 ± 0.87 %).

Within-group analysis identified a significant phase × AOI interaction, $F(9, 54) = 3.3$, $p < 0.004$, $\eta p^2 = 0.35$, in the NJ group; however, there were no significant differences between the relative number of fixations on each AOI during the pre-*matte* preparation phase compared to the post-*matte* preparation phase ($p > 0.05$). There was no significant phase × AOI interaction for the NAT coaches, $F(9, 63) = 1.03$, $p > 0.05$, $\eta p^2 = 0.13$, or the INT coaches, $F(9, 54) = 0.8$, $p > 0.05$, $\eta p^2 = 0.12$; Figure 7.3a - c).

**7.6.3 Relative total fixation duration on the areas of interest (AOIs).** There was no significant phase × level × AOI, $F(18, 171) = 0.66$, $p > 0.05$, $\eta p^2 = 0.07$) interaction. A significant phase × AOI interaction was observed for collapsed group data, $F(9, 171) = 1.89$, $p < 0.05$, $\eta p^2 = 0.19$. The relative total fixation duration on WU was significantly longer, $t(21) = -2.38$, $p < 0.03$, $d = -0.69$, during the post-*matte* preparation phase (53.12 ± 17.99 %) compared to during the pre-*matte* preparation phase (41.41 ± 17.01 %). During the post-*matte* preparation phase the relative total fixation duration on SP (1.89 ± 2.46 %) was significantly less, $t(21) = 2.72$, $p < 0.02$, $d = 0.85$, than during the pre-*matte* preparation phase (8.66 ± 10.96 %), as was the relative total fixation on BL (post-*matte*: 1.1 ± 2.09 %; pre-*matte*: 3.93 ± 4.86 %; $t(21) = 2.94$, $p < 0.01$, d = 0.76), and SB (post-*matte*: 3.61 ± 6.72 %;

pre-*matte*: 8.53 ± 8.13 %, $t(21) = 2.85$, $p < 0.02$, $d = 0.66$). Within-group analysis found that there was no significant phase × AOI interaction for the NJ group, $F(9, 54) = 2.81$, $p > 0.05$, $\eta p^2 = 0.32$, NAT coaches, $F(9, 63) = 1.09$, $p > 0.05$, $\eta p^2 = 0.32$, and INT coaches, $F(9, 54) = 1.64$, $p > 0.05$, $\eta p^2 = 0.13$ (Figure 7.4a - c).

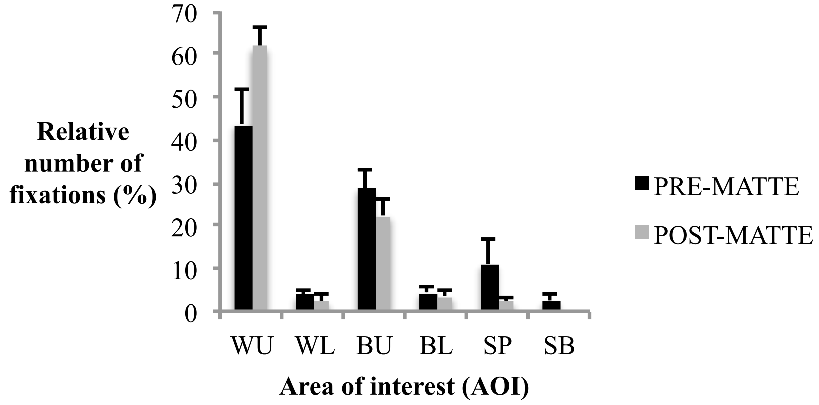


**Figure 7.3a** Pre- versus post-*matte* relative number of fixations (%) NJ group (mean + SE)

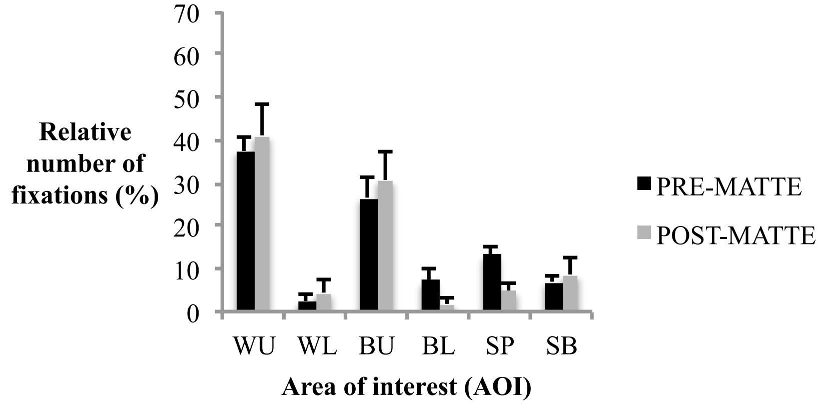


**Figure 7.3b** Pre- versus post-*matte* relative number of fixations (%) NAT coaches (mean + SE)

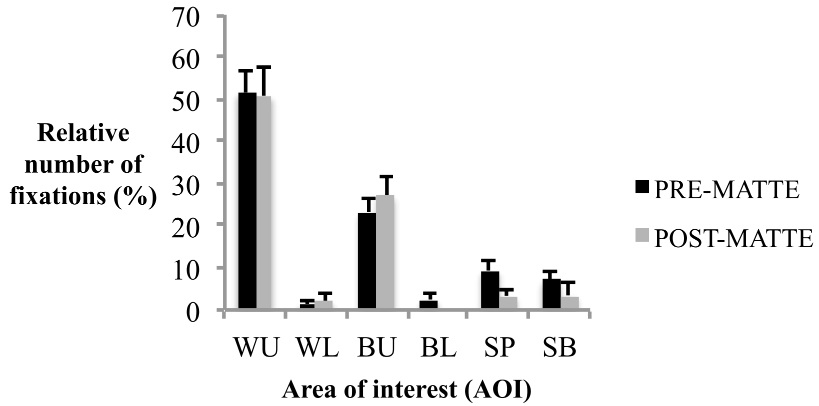


**Figure 7.3c** Pre- versus post-*matte* relative number of fixations (%) INT coaches (mean + SE)

NJ = non-judo; NAT = national; INT = international; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard

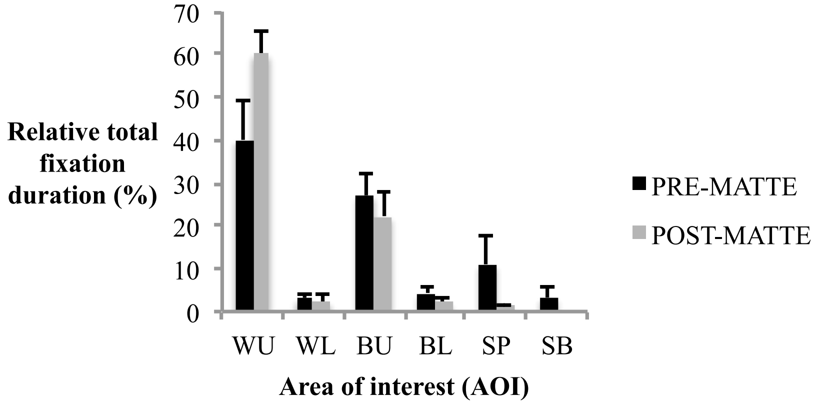


**Figure 7.4a** Pre- versus post-*matte* relative total fixation duration (%) NJ group (mean + SE)

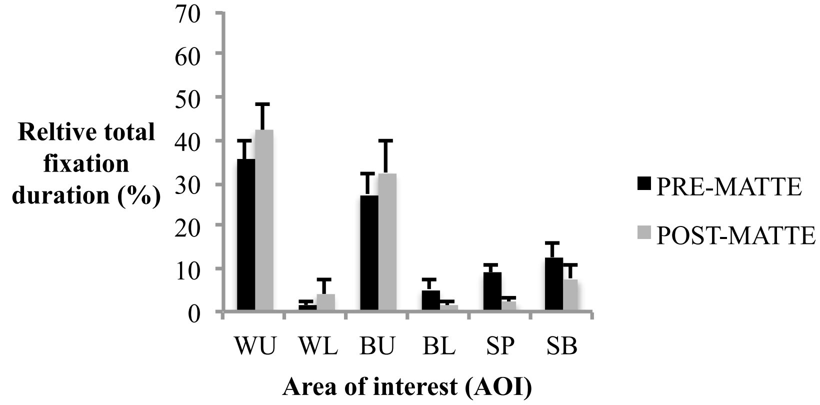


**Figure 7.4b** Pre- versus post-*matte* relative total fixation duration (%) NAT coaches (mean + SE)

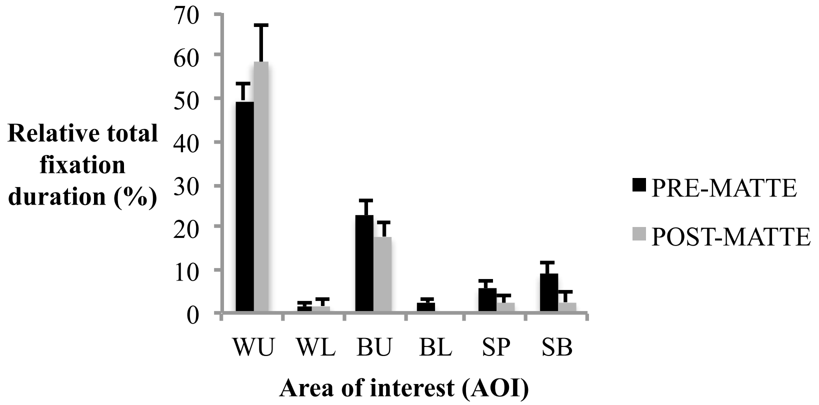


**Figure 7.4c** Pre- versus post-*matte* relative total fixation duration (%) INT coaches (mean + SE)

NJ = non-judo; NAT = national; INT = international; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard

### 7.7 Study 2: Discussion

Previous research suggests that elements of individuals' visual search strategies can remain consistent over time (e.g., Biggs et al., 2013; Carter and Luke, 2018), and that consistency may help to reduce the cognitive load associated with visual search tasks (Biggs et al., 2013; Dickinson and Zelinsky, 2007). Collectively, the findings from chapter 6: Experiment 2, and from study 1 of the present chapter, suggest that judo coaches may utilise similar search strategies during pre- and post-*matte* preparation phases. Therefore, study 2 of the present chapter directly compared data collected during the pre-*matte* preparation phase to data collected during the post-*matte* preparation phase to investigate the consistency of coaches' search strategies (with regard to the relative number of fixations and relative total fixation duration) as judo contests progress.

The results from the present study did not show any significant interaction between the level of coaching expertise and phase (i.e., the pre- or post-*matte* preparation phase) for the total number of fixations. However, there was significant effect of phase on the total number of fixations (with all groups collapsed), with a significantly greater number of fixations observed during the pre-*matte* preparation phase compared to during the post-*matte* preparation phase. Furthermore, within-group analysis indicated that the post-*matte* decrease in the total number of fixations was evident in all groups. As the total number of fixations was not a relative measure, the difference between the preparation phases was expected since the post-*matte* preparation phase clips were shorter in duration (≈ 4 s) than the pre-*matte* preparation phase clips (≈ 7 s and ≈ 8 s). Using relative measures to account for the differences in preparation phase duration, no significant interaction between level of expertise, phase, and AOI for the relative number of fixations and the relative total fixation duration was observed. However, with the data collapsed across groups, significant differences between the relative number of fixations and relative total fixation duration on the AOIs were observed. Reduced fixation frequency and total duration on SP post-*matte* compared to pre-*matte* was observed. Additionally, a post-*matte* increase in the fixation duration on WU was found. Changes in the search strategy of the NJ group, particularly with regard to WU (i.e., a significant AOI x phase interaction for the relative number of fixations, and an increase of ~ 18 % for the relative number of fixations on WU from pre- to post-*matte*) may account for the significant differences observed with the data collapsed.

The apparent changes in the pre- to post-*matte* preparation phase search strategies of the NJ group support the findings of study 1 of the present experimental chapter, whereby the NJ group used a post-*matte* search strategy that predominantly fixated on WU, in contrast to their pre-*matte* search strategy of fixating WU and BU in a comparable manner (as reported in chapter 6. Experiment 2). As previously discussed, it is possible that on-screen instructions (reiterating the requirement to provide coaching instructions to the *judoka* wearing white) provided to participants during the *matte* period (i.e., immediately prior to viewing the post-*matte* preparation phase) guided the NJ group's subsequent search towards WU (Knapp and Abrams, 2012; Kugler et al., 2015; Wood, Vine and Wilson, 2016). Such a cue was not provided prior to the pre-*matte* preparation phase. Due to a lack of coaching experience, the NJ group may have required a cue to reiterate the task, whilst the NAT and INT coaches (due to their coaching experience) did not require a cue, and appeared to have used consistent search strategies (developed as a consequence of their experience) during the pre- and post-*matte* preparation phases. The consistent search strategies used by the NAT and INT coaches were despite the on-screen instructions reiterating the task, and the availability of contest-specific information between the phases.

In conclusion, the NJ group appeared to adopt an alternative search strategy during the post-*matte* preparation phase compared to that used during the pre-*matte* preparation phase. Due to their lack of judo coaching experience, it is feasible that the on-screen instructions, and not contest specific information, guided their post-*matte* preparation phase search strategy to fixate WU more frequently. Contrastingly, the NAT and INT coaches appeared to use consistent search strategies during the pre- and post-*matte* preparation phases. This consistency is despite exposure to contest specific information (and on-screen instructions) prior to the post-*matte* preparation phase that had the potential to influence their post-*matte* search strategies. The search strategy used by judo coaches during preparation phases may be a consequence of their experience of international level coaching.

### 7.8 General discussion

The aim of the present chapter was to investigate the effect of prior exposure to contest specific information on judo coaches' subsequent visual search strategies (i.e., during the post-*matte* preparation phase), and the consistency of judo coaches' search strategies as contests progress. The results from study 1 of the present experimental chapter indicate that the NJ group and INT coaches fixated on WU more frequently and for a longer total duration compared to BU (and all other AOIs), whereas the NAT coaches fixated on WU and BU in a comparable manner. In study

2 the results indicate that all groups utilised a search strategy during the post-*matte* preparation phase that was similar to the search strategy that they used during the pre-*matte* preparation phase. However, descriptively the results suggest that the NJ group may have fixated more frequently on WU during the post-*matte* preparation phase compared to during the pre-*matte* preparation phase.

The visual search strategies used by the NAT and INT coaches during the post-*matte* preparation phase, whereby the NAT coaches fixated on WU and BU in a comparable manner, and the INT coaches predominantly fixated on WU, appear similar to the pre-*matte* preparation phase search strategies of these groups, as reported in chapter 6: Experiment 2. Thus, it appears that despite exposure to contest specific information prior to observing the post-*matte* preparation phase, the NAT and INT coaches utilised a similar search strategy to when prior exposure to contest specific information was absent (i.e., the pre-*matte* preparation phase). That there were no significant differences observed between the NAT and INT coaches pre- and post-*matte* preparation phase search strategies in study 2 of the present experimental chapter, further suggests the use of similar search strategies pre- and post-*matte*, and indicates consistency in their search strategies as contests progress. The findings regarding the post-*matte* search strategies of the NAT and INT coaches were as hypothesised, whereby the NAT coaches used a strategy that appeared to use central vision to obtain information from the upper bodies of each *judoka*, and the INT coaches predominantly fixated the upper body of the *judoka* they were instructed to provide coaching point for (i.e., WU).

Whilst the NAT and INT coaches demonstrated consistency between their pre- and post-*matte* preparation phase search strategies, the NJ group appeared to utilise an alternative post-*matte* search strategy compared to their pre-*matte* search strategy. During the post-*matte* preparation phase the NJ group predominantly fixated on WU, yet, as reported in chapter 6: Experiment 2, during the pre-*matte* preparation phase the NJ group fixated on WU and BU in a comparable manner. As hypothesised, the greater number of fixations on WU may have been an attempt to obtain information from an area in the visual scene that helped the NJ group understand an unfamiliar task. Moreover, the greater number of fixations on WU during the post-*matte* preparation phase compared to during the pre-*matte* preparation phase, further suggests an alteration in search strategy by the NJ group, and a lack of consistency in search strategy as the contest progressed. Such a lack of consistency in the NJ group's search strategy was expected. However caution is needed when interpreting these results, as pre- versus post-*matte* search strategy differences in the NJ group are descriptive; thus further research is warranted.

The predominant use of WU by the INT coaches as the contest progressed suggests that WU provided relevant information to them during both the pre- and post-*matte* preparation phases. As discussed in chapter 6: Experiment 2, due to the unfamiliarity with the *judoka* they had been asked to provide coaching instructions for (i.e., the *judoka* wearing white), the INT coaches likely fixated on WU during the pre-*matte* preparation phase to establish the *judoka's* handedness. However, during the post-*matte* preparation phase establishing handedness is unlikely to explain the INT coaches' utilisation of WU. It is probable that the INT coaches would have established handedness during the *hajime*-*matte* block prior to the post-*matte* preparation phase, and would not need to utilise WU to obtain information regarding handedness during the post-*matte* preparation phase. Consequently, that the INT coaches utilised WU during the post-*matte* preparation phase in a similar manner to how they utilised WU during the pre-*matte* preparation phase, suggests that WU was an AOI that contained relevant information (other than handedness) for the INT coaches.

Having likely established handedness prior to the post-*matte* preparation phase, the INT coaches' use of WU during the post-*matte* preparation phase may have been to obtain information about gripping and body position. Elite judo coaches have previously self-reported that grip and body position are key areas that they attend to throughout contests (Santos et al., 2015), and such information would have been located within the upper body AOIs. As identified in chapter 6: Experiment 2, gripping is an important aspect of judo (e.g., Collins and Challis, 2013), and by fixating on WU during the post-*matte* preparation phase the INT coaches could have been attempting to gain further information about their *judoka's* gripping strategy, and their *judoka's* susceptibility to their opponent's gripping strategies. Furthermore, WU would have provided information about the upper body positioning of their *judoka.* During a contest upper body positioning is important for a *judoka.* For example, a "bent-over" position (i.e., flexed hips and trunk) makes a *judoka* susceptible to dominant grips (e.g., over the back) and attacks from their opponent, and may be perceived as negative (i.e., overly defensive or passive) by the referee, possibly resulting in a *shido* (penalty) against the *judoka* (IJF, 2014). Thus, the INT coaches' use of WU during the post-*matte* preparation phase may be explained by their need to obtain information about gripping, and the body position of their *judoka* and how it could influence the outcome of the contest, and inform their next opportunity to provide feedback (i.e., during the next *matte* period). It also is possible that the INT coaches' frequent fixations on WU during the post-*matte* preparation phase represent a "checking" behaviour, where the INT coaches frequently fixate their *judoka* to "check" (i.e., to evaluate) if their feedback provided during the previous *matte* period is being implemented. Whilst any feedback provided in the present study could not be implemented (as contests were pre-recorded video clips), "checking" behavior may be part of an established search strategy driven by top-down signals, and therefore implemented regardless.

Whilst WU appears to have contained relevant information for the INT coaches during both the pre- and post-*matte* preparation phases, WU may also have acted as a visual pivot for the INT coaches' visual search during the post-*matte* preparation phase. As discussed in chapter 6: Experiment 2, using WU as a visual pivot would have allowed the INT coaches to use central vision to obtain information about their *judoka*, and to covertly shift their attention from the centre to the periphery of the visual field to obtain information about the position and movements of the opponent when necessary (e.g., Piras, Pierantozzi and Squatrito, 2014; Piras and Vickers, 2011). The INT coaches' similar pre- and post-*matte* preparation phase search strategies, suggests that the use of WU as a visual pivot may be an aspect of their search strategy that remains consistent.

Adopting a consistent search strategy as the contest progresses may have allowed the INT coaches to process the large amounts of visual information presented to them when observing contests without overloading their cognitive resources. Consistent visual search strategies have been observed in experienced coaches (Damas and Ferreira, 2013). A consistent search strategy, likely developed as a result of experience, would contribute to reducing cognitive load by allowing coaches to utilise a well-practiced strategy, and not having to use cognitive resources to develop novel strategies for each contest they observe (e.g., Biggs et al., 2013; Dickinson and Zelinsky, 2007). Additionally, it is possible that the INT coaches' search strategy resulted from automatic processing, with their attention automatically drawn to relevant stimuli (Schnieder and Chien, 2003). Such processing is fast, efficient, and requires little cognitive effort (Chien and Schnieder, 2005; Schnieder and Chien, 2003), and is likely a consequence of the INT coaches' greater experience of international level coaching. Through their greater experience of international coaching, the INT coaches would have had the opportunity to practice and develop their search strategy. Such practice has the potential to reduce activity in brain regions associated with controlled processing (i.e., processing requiring greater cognitive resources), thus contributing to more efficient and ultimately automatic processing (Chien and Schnieder, 2005).

Further reductions in cognitive load would have been achieved by the INT coaches fixating predominantly on AOIs that provided relevant (rather than irrelevant) information (i.e., WU), thus reducing the amount of information to be processed, and preserving working memory capacity (Brouwers et al., 2016; Perry et al., 2013; Piras, Lobietti and Squatrito, 2014). Such preservation of working memory capacity may allow coaches to maintain attention on the task (i.e., provide coaching instructions to the *judoka* in white) and to not be susceptible to salient and distracting features in the visual scene (Wood, Vine and Wilson, 2016). Being able to sustain attention on the task, and reduced susceptibility to salient and distracting features, is indicative of an ability to maintain top-down attentional control (Engle and Kane, 2004; Wood, Vine and Wilson, 2016), and may be a result of the INT coaches' experience of coaching at the elite level (e.g., Vine, Moore and Wilson, 2011).

As with the INT coaches, the NAT coaches also used a search strategy during the post-*matte* preparation phase that was similar to the strategy they used during the pre-*matte* preparation phase (as reported in chapter 6: Experiment 2). Yet, as discussed in chapter 6: Experiment 2, during the pre-*matte* preparation phase the NAT coaches used an alternative strategy to the INT coaches, whereby they fixated on WU and BU in a comparable manner; this alternative strategy was also used during the post-*matte* preparation phase. However, whilst the NAT coaches' adoption of a consistent search strategy may resulted from automatic processing (Chien and Schnieder, 2005; Schnieder and Chien, 2003), and reduced cognitive load by negating the need to create a novel search strategy for each contest (e.g., Biggs et al., 2013; Dickinson and Zelinsky, 2007), the comparable use of WU and BU suggests a search strategy that is characteristic of less elite level coaching experience.

As discussed in chapter 6: Experiment 2, the NAT coaches' use of this alternative strategy during the pre-*matte* preparation phase may be explained by a lack of awareness regarding *judokas'* strategies of disguising handedness (and therefore the need to frequently return to fixate on WU to obtain accurate information). Yet, as with the INT coaches, the NAT coaches are likely to have established the *judokas'* handedness during the *hajime-matte* block prior to the post-*matte* preparation phase; hence, explanations for the NAT coaches' post-*matte* search strategies based on handedness are unlikely. It is possible that the NAT coaches' search strategy during the post-*matte* preparation phase (and also the pre-*matte* preparation phase) was due to an inability to utilise relational information (in a manner similar to the INT coaches), thus resulting in a greater reliance on central vision to obtain information from surface features (i.e., information contained within the upper body AOIs). Less-skilled sport performers tend to utilise such surface features when performing perceptual-cognitive tasks, whereas skilled sport performers can utilise relational information (e.g., the position of one athlete relative to another; North et al., 2009). It is possible that the greater domain-specific knowledge of skilled sport performers possibly allows them to encode and compare the relational information they observe to information about similar scenarios stored in long-term memory (North et al., 2009; Piras, Lobietti and Squatrito, 2014). However, less-skilled performers (due to less experience) do not have the same amount of information available to make such comparisons (Piras, Lobietti and Squatrito, 2014). Accordingly, it is feasible that due to greater domain-specific knowledge the INT coaches were able to utilise WU as a visual pivot; while the NAT coaches had to obtain information from surface features (using central vision) due to less experience of elite level coaching, and therefore less relevant information in long term memory to allow effective comparisons with relational information.

Unlike the NAT and INT coaches, the NJ group appear to have adopted an alternative search strategy during the post-*matte* preparation phase compared to during the pre-*matte* preparation phase. As reported in chapter 6: Experiment 2, the

NJ group fixated on WU and BU in a comparable manner. However, findings from the present chapter show that during the post-*matte* preparation phase the NJ group fixated on WU more frequently and for a greater total duration compared to BU. Moreover, whilst not significant, descriptive data suggests that the NJ group appeared to have fixated on WU more frequently post-*matte* (~ 62 % of fixations) compared to pre-*matte* (~ 44 % of fixations). Hence, it is possible that information obtained prior to the post-*matte* preparation phase influenced the NJ group's post-*matte* search strategy, resulting in an increased frequency of fixations on WU.

As previously discussed in chapter 6: Experiment 2, it is feasible that the drive for the NJ group's pre-*matte* preparation phase search strategy was a combination of top-down, goal-directed signals (i.e., the instruction to provide coaching points for the *judoka* wearing white, and attempts to understand an unfamiliar visual scene by looking at the *judokas*' head and eyes), and bottom-up, stimulus-driven signals (i.e., the salience of the upper body AOIs). However, during the post-*matte* preparation phase, despite the continued salience of BU and the unfamiliar visual scene, the NJ group fixated on WU more frequently and for longer than on BU.

The presence of the on-screen instruction visible to participants during the *matte* period provides a possible explanation for the NJ group's post-*matte* search strategy. This instruction to provide feedback to the specified *judoka* (i.e., the *judoka* wearing white) could have acted as a cue by reiterating the task instructions (i.e., provide coaching instructions to the *judoka* wearing white during the *matte* period) given to participants at the start of the data collection period. Cues provided prior to a visual search task can guide subsequent visual search strategies (Knapp and Abrams, 2012;

Kugler et al., 2015; Wood, Vine and Wilson, 2016). Individuals may encode and hold the cue in working memory, with the cue then guiding their attention and subsequent visual search to the cued area (i.e., WU; Knapp and Abrams, 2012; Kugler et al., 2015; Wood, Vine and Wilson, 2016). Additionally, the reiteration of the task could have facilitated top-down, goal-directed signals regarding the task for the NJ group. Such top-down, goal-directed signals can suppress stimulus-driven, bottom-up signals (i.e., from salient features in a visual scene; Geyer, Muller and Krummenacher, 2008; Vickers, 2007; Vine, Moore and Wilson, 2011). Therefore, salient signals from BU may have been suppressed, resulting in the reduced fixation frequency and duration on BU compared to WU during the post-*matte* preparation phase.

The possible role of the *matte* period on-screen instruction on the NJ group's post-*matte* search strategy is despite the provision of task instructions (i.e., provide coaching instructions to the *judoka* wearing white) at the start of data collection sessions, and the availability of contest specific information during the *hajime-matte* block prior to the post-*matte* preparation phase. That the NJ group appear to have fixated less on WU during the pre-*matte* preparation phase despite the provision of task instructions, suggests that the instructions were not retained to an extent that they guided eye movements to WU, and aided in the suppression of salient signals from BU.

As the NJ group was undertaking an unfamiliar task they would have not practiced and developed a search strategy for observing judo contest preparation phases, and would have lacked domain-specific knowledge. In the absence of practice, it is feasible that the NJ group utilised controlled processing (i.e., processing requiring greater cognitive resources; Scheider and Chien, 2003), and experienced greater demands on their cognitive resources in comparision to the NAT and INT coaches. Moreover, observing unfamiliar situations (i.e., judo contests) over 45 mins duration may have challenged further their cognitive resources and attentional capacities. Under such conditions requiring sustained attention cognitive load can increase and working memory capacity may quickly be exceeded (Brouwers et al., 2016; Zoudji, Thon and Debu, 2010). Whilst breaks between blocks of clips were provided, a lack of domain-specific knowledge would have meant that the NJ group did not have relevant information stored in long-term memory to aid in completion of the task, and contribute to preserving working memory capacity (Piras, Lobietti and Squatrito, 2014; Zoudji, Thon and Debu, 2010). Consequently, despite the provision of task instructions at the start of data collection sessions that could have contributed to top-down drive for visual search (i.e., the *judoka* wearing white is important to the task), working memory capacity may have been exceeded. Therefore, during the pre-*matte* preparation phase the NJ group may not have been able maintain top-down attentional control, and would therefore have been susceptible to salient distractors (i.e., the *judoka* wearing blue; Wood, Vine and Wilson, 2016). However, for the NJ group, the provision of the *matte* period on-screen instructions may have ameliorated the challenges of maintaining top-down attentional control, by providing a cue to look at an area (i.e., WU) that was related to the task (Brouwers et al., 2016). Furthermore, in the present chapter the cue (i.e., the *matte* period on-screen instructions) was likely to have been the only meaningful information available to the NJ group, as the contest specific information available to them during the *hajime-matte* (prior to the post-*matte* preparation phase) would have little meaning due to their lack of familiarity with the task and visual scene.

Whilst there is a suggestion of a difference in NJ groups' pre- and post-*matte* search strategy, and consistency in the pre- and post-*matte* search strategies of the NAT and INT coaches, it must be recognised that a specific contest situation was analysed (i.e., pre- and post-*matte* preparation phases separated by a single *hajime-matte* block). Although the intervening block contained information that could have influenced participants' post-*matte* search strategies (i.e., information about the *judokas* and context of the contest), when several *hajime-matte* blocks separate preparation phases a greater amount of such information would be available to potentially influence participants' search strategies. Therefore, conclusions drawn from the findings of the studies in the present experimental chapter can only be generalised to the specific contest situation analysed.

### 7.9 Conclusion

The present chapter investigated how the visual search strategies of sub-elite (NAT coaches) and elite (INT coaches) judo coaches and participants with no judo experience (NJ group) are affected by prior exposure to contest specific information, and the consistency of participants' search strategies as judo contests progress. The present chapter provides the first investigation into judo coaches' visual search strategies during a later contest phase, and adds to the investigation of coaches' search strategies during the pre-*matte* preparation phase (i.e., an earlier contest phase), as reported in chapter 6: Experiment 2.

The elite coaches adopted a visual search strategy that predominantly utilised WU (possibly as a visual pivot) during both the pre- and post-*matte* preparation phases. The adoption of a post-*matte* search strategy that was similar to that used pre-*matte*, despite prior exposure to contest specific information, indicates consistency and the continuing relevance of WU to the elite coaches as contests progress. The adoption of a consistent search strategy that predominantly utilised WU may have resulted from automatic processing, and allowed the elite coaches to reduce cognitive load and preserve working memory capacity. The preservation of working memory capacity could have facilitated maintenance of top-down attentional control in the elite coaches.

The sub-elite coaches appeared to adopt an alternative visual search strategy to the elite coaches, whereby they utilised WU and BU to a comparable extent. The sub-elite coaches were consistent in utilising this strategy during both the pre- and post-*matte* preparation phases despite prior exposure to contest specific information, and like the INT coaches this strategy may have resulted from automatic processing. However, whilst consistent, the search strategy adopted by the sub-elite coaches appears to be characteristic of less elite level coaching experience. The comparable use of WU and BU suggests that the sub-elite coaches utilised central vision to obtain information about each *judoka*. The use of central vision indicates that the sub-elite coaches had to obtain information from surface features. A lack of domain-specific knowledge could have contributed to the sub-elite coaches' search strategy by limiting their ability to utilise a visual pivot, and therefore relational information.

Unlike the sub-elite and elite coaches, the NJ group appeared to adopt a different visual search strategy during the post-*matte* preparation phase compared to during the pre-*matte* preparation phase. The NJ group's increased utilisation of WU during the post-*matte* preparation phase is possibly a consequence of the on-screen instructions provided to participants during the *matte* period. Due to the NJ group's lack of familiarity with the task and visual scene, the contest specific information available prior to the post-*matte* preparation phase would lack meaning. Therefore, the on-screen instructions provided during the *matte* period (and prior to the post-*matte* preparation phase) may have provided the NJ group with meaningful information, acting as a cue to be stored in working memory, and thus facilitating top-down drive for their post-*matte* visual search in the absence of pre-determined top-down driven search strategies developed through practice.

Whilst the findings from the present chapter suggest consistency in the sub-elite and elite coaches, and a lack of consistency in the NJ group, it must be noted that interpretations of search strategy consistency refer to the variables and AOIs used. It is feasible that participants may have been searching and fixating upon several areas within the upper body AOIs to obtain information about various aspects (e.g., gripping, body position etc.), and future studies should consider approaches to investigate search strategies within the upper body AOIs. Furthermore, analysis of additional measures of gaze behavior and search strategies (e.g., temporal sequencing, entropy) should be considered to further investigate judo coaches' visual search strategies, and how they develop as contests progress.

# 8. Experimental chapter 4: Do judo coaches' visual search strategies change when viewing previously seen preparation phases of judo contests?

## 8.1 Introduction

In chapter 7: Experiment 3, the visual search strategies of sub-elite (NAT coaches) and elite (INT coaches) judo coaches (and participants with no judo experience; NJ group) during post-*matte* preparation phases of judo contests were analysed, and then compared to the search strategies used during pre-*matte* preparation phases. The findings from the previous chapter, in conjunction with the findings from chapter 6: Experiment 2, suggest that the INT coaches adopted a search strategy that predominantly utilised the upper body of the *judoka* participants had been instructed to provide coaching instructions to (i.e., WU) during both pre- and post-*matte* preparation phases. However, the NAT coaches adopted an alternative search strategy that utilised WU and the upper body of the opponent (i.e. BU) in a comparable manner during the pre- and post-*matte* preparation phases. These findings suggest that whilst the NAT coaches appear to have adopted an alternative search strategy to the INT coaches, both groups were consistent in the use of their chosen search strategy as contests progressed. This consistency was despite the provision of contest specific information (that could have influenced subsequent search strategy) during the *hajime*-*matte* block preceding the post-*matte* preparation phase. In the NJ group such consistency was not observed, as during the post-*matte* preparation phase the NJ group appeared to utilise WU to a greater extent than during the pre-*matte* preparation phase. It is probable that on-screen instructions provided during the *matte* period, rather than contest specific information from the preceding *hajime*-*matte* block, influenced the NJ group's post-matte search strategy.

To further investigate the consistency of participants' visual search strategies when observing the judo contests preparation phases it would be beneficial to investigate consistency across identical trials (Carter and Luke, 2018; Henderson and Luke, 2014). Whilst in the previous experimental chapter search strategies during pre- and post-*matte* preparation phases were compared, and therefore the task (i.e., provide coaching instructions to the *judoka* wearing white) and stimuli (i.e., available AOIs) were the same, the context in which each preparation phase was observed differed (e.g., contest-specific information was available prior to the post-*matte* preparation phase; scores and penalties would have differed between phases). Therefore, whilst the task remained constant, additional information was available to participants when addressing the task during the post-*matte* preparation phase. Although the availability of additional information did not appear to alter the NAT and INT coaches' search strategies, to help further understand the consistency observed, it would be valuable to compare preparation phases search strategies where no additional information is available and the context remains the same. Therefore, the present chapter aims to investigate the consistency of visual search strategies in sub-elite and elite judo coaches, and participants with no judo experience, by comparing their search strategies during an initial exposure to a pre-*matte* preparation phase to their search strategies during a repeated (i.e., second) exposure to the same pre-*matte* preparation phase. Following the findings regarding judo coaches' consistency from chapter 7: Experiment 3, it is hypothesised that the elite and sub-elite coaches will demonstrate the same visual search strategy during initial and repeated viewings of pre-*matte* preparation phases. In contrast to the sub-elite and elite coaches, the participants with no judo experience with judo contests will likely lack automatic processing and contest-specific, top-down signals to consistently direct their attention, therefore differences between their initial and repeated viewing search strategies are expected.

## 8.2 Method

**8.2.1 Participants.** Fifteen qualified judo coaches and seven individuals with no experience of judo (participating or coaching) took part in the study. Participant grouping and details can be found in chapter 4: Methods.

**8.2.2 Materials and apparatus.** Video footage was obtained, edited, and viewed by participants as per the details in chapter 4: Methods. Instructions to participants regarding coaching and when to provide feedback were as described in chapter 4: Methods.

**8.2.3 Procedure.** The data collection procedure was as described in chapter 4: Methods.

**8.2.4 Data analysis.** Two of the five repeated clips used (see chapter 4: Methods) were selected for tracking and analysis. With the exception of incidences in both clips where a *judoka* briefly obscured the view of their opponent, the two clips allowed a clear view of the *judokas* for the majority of the pre-*matte* preparation phases. The remaining three repeated clips did not allow a clear view of the *judokas* for sufficient time to be included in the analysis. Due to the incidences of a *judoka* briefly obscuring the view of their opponent, the two repeat clips were not originally selected for tracking and analysis in chapter 6: Experiment 2. However, upon review of the clips for the present chapter, it was identified that tracking of participants' eye movements was feasible for the purpose of comparing visual search strategies during an initial and repeated viewing of pre-*matte* preparation phases. The duration of the pre-*matte* preparation phases of the selected clips were ≈ 5 s and ≈ 10 s. Average preparation phase duration is 6.56 s ± 0.97 s (Miarka et al., 2012; 2016). The use of relative measures as described in chapter 4: Methods was used to account for the differences in preparation phase duration. Eye movements were tracked using the AOI image and process described in chapter 4: Methods. Due to corrupted file, eye movements for a participant from the INT coaches could not be tracked, resulting in the INT group consisting of 6 coaches for analysis.

**8.2.5 Statistical analysis.** The intra- and inter-rater reliability of frame-by-frame eye movement tracking is reported in chapter 4: Methods. The total number of fixations during the initial and repeated viewing of the pre- *matte* preparation phases was compared using repeated measures 2 (viewing) × 3 (level) ANOVA. The relative number of fixations on the AOIs and the relative total fixation durations on the AOIs during the initial and repeated viewing of the pre- *matte* preparation phases were compared using a repeated measures 2 (viewing) × 3 (level) × 10 (AOI) ANOVA. Effect size was calculated using eta squared ($\eta^2$) and partial eta squared ($\eta p^2$). Where appropriate, post-hoc pairwise comparisons using Fisher's least significant difference (LSD) were performed. Post-hoc effect sizes were calculated using Cohen's *d*.

To establish initial versus repeated viewing differences in each group, within-group analysis for each variable was carried out. Within-group differences for the total number of fixations were analysed using a paired samples T-test for each group.

Within-group differences for the relative number of fixations and the relative total fixation duration were analysed using a repeated measures 2 (viewing) × 10 (AOI) ANOVA. Post-hoc pairwise comparisons using Fisher's LSD were performed where appropriate. For each group, paired samples T-tests were used to compare the relative number of fixations and relative total fixation duration on individual AOIs during the initial and repeated viewing. Post-hoc effect sizes were calculated using Cohen's *d*.

Between-group main effects and interactions reported in the results section of this chapter refer to primary and secondary AOIs. Post-hoc analyses of differences between all AOIs during initial and repeated viewings are located in Appendix D. Within-group post-hoc analyses of primary AOIs only are reported within the results section of the present chapter. Within-group post-hoc analyses of secondary AOIs during initial and repeated viewings can be found in Appendix D.

## 8.3 Results

**8.3.1 Total number of fixations.** The total number of fixations was not affected by viewing, $F(1, 18) = 0.4$, $p > 0.05$, $\eta p^2 = 0.02$. There was no significant viewing × level interaction for the total number of fixations, $F(2, 18) = 0.71$, $p > 0.05$, $\eta p^2 = 0.07$.

**8.3.2 Relative number of fixations on the areas of interest (AOIs).** There was no significant viewing × level × AOI interaction, $F(18, 162) = 1.05$, $p > 0.05$, $\eta p^2 = 0.11$, for the relative number of fixations on the AOIs. With the groups collapsed, there was no significant viewing × AOI interaction, $F(9, 162) = 0.9$, $p > 0.05$, $\eta p^2 =$

0.05. Within-group analysis found no significant viewing × AOI interaction in the NJ group, $F(9, 54) = 0.71$, $p > 0.05$, $\eta p^2 = 0.11$, NAT coaches $F(9, 63) = 1.42$, $p > 0.05$, $\eta p^2 = 0.17$, or INT coaches, $F(9, 45) = 0.97$, $p > 0.05$, $\eta p^2 = 0.16$ (Figure 8.1a - c).

**8.3.3 Relative total fixation duration on the areas of interest (AOIs).** There was no significant viewing × level × AOI interaction, $F(18, 162) = 1.34$, $p > 0.05$, $\eta p^2 = 0.13$ for the relative total fixation duration on the AOIs. With the groups collapsed, there was a significant viewing × AOI interaction, $F(9,162) = 2.87$, $p < 0.05$, $\eta p^2 = 0.14$. The relative total fixation duration on BU, $t(20) = -2.51$, $p < 0.05$, $d = - 0.51$, was significantly greater during the repeat viewing (34.35 ± 12.16 %) compared to the initial viewing (28.22 ± 11.65 %). Additionally, the relative total fixation on SB, $t(20) = 2.24$, $p < 0.05$, $d = - 0.51$, was also significantly greater during the repeated viewing (4.16 ± 4.65 %) compared to during the initial viewing (2.23 ± 2.69 %).

Within-group analysis found no significant viewing × AOI interaction in the NJ group, $F(9, 54) = 1.37$, $p > 0.05$, $\eta p^2 = 0.19$, or INT coaches, $F(9, 45) = 0.63$, $p > 0.05$, $\eta p^2 = 0.11$. In the NAT coaches a significant viewing × AOI interaction was observed, $F(9, 63) = 3.61$, $p < 0.002$, $\eta p^2 = 0.34$. Within-group analysis in the NAT coaches found that the relative total fixation duration on WU during the initial viewing (37.61 ± 12.09 %) was significantly greater ($t(7) = 2.6$, $p < 0.04$, $d = 0.65$) than the relative total fixation duration on WU during the repeated viewing (28.67 ± 15.37 %). There was a trend ($t(7) = - 2.34$, p = 0.52, $d = - 1.05$), of the relative total fixation duration on BU during the initial viewing (28.71 ± 8.9 %) being less (10.8 %) than during the repeated viewing (39.5 ± 11.44 %; Figure 8.2a - c).

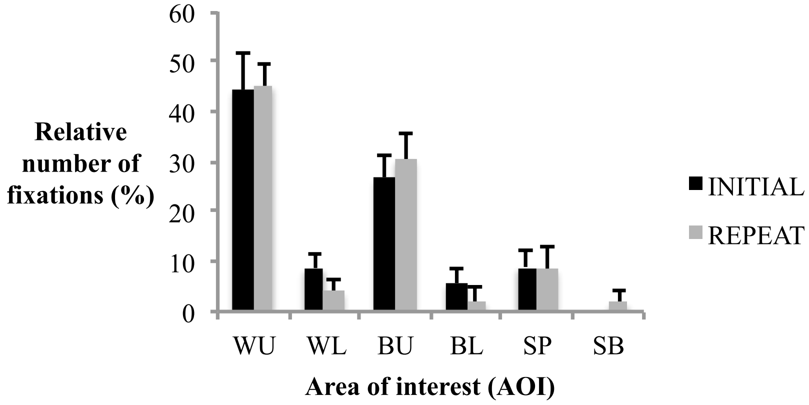


**Figure 8.1a** Initial versus repeated viewing relative number of fixations (%) NJ group (mean + SE)

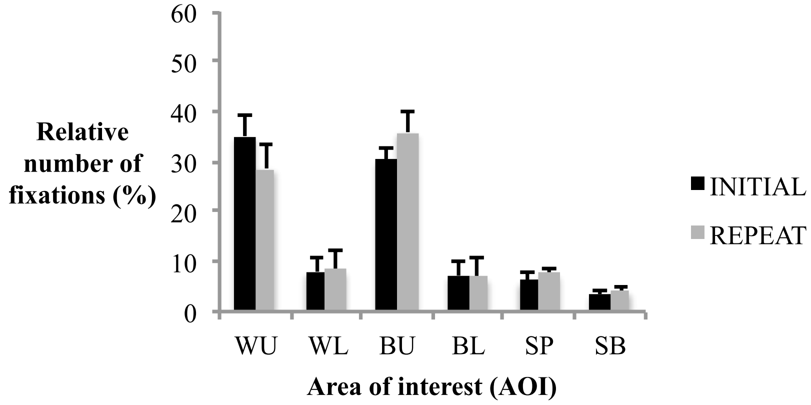


**Figure 8.1b** Initial versus repeated viewing relative number of fixations (%) NAT coaches (mean + SE)

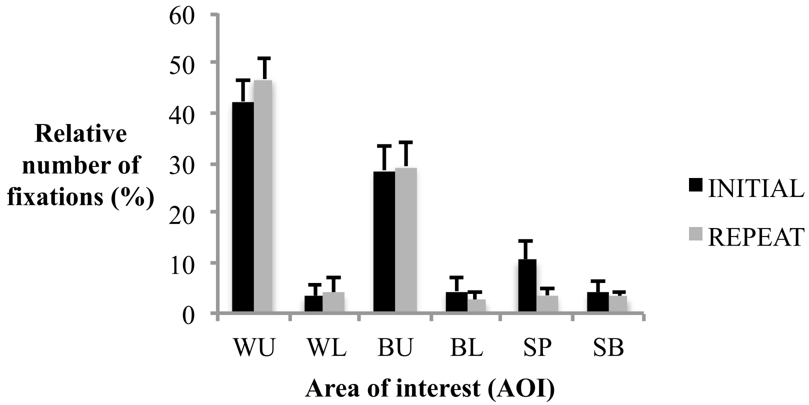


**Figure 8.1c** Initial versus repeated viewing relative number of fixations (%) INT coaches (mean + SE)

NJ = non-judo; NAT = national; INT = international; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard

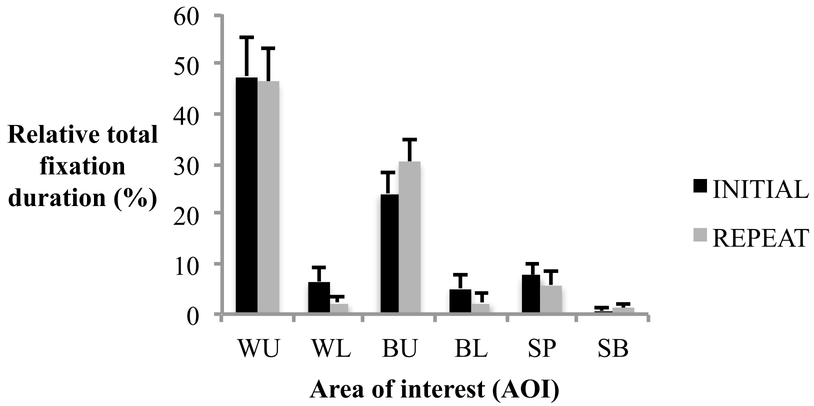


**Figure 8.2a** Initial versus repeated viewing relative total fixation duration (%) NJ group (mean + SE)

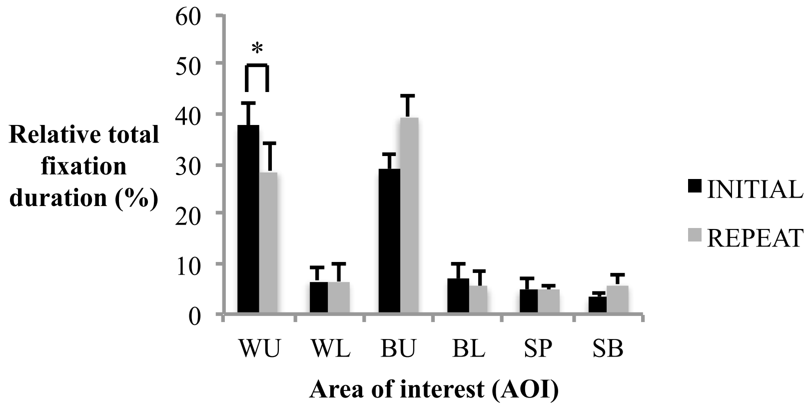


**Figure 8.2b** Initial versus repeated viewing relative total fixation duration (%) NAT coaches (mean + SE)

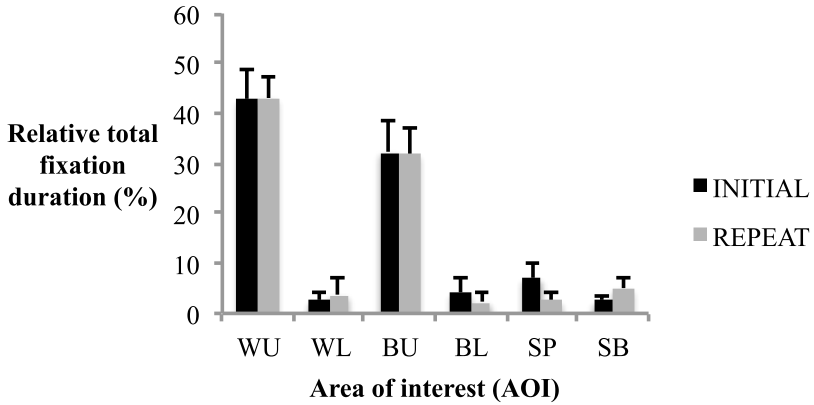


**Figure 8.2c** Initial versus repeated viewing relative total fixation duration (%) INT coaches (mean + SE)

NJ = non-judo; NAT = national; INT = international; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard;
* denotes significant difference between initial and repeated viewing

## 8.4 Discussion

The aim of the present chapter was to investigate the visual search strategies of sub-elite and elite judo coaches (and participants with no judo experience) during initial and repeated viewings of the same judo contest preparation phases. The investigation of search strategies during initial and repeated viewings of contest preparation phases adds to the understanding of consistency in judo coaches' search strategies gained from previous experimental chapters.

In the present chapter no significant effect of viewing (initial or repeated) on the total number of fixations was observed (initial: 28.62 ± 7.62; repeated: 29.31 ± 6.15). Additionally, there was no significant interaction between viewing and level of expertise for the total number of fixations. There was no significant viewing × level × AOI interaction for the relative number of fixations on the AOIs or the relative total fixation duration on the AOIs. However, a significant viewing × AOI (with groups collapsed) for the relative total fixation duration was identified, with BU and SB being fixated for significantly greater durations during the repeated viewing (BU: 34.35 ± 12.16 %; SB: 4.16 ± 4.65 %) compared to during the initial viewing (BU: 28.22 ± 11.65 %; SB: 2.23 ± 2.69 %). No significant viewing × AOI (with groups collapsed) for the relative number of fixations was observed.

As hypothesised no significant viewing × AOI interaction for the relative number of fixations and total fixation duration was observed in the INT coaches. Contrary to the initial hypothesis, no significant viewing × AOI interactions for the relative number of fixations and total fixation duration were observed in the NJ group. Also contrary to the initial hypothesis, a significant viewing × AOI interaction for the relative total fixation duration was found for the NAT coaches. The NAT coaches fixated WU for a significantly shorter duration during the repeated viewing (28.67 ± 15.37 %) compared to the initial viewing (37.61 ± 12.09 %). Furthermore, whilst not significant, the NAT coaches fixated BU for a longer duration during the repeated viewing (39.5 ± 11.44 %) compared to during the initial viewing (28.71 ± 8.9 %), with a large effect size ($d$ = - 1.05) also observed. Collectively, the findings from the present chapter suggest that the NJ group and INT coaches used visual search strategies during the repeated viewing that were similar to those that they each used during the initial viewing. However, the NAT coaches appear to have used an alternative strategy during the repeated viewing, whereby the total fixation duration on BU was ~ 10% longer, and the total fixation duration on WU ~ 10% shorter, compared to during the initial viewing.

The INT coaches' search strategy in the present chapter during the initial and repeated viewings is descriptively similar to that used by the INT coaches during the pre-*matte* preparation phases analysed in chapter 6: Experiment 2 (i.e., WU fixated most frequently and for the longest duration compared to other AOIs). Moreover, that the INT coaches used this search strategy during the initial and repeated viewings in the present chapter, suggests a consistent search strategy is used when observing pre-*matte* preparation phases of judo contests (when tasked with providing coaching instructions to an unfamiliar *judoka*), regardless of whether the phase has been previously observed. By using a consistent search strategy the coaches would not have to use cognitive resources to create a novel strategy for each contest, thus potentially sparing cognitive resources for making coaching decisions (e.g., Biggs et al., 2013; Dickinson and Zelinsky, 2007). Furthermore, the consistent use of a search strategy that appears to predominantly utilise WU (i.e., the upper body of the *judoka* whom the coaches have been tasked to provide coaching instructions for), suggests that WU contains relevant information for the INT coaches during pre-*matte* preparation phases.

As discussed in chapter 6: Experiment 2, during the pre-*matte* preparation phase the INT coaches may have fixated on WU to accurately establish the *judoka's* handedness; this is also a potential explanation for the INT coaches' search strategy during both the initial and repeated viewings of the pre-*matte* preparation phases in the present chapter. Yet, in the present chapter, it is possible that information (i.e., the *judoka's* handedness) from the initial viewing could have been retained, therefore negating the need for handedness to be established during the repeated viewing. If such information was retained, that the INT coaches appear to have used a similar strategy during the repeated viewing (i.e., fixated WU most frequently and for the longest total duration) to that used during the initial viewing, suggests that information other than handedness was located in WU (e.g., body position; as discussed in chapter 7: Experiment 3). However, for this situation to occur the INT coaches would need to have recognised that they were viewing a scene they had previously viewed. Previous investigations have found that skilled athletes (e.g., Williams et al., 2006; Williams, North and Hope, 2012), and coaches (Grundel et al., 2013), are able to accurately recognise previously viewed structured, sport-specific scenes. However, whilst Williams et al. (2006) found that skilled soccer athletes were able to recognise such scenes in ~ 3 s, Grundel et al. (2013) measured recognition accuracy only, and not the time taken to accurately recognise the previously viewed scenes. Consequently, little is known about the time required for coaches to recognise previously viewed scenes.

Unlike Grundel et al. (2013) and Williams et al. (2006), the aim of the present chapter was not to investigate the participants' ability to recognise previously viewed scenes. In the present chapter, repeated clips were included to investigate the consistency of participants' visual search. Participants in Grundel et al. (2013) and Williams et al. (2006) were actively engaged in trying to recognise previously viewed scenes during repeated viewings, whilst in the present chapter participants' were not required to attempt to recognise and report contests that had been previously viewed. It is a limitation of the present experiment that participants were not required to report recognition of previously viewed contests. Future studies should consider investigating judo coaches' ability to recognise previously viewed contests, and how this ability influences their visual search strategies.

Whilst it is not known if participants in the present experiment recognised that they were viewing previously seen contests, that participants were not instructed to recognise previously seen contests suggests that they would have approached each contest as unseen, and with the aim of fulfilling the given task (i.e., provide coaching instructions for the *judoka* wearing white). Furthermore, anecdotally, in discussion with participants after data collection, few reported having watched a clip more than once. For those participants who did report having watched a clip more than once, the information that aided their recognition occurred after the preparation phase (i.e., the phase being analysed), suggesting that during the preparation phase they were behaving as if the clip had not been previously viewed. It has previously been identified that athletes' eye movements vary when performing different perceptual-cognitive tasks (e.g., anticipation, decision-making, recognition, pattern recall), and that this suggests that the perceptual processes underpinning perceptual-cognitive skills vary (North et al., 2009; Gorman, Abernethy and Farrow, 2015). For example, North et al., (2009) found that soccer players performing an anticipation task fixated more AOIs, made more fixations, demonstrated shorter fixation durations, and reduced relative viewing time of AOI categories (e.g., attacking team) compared to when performing a recognition task (i.e., reporting if a scene had previously been viewed). Consequently, whilst it is not known if sport coaches' visual search strategies vary when performing different perceptual-cognitive tasks, it can be expected that participants in the present experiment adopted a strategy to address the given task, as they were not engaged in attempts to recognise previously viewed contests.

Despite participants in the present experiment not being required to engage in attempts to recognise previously viewed contests, it is possible that recognition could have occurred. However, whilst participants observed contest clips of ~ 60 s, only the pre-*matte* preparation phase (~ 5 – 10 s) was analysed. The pre-*matte* preparation phase duration was similar to the 10 s duration provided by Grundel et al. (2013) for coaches to recognise if they were viewing a previously viewed scene. Yet, coaches in Grundel et al. (2013) were engaged in trying to recognise previously viewed scenes, whereas this was not the case in the present experiment. Therefore, it is feasible that the preparation phase (or a substantial proportion of it) would have elapsed prior to recognition occurring, and thus participants' search strategies were representative of viewing unseen contests. However, it must be noted that if recognition did occur, this recognition would have had the potential to influence participants' search strategies during the repeated viewing. As previously discussed (in chapter 7: Experiment 3), previously viewed scenes may facilitate subsequent visual search of the same scene by providing information about target location, and thus reducing the time and number of fixations needed to locate targets (Dowd and Mitroff, 2013; Hollingworth, 2009; Kit et al., 2014; Li et al., 2016; Vo and Wolfe, 2015; Wood, Vine and Wilson, 2016). In the absence of a task requiring participants to identify if they recognised previously viewed scenes, any potential influence of the previously viewed scenes (and recognition of them) on subsequent search strategies cannot be established, and some caution may be needed when interpreting the findings.

Whilst a substantial proportion of the pre-*matte* preparation phase may have elapsed before any recognition occurred, as previously identified, athletes are able to recognise previously viewed scenes in ~ 3 s (Williams et al., 2006). If the participants in the present experiment were able to recognise scenes in a similar length of time, ≥ 40 % of the phase would have remained where their visual search strategies may have been influenced by recognition of the contest. Yet, it is unlikely that participants in the present experiment would have been able to recognise previously viewed contests in such a short duration due to the study design. In the present experiment participants viewed 29 contest clips (five of which were repeated), each ~ 60 s in duration, with the repeated clips separated by a minimum of 8 minutes. Previous recognition studies have used fewer clips (e.g., 20 clips; Williams et al., 2006), of shorter duration (e.g., 10 s; Grundel et al., 2013), with shorter minimum periods between repeat clips (e.g., 5 mins; Williams et al., 2006).

Additionally, in both Williams et al. (2006) and Grundel et al. 2013) 50 % of the clips viewed were repeat clips. Accordingly, participants in the present experiment were presented with greater amount of visual information, and a lower percentage of repeat clips (~ 17 %), compared to studies where investigating recognition ability was the aim. The greater amount of visual information would have challenged participants' ability to consolidate (store) information in visual working memory (Vogel, Woodman and Luck, 2006), and the capacity of their visual working (Eng, Chen and Jing, 2005). Furthermore, due to either being engaged in the given task or taking only short breaks (< 5 mins) from viewing contests, opportunities for information consolidation from visual working memory to long-term memory (e.g., rest) would have been limited (Ellmore et al., 2016). Consequently, if information were not consolidated effectively it would not have been available for participants to retrieve and use to aid recognition when viewing previously seen contests.

Whilst it appears that the INT coaches adopted a similar search strategy during initial and repeated viewings, results from the present chapter suggest that the NAT coaches' repeated viewing search strategy differed to their initial viewing search strategy. During the repeated viewing, the NAT coaches' total fixation duration on WU was ~ 10 % shorter than during the initial viewing, whilst their total fixation duration on BU was ~ 10 % longer compared to the initial viewing. As previously discussed, recognition of previously viewed contests by participants was unlikely; therefore, the results suggest that the NAT coaches' search was possibly driven by a different combination of signals (top-down and bottom-up) during each viewing, despite identical visual information. Whereas a consistent search strategy (likely developed as a consequence of experience) would be driven by the same top-down signals for each task attempt, a search strategy that varies suggests a novel strategy for each task attempt (e.g., Biggs et al., 2013), or that salient features in the scene are attracting eye movements due to a lack of top-down signals suppressing the signals from these features (e.g., Vickers, 2007; Vine, Moore and Wilson, 2011).

Due to the NAT coaches' experience it is probable there would have been a top-down drive to obtain contest-specific information during both the initial and repeated viewings. That the NAT coaches fixated on upper body AOIs (i.e., WU and BU) most frequently and for the longest duration (compared to other AOIs) during each viewing indicates that they were attempting to obtain contest-specific information, as these AOIs appear to be where relevant information is located (e.g., gripping, body position; as discussed in chapter 6: Experiment 2). Yet, it does appear that the NAT coaches modified an aspect of their search strategy by increasing the length of time spent fixating BU, and reducing the amount of time spent fixating WU, during the repeated viewing. Consequently, whilst the NAT coaches' search strategy during both the initial and repeated viewings predominantly utilised the upper body AOIs, the relative importance of these upper body AOIs appears to change from the initial to the repeated viewing. The continued, but modified, use of task-relevant AOIs (i.e., upper body AOIs) during the repeated viewing, suggests that top-down signals, rather than salient features, may account for the change in search strategy. However, it is not known why the NAT coaches changed their search strategy. It is possible that due to their lack of international coaching experience the NAT coaches are yet to develop the consistency of the INT coaches when observing the preparation phase of elite level contests (as shown in the present chapter and chapter 7: Experiment 3). Alternatively, it is possible that the NAT coaches recognised that they had previously viewed the preparation phase, and made a decision to reduce the time spent fixating WU and to fixate on BU for longer, based on information obtained during their initial viewing. The use of adjunct measures, such as verbal reports of thinking, in future research may aid in further establishing the reasons for the modification of the NAT coaches' search strategy.

The NAT coaches' use of a different search strategy for each preparation phase may have increased cognitive load, possibly due to having to use cognitive resources to create a novel strategy for each viewing (e.g., Biggs et al., 2013). Increased cognitive load would have potentially reduced the cognitive resources available to make coaching decisions. Yet, as identified by Biggs et al. (2013), inconsistent search strategies observed in participants with less task-specific experience, do not necessarily result in a decreased ability to complete search tasks. Moreover, it is possible that different search strategies may result in similar decision-making outcomes (Dicks et al., 2017). However, in the present experiment, as no task was included to assess coaching decision-making, it is not known if using inconsistent or different search strategies for each preparation phase would have resulted in different coaching decisions. Future studies should consider the inclusion of tasks to investigate the relationship between the consistency of visual search strategies and coaching decision-making.

As with the INT coaches, the NJ group used the same strategy during initial and repeated viewings. However, unlike the INT coaches, the NJ group's consistent search strategy was possibly due to their lack of judo experience, rather than consistent task-related, top-down signals driving their search during each viewing.

As discussed in chapter 6: Experiment 2, the NJ group's search strategy during initial viewings of pre-*matte* preparation phases is likely influenced by a combination of aspects (i.e., identification of the *judoka* wearing white in task instructions, attempts to understand an unfamiliar scene by fixating AOIs containing the head and face, and salient features; e.g., Birmingham, Bischof and Kingstone, 2008). It is feasible that, in the absence of task-specific, top-down signals due to the NJ group's lack of judo experience, such aspects would also have influenced the NJ group's search strategy during the repeated viewing.

### 8.5 Conclusion

The aim of the present chapter was to investigate the visual search strategies of sub-elite (NAT coaches) and elite (INT coaches) judo coaches, and participants with no judo experience (NJ group), during initial and repeated viewings of judo contest pre-*matte* preparation phases. The investigation of participants' search strategies during initial and repeated viewings of preparation phases further contributes to the understanding of consistency in judo coaches' visual search, and provides an indication of the reliability of the eye tracking measures used, and the repeatability of the study.

Elite coaches exhibited similar search strategies during initial and repeated viewings of the pre-*matte* preparation phases. The use of similar search strategies during the initial and repeated viewings suggests consistency in the elite coaches' search strategies. The use of a consistent search strategy may have helped preserve cognitive resources, and be a consequence of consistent, task-specific top-down signals. Experience of international level coaching may have contributed to the elite coaches development of a consistent search strategy.

Unlike the elite coaches, the sub-elite coaches appeared to use a different search strategy during the repeated viewing compared to during the initial viewing. During the repeated viewing the sub-elite coaches fixated WU for significantly shorter duration compared to during the initial viewing, whilst fixating BU for a longer duration than during the initial viewing. The use of different search strategies for pre-*matte* preparation phases may increase cognitive load, as novel search strategies may need to be created for each contest. A lack of consistent, task-specific top-down signals, may account for the different strategies used by the sub-elite coaches. The NAT coaches' lesser experience of international coaching provides a possible explanation for the lack of consistent, task-related top-down signals. It is possible that consistent pre-*matte* preparation phase search strategies are developed as a consequence of greater international coaching experience.

Participants with no judo experience used a similar search strategy during the initial and repeated viewings. However, unlike the elite coaches, it is unlikely that consistent, task-specific, top-down signals drove the NJ group's search strategy. Instead, task instructions that identified the *judoka* in white as relevant, attempts to understand an unfamiliar scene, and salient features provide possible explanations for the NJ group's search strategy.

# 9. Experiment 5: How does level of coach and prior exposure to contest specific information affect the entropy of judo coaches' visual search strategies?

## 9.1 Introduction

The previous experimental chapters have investigated the visual search strategies of sub-elite (NAT coaches) and elite (INT coaches) judo coaches and participants with no judo experience (NJ group) during pre- and post-*matte* preparation phases of judo contests. Findings from the previous experimental chapters suggest that during the pre-*matte* preparation phases the elite coaches fixated on WU (i.e., the upper body of the *judoka* they had been instructed to provide coaching points to) more frequently and for longer than BU (i.e., the opponent's upper body). However, the sub-elite coaches appeared to adopt an alternative strategy, whereby they fixated on WU and BU to a comparable extent during pre-*matte* preparation phases.

As shown in chapter 6: Experiment 2 and chapter 7: Experiment 3 both the elite and sub-elite coaches demonstrated consistency by using the same search strategy during the post-*matte* preparation phase as during the pre-*matte* preparation phase. The elite coaches predominantly fixated on WU during both preparation phases, whereas the sub-elite fixated on WU and BU in a comparable manner. Interestingly, pre-*matte*, the NJ group used a strategy similar to the sub-elite coaches (i.e., comparable use of WU and BU). However, post-*matte*, rather than fixating WU and BU in a comparable manner, the NJ group predominantly fixated WU in a manner similar to the elite coaches. When viewing previously seen pre-*matte* preparation phases (i.e., a repeated viewing as in chapter 8: Experiment 4), the NJ group and elite coaches demonstrated consistency by using the same search strategies as when they initially viewed the phases. Yet, the sub-elite coaches changed their strategy during the repeated viewing, compared to the initial viewing, by decreasing their fixation duration on WU, and increasing their fixation duration on BU.

The previous experimental chapters are the first investigations into judo coaches' visual search strategies. The findings from these experimental chapters add to the limited number of investigations into the visual search strategies of sport coaches, and contribute to the understanding of sport coaches' search strategies. Moreover, these experimental chapters can assist in identifying areas, and developing hypotheses, for further investigation into judo coaches' visual search strategies. However, the variables analysed in the previous experimental chapters (i.e., total number of fixations made during the phase; relative number of fixations on each AOI; relative total fixation duration on each AOI; the average fixation duration on each AOI), and the averaging of these variables across participants and trials summarise fixation data, thereby not accounting for all aspects of participants' visual search strategies (Button et al., 2011; Dicks et al., 2017; Manzanares et al., 2015). To supplement summary fixation data, and provide a more complete understanding of athletes' search strategies, Markov chain modelling has been utilised to investigate the frequency of transitions between AOIs, and the entropy (predictability, or alternatively randomness) of participants' search strategies in sport (van Maarseveen et al., 2018) and other areas (e.g., aircraft flight tasks; Allsop and Gray, 2014). However, the use of such approaches to supplement summary fixation data in investigations of visual search strategies in sport at present is uncommon, with only a limited number of studies incorporating entropy analysis (e.g., van Maarseveen et al., 2018; Ryu et al., 2016).

In Markov chain modelling the probability of fixating on an AOI depends upon the location of the previous fixation (Allsop and Gray, 2014; Button et al., 2011). Using Markov chain modelling to develop first-order transition (Appendix E: Figure E1) and conditional transition-probability (Appendix E: Figure E2) matrices provides the basis for the calculation of entropy (i.e., the predictability, or alternatively randomness) in visual search behaviour (Allsop and Gray, 2014). By applying the entropy calculation (see section 9.2.5 Statistical analysis) to the conditional transition-probability matrix (Appendix E: Figures E3a - c), the predictability of an individual's visual search behaviour can be established (Allsop and Gray, 2014). Markov chain modelling and the calculation of entropy has been utilised to investigate the predictability of athletes' visual search strategies (e.g., van Maarseveen et al., 2018; Ryu et al., 2016), and the search strategies of individuals engaged in tasks where appropriate allocation of visual attention is crucial (e.g., airplane flight tasks; Allsop and Gray, 2014; Allsop et al., 2017). Ryu et al. (2016) found that recreational basketball players demonstrated greater entropy (i.e., greater randomness in their visual search behaviour) when vision was not restricted, compared to either central or peripheral vision restriction (by blurring the respective areas in the visual scene). Furthermore, greater entropy was observed when central vision was restricted (allowing only peripheral vision) compared to when peripheral vision was restricted (allowing only central vision). The entropy observed for each visual condition did not alter following a period of training under these visual conditions. In addition to the findings of Ryu et al. (2016), van Maarseveen and colleagues (2018) found that, with vision unrestricted, national level youth soccer players demonstrated greater entropy when completing a soccer-specific pattern recall task when compared to soccer-specific anticipation task. Additionally, greater entropy was observed when completing a soccer-specific decision-making task compared to the anticipation task. The findings of van Maarseveen et al. (2018) suggest that the underlying processes for different perceptual-cognitive tasks (i.e., pattern-recall, decision-making, and anticipation) may vary.

Further to investigations of entropy in athletes, Allsop and Gray (2014) and Allsop et al. (2017) investigated the effects of anxiety and cognitive load on entropy and the frequency of transitions between AOIs during simulated airplane landing tasks. Whilst entropy indicates the randomness of visual search behaviour, analysing the frequency of transitions between AOIs can help to identify the structure and sequence of individuals' visual search (i.e., where they most frequently move their eyes to and from). In Allsop and Gray (2014), increased entropy was observed under anxiety-inducing conditions compared to when the anxiety-inducing conditions were absent. However, the most frequent transitions made between AOIs remained the same in the presence or absence of anxiety-inducing conditions. More recently, Allsop and colleagues (2017) again identified that increases in entropy were positively associated with increases in anxiety; however, this was only observed during a task manipulation (inclusion of an auditory *n*-back task) that increased cognitive load. With no anxiety-inducing conditions present, no significant differences in entropy were observed between low and high cognitive load manipulations; yet the transition frequency between AOIs decreased when cognitive load was increased.

The previous studies identified (e.g., Allsop and Gray, 2014; van Maarseveen et al., 2018; Ryu et al., 2016), utilising Markov chain modelling, have added to the understanding of visual search strategies, and have possibly identified aspects of participants' visual search strategies that may not have been observed using summary fixation data (Button et al., 2011; Manzanares et al., 2015). However, to date, the limited number of investigations into coaches' visual search strategies have not utilised Markov chain modelling, and have only reported summary fixation data. Investigations of coaches' visual search strategies using Markov chain modelling will add to the literature that has previously investigated coaches' visual search strategies using summary fixation statistics (e.g., Moreno et al., 2002; Robertson et al., 2018), and increase the understanding of coaches' visual search strategies. Therefore, the present chapter aims to use Markov chain modelling to investigate the visual search strategies of judo coaches (and participants with no judo experience) when observing judo contests.

Markov chain modelling will be utilised to investigate the most frequent transitions between AOIs, and the entropy of the visual search strategies of sub-elite and elite judo coaches (and participants with no judo experience) during pre- and post-*matte* preparation phases of judo contests. The frequency of transitions between AOIs and entropy will be analysed during the pre-*matte* preparation phase, and during the post-*matte* preparation phase. Additionally, the frequency of transitions between AOIs and entropy during the pre- and post-*matte* preparation phases will be compared. The pre- and post-*matte* preparation phases will be from the same contests, and therefore will be separated by a *hajime-matte* block and a *matte* period. As discussed in chapter 7: Experiment 3, the *hajime-matte* block and *matte* period can potentially provide information to participants, and therefore have the potential to influence their visual search strategies during the post-*matte* preparation phase. By investigating the frequency of transitions and entropy during the pre- and post-*matte* preparations phases, the present chapter will add to the understanding of judo coaches' visual search strategies gained using summary fixation data in the previous experimental chapters.

Due to the elite coaches' predominant use of WU during the pre-*matte* preparation phase, compared to the similar use of WU and BU by the sub-elite coaches and participants with no judo experience (as reported in chapter 6: Experiment 2), it is hypothesised that the elite coaches will demonstrate the most predictable pre-*matte* visual search strategy (i.e., demonstrate less entropy). Additionally, due to the consistency of the elite and sub-elite coaches search strategies across the pre-and post-*matte* preparation phases (as reported in chapter 7: Experiment 3), it is expected that the predictability of their search during each phase will not differ. However, the predictability of the search strategy of the participants with no judo experience is expected to increase (i.e., entropy decreases) post-*matte* compared to pre-*matte*, as they have previously been reported (in chapter 7: Experiment 3) to change their search strategy to predominantly fixate WU during the post-*matte* preparation phase.

## 9.2 Method

**9.2.1 Participants.** Fifteen qualified judo coaches and seven individuals with no experience of judo (participating or coaching) took part in the study. Participant grouping and details can be found in chapter 4: Methods.

**9.2.2 Materials and apparatus.** Video footage was obtained, edited, and viewed by participants as per the details in chapter 4: Methods. Instructions to participants regarding coaching and when to provide feedback were as described in chapter 4: Methods.

**9.2.3 Procedure.** The data collection procedure was as described in chapter 4: Methods.

**9.2.4 Data analysis.** Eye movement data obtained from chapter 6: Experiment 2 (i.e., eye movements during observation of pre-*matte* preparation phases), and study 1 of chapter 7: Experiment 3 (i.e., eye movements during observation of post-*matte* preparation phases) were used in the analysis.

**9.2.5 Statistical analysis.** Intra- and inter-rater reliability of frame-by-frame eye movement tracking was established as reported in chapter 4: Methods. For each preparation phase (pre-*matte* and post-*matte*), the dependent variables analysed were: (i) the total number of transitions between AOIs, (ii) the relative number of transitions from an AOI to another AOI (e.g., from WU to BU; calculated by the number of transitions from an AOI to another AOI/total number of transitions between AOIs), and (iii) entropy. The dependent variables from the pre- and post-*matte* preparation phase were then compared. The use of relative values for the number of transitions between AOIs and the entropy calculations accounted for differences in the duration of the pre- and post-*matte* preparation phase clips. For each variable, the mean value of the two relevant clips (pre-*matte* or post-*matte*) was used. Due to the loss of post-*matte* preparation phase data for an INT coaches participant, the INT coaches' group mean for each variable was used to account for the missing data and allow pairwise comparison of means between the pre- and post-*matte* preparation phases.

To calculate values for each variable the process utilised by Allsop and Gray (2014) and Ryu et al. (2016) was used. First-order transition matrices of *p(i to j)* were created for each clip viewed by all participants, and allowed the calculation of the total number of transitions between all AOIs, and the relative number of transitions between each AOI (Appendix E). In a first-order transition matrix *i* represents the AOI the individual is transitioning "from", and *j* represents the AOI the individual is transitioning "to" (e.g., "from" WU "to" BU). The first-order transition matrices created were based upon dwells (rather than fixations as used in previous experimental chapters). As discussed in chapter 5: Experiment 1, a dwell is any time that the eyes stabilise over an AOI, thus accounting for all eye movements during a visual search task (e.g., Vansteenkiste et al., 2014b); whilst a fixation is defined as the eyes stablising over an AOI for a specified minimum duration (e.g., ≥ 120 ms; Williams et al., 1994), and therefore not necessarily accounting for all eye movements during a visual search task. Both approaches have been utilised in the visual search literature (e.g., Piras, Pierantozzi and Squatrito, 2014; van de Merwe, van Dijk and Zon, 2012), and potentially provide different descriptions of an individual's visual search strategy. However, as observed in the preliminary dwell versus fixation analysis reported in chapter 4: Methods, the two approaches provided similar descriptions of judo coaches' visual search strategies. Therefore, the use of dwells, rather than fixations, to create the first-order transition matrices was deemed acceptable. Moreover, when creating first-order transition matrices, an approach that accounts for all eye movements (i.e., dwells) may be more appropriate, as not accounting for all eye movements would potentially result in transitions between AOIs being missed. As such, if eye movements are missed the resulting entropy calculation will fully not account for the randomness (or predictability) of an individual's visual search.

Following the creation of the first-order transition matrices, each matrix was converted into a conditional transitional-probability matrix of p(*j/i*). The conditional transitional-probability matrices each provided a 1st order Markov process where the probability of dwelling on the next ($j^{th}$) AOI is based on the current dwell ($i^{th}$) on an AOI (Appendix E). Entropy was then calculated using Ellis and Stark's (1986) conditional information equation:

$$Entropy = -\sum_{i=1}^{n} p(i)\left[\sum_{j=1}^{n} p(j/i)\log_2 p(j/i)\right], i \neq j$$

where $p(i)$ is the zero-order probability of fixating on the $i^{th}$ AOI (based on the percentage time dwelling on that AOI), $p(j^{th})$ is the conditional probability of viewing AOI *j* if the previous fixation was on AOI *i,* and *n* is the number of AOIs (i.e., 9 in the present experimental chapter; Appendix E).

***9.2.5.1 Analysis of pre- and post-matte preparation phases.*** The pre- and post-*matte* preparation phases were analysed separately, but using the same approach. An independent one-way ANOVA was used to analyse between-group differences for the total number of transitions between AOIs and entropy. To analyse the relative number of transitions from an AOI to another AOI, a 3 (coaching level) × 6 (transition) ANOVA was utilised. Due to the high number of possible transitions between the nine AOIs (i.e., 72 possible transitions), following descriptive identification of the most frequent transition combinations, it was decided to limit further statistical analysis to transitions between the AOIs most frequently utilised by participants (i.e., WU, BU, SP; as identified in chapter 6: Experiment 2 and chapter 7: Experiment 3). The selection of these three AOIs meant that six transitions from an AOI to another AOI were included in the analysis (i.e., (i) WU to BU, (ii) WU to SP, (iii) BU to WU, (iv) BU to SP, (v) SP to WU, (vi) SP to BU). Effect size was calculated using eta squared ($\eta^2$) and partial eta squared ($\eta p^2$). Where appropriate, post-hoc pairwise comparisons using Fisher's least significant difference (LSD) were performed. Post-hoc effect sizes were calculated using Cohen's *d*.

Due to the exploratory nature of the present chapter, within-group differences for the relative number of transitions for the six transitions identified previously, were analysed using a repeated-measures one-way ANOVA with the transitions as the within-subject factor. Effect size was calculated using $\eta p^2$. Post-hoc pairwise comparisons using Fisher's LSD were performed where appropriate. Post-hoc effect sizes were calculated using Cohen's *d*.

***9.2.5.2 Comparison of pre- and post-matte preparation phases.*** To compare the total number of transitions between all AOIs and entropy during the pre- and post-*matte* preparation phases a repeated measures 2 (phase) × 3 (level) ANOVA was used. The relative number of transitions between the selected AOIs during the pre- and post-*matte* preparation phases were compared using a repeated measures 2 (phase) × 3 (level) × 6 (transitions) ANOVA. Effect size was calculated using eta squared ($\eta^2$) and partial eta squared ($\eta p^2$). Where appropriate, post-hoc pairwise comparisons using Fisher's least significant difference (LSD) were performed. Post-hoc effect sizes were calculated using Cohen's *d*.

To establish pre- versus post-*matte* preparation phase differences in each group, within-group analysis for each variable was carried out. Within-group differences for the total number of transitions between the AOIs and entropy were analysed using a paired samples T-test for each group. Within-group differences for the relative number of transitions between the selected AOIs were analysed using a repeated measures 2 (phase) × 6 (transitions) ANOVA. Post-hoc pairwise comparisons using Fisher's LSD were performed where appropriate. For each group, paired samples T-tests were used to compare the relative number of transitions between the selected AOIs. Post-hoc effect sizes were calculated using Cohen's *d*.

## 9.3 Results

**9.3.1 Pre-*matte* preparation phase: entropy.** During the pre-*matte* preparation phase the entropy of the NJ, NAT, and INT groups' visual search was 1.09 ± 0.38 bits, 0.88 ± 0.25 bits, and 0.78 ± 0.23 bits respectively. There was no significant between-group difference for the entropy observed during the pre-*matte* preparation phase, $F(2, 19) = 1.08$, $p > 0.05$, $\eta^2 = 0.32$ (Table 9.1).

**9.3.2 Pre-*matte* preparation phase: total number of transitions between areas of interest (AOIs).** The total number of transitions between the AOIs made by the NJ, NAT, and INT group during the pre-matte preparation phases were 14.14 ± 5.14, 12.81 ± 2.63, and 11.79 ± 3.7 respectively. There was no significant between-group difference for the total number of transitions made during the pre-*matte* preparation phase, $F(2, 19) = 0.7$, $p > 0.05$, $\eta^2 = 0.26$ (Table 9.1).

**9.3.3 Pre-*matte* preparation phase: relative number of transitions between each area of interest (AOI).** The six possible transitions between the selected AOIs (i.e., WU to BU; WU to SP; BU to WU; BU to SP; SP to WU; SP to BU) accounted for the six most frequent transitions in all groups (Table 9.2). There was no significant AOIs by coaching level interaction, $F(10, 95) = 0.27$, $p > 0.05$, $\eta p^2 = 0.14$. Within-group analysis found no significant effect of transition on the relative number of transitions made between each of the selected AOIs for the NJ group, $F(5, 30) = 0.84$, $p > 0.05$, $\eta p^2 = 0.12$; NAT coaches, $F(5, 35) = 0.48$, $p > 0.05$, $\eta p^2 = 0.07$; or INT coaches, $F(5, 30) = 0.89$, $p > 0.05$, $\eta p^2 = 0.13$.

**Table 9.1.** Pre- versus post-*matte* preparation phase entropy and total number of transitions between areas of interest (AOIs; mean ± SD)

| | **Entropy (bits)** | | **Total number of transitions** | |
|---|---|---|---|---|
| **Group** | **Pre-*matte*** | **Post-*matte*** | **Pre-*matte*** | **Post-*matte*** |
| **NJ** | 1.09 ± 0.38 | 0.42 ± 0.31* | 14.14 ± 5.14 | 5.71 ± 2.8* |
| **NAT** | 0.88 ± 0.25 | 0.47 ± 0.21* | 12.81 ± 2.63 | 6.56 ± 2.18* |
| **INT** | 0.78 ± 0.23 | 0.34 ± 0.24* | 11.79 ± 3.7 | 5.25 ± 2.81* |

NJ = non-judo; NAT = national; INT = international * denotes significantly different ($p < 0.05$) from pre-*matte*

**9.3.4 Post-*matte* preparation phase: entropy.** During the post-*matte* preparation phase the entropy of the NJ, NAT, and INT groups' visual search was 0.42 ± 0.31 bits, 0.47 ± 0.21 bits, and 0.34 ± 0.24 bits respectively. There was no significant between-group difference for the entropy observed during the post-*matte* preparation phase, $F(2, 18) = 0.45$, $p > 0.05$, $\eta^2 = 0.22$ (Table 9.1).

**9.3.5 Post-*matte* preparation phase: total number of transitions between areas of interest (AOIs).** The total number of transitions between the AOIs made by the NJ, NAT, and INT group during the post-*matte* preparation phases were 5.71 ± 2.8, 6.56 ± 2.18, and 5.25 ± 2.81 respectively. There was no significant between-group difference for the total number of transitions made during the post-*matte* preparation phase, $F(2, 18) = 0.47$, $p > 0.05$, $\eta^2 = 0.22$ (Table 9.1).

**9.3.6 Post-*matte* preparation phase: relative number of transitions between each area of interest (AOI).** Of the transitions between the selected AOIs, transitions from WU to BU, BU to WU, WU to SP, and SP to BU were the four most frequent transitions observed in the NJ group. Transitions from SP to WU and BU to SP were the 13$^{th}$ and 14$^{th}$ most frequent transitions respectively. In the NAT coaches, transitions from WU to BU, BU to WU, and SP to BU were the three most frequent transitions, with transitions from WU to SP, BU to SP, and SP to WU the 6$^{th}$, 13$^{th}$, and 24$^{th}$ most frequent transitions respectively. Transitions from WU to BU and BU to WU were the most frequent in the INT coaches, with transitions from SP to BU, WU to SP, BU to SP, and SP to WU the 5$^{th}$, 8$^{th}$, 10$^{th}$, and 13$^{th}$ most frequent transitions respectively (Table 9.2).

There was no significant interaction between the relative number of transitions between each of the selected AOIs and coaching level, $F(10, 90) = 0.202$, $p > 0.05$, $\eta p^2 = 0.22$. Within-group analysis found no significant effect of transition on the relative number of transitions made between each AOI for the NJ group, $F(5,30) = 3.38$, $p > 0.05$, $\eta p^2 = 0.36$, and the INT coaches $F(5, 25) = 3.35$, $p > 0.05$, $\eta p^2 = 0.4$. In the NAT coaches a significant effect of transition on the relative number of transitions made between each AOI, $F(5, 35) = 4.59$, $p < 0.05$, $\eta p^2 = 0.4$ was observed. Follow-up pairwise comparisons in the NAT coaches identified that the relative number of transitions from WU and BU (15.93 ± 15.78 %) was significantly greater ($p > 0.05$, $d = 1.43$) than the relative number of transitions from SP to WU (00.00 ± 00.00 %). Additionally, the relative number of transitions from BU and WU (13.87 ± 9.86 %) was significantly greater ($p > 0.05$, $d = 1.2$ to 1.99) than the relative number of transitions from WU to SP (4.38 ± 5.21 %), BU to SP (1.56 ± 4.42 %), and SP to WU. The relative number of transitions from WU to SP was significantly greater ($p > 0.05$, $d = 1.19$) than the relative number of transitions from SP to WU.

**9.3.7 Pre- versus post-*matte* preparation phase: entropy.** There was no significant phase × coaching level interaction for entropy, $F(2, 19) = 0.92$, $p > 0.05$, $\eta p^2 = 0.09$. There was a significant effect of phase on entropy, $F(1, 19) = 73.04$, $p < 0.001$, $\eta p^2 = 0.79$, with significantly lower entropy values during the post-*matte* preparation phase (0.41 ± 0.24 bits) compared to during the pre-*matte* preparation phase (0.89 ± 0.29 bits). Within-group analysis identified that all groups demonstrated significantly less entropy post-*matte* compared to pre-*matte*. In the NJ group entropy during the pre-*matte* preparation phase was 1.09 ± 0.38 bits compared to 0.42 ± 0.31 bits during the post-*matte* preparation phase, $t(6) = 7.37$, $p < 0.001$, $d = 1.93$. In the NAT coaches pre-*matte* preparation phase entropy was 0.88 ± 0.25 versus 0.47 ± 0.21 bits during the post-*matte* preparation phase, $t(7) = 4.51$, $p < 0.01$, $d = 1.78$, and in the INT coaches pre-*matte* entropy was 0.78 ± 0.23 bits compared to 0.34 ± 0.22 bits post-*matte*, $t(6) = 3.76$, $p < 0.01$, $d = 1.96$.

**9.3.8 Pre- versus post-*matte* preparation phase: total number of transitions between areas of interest (AOIs).** There was no significant phase × coaching level interaction for the total number of transitions, $F(2, 19) = 1.11$, $p > 0.05$, $\eta p^2 = 0.11$. There was a significant effect of phase on the total number of transitions between the AOIs, $F(1, 19) = 120.33$, $p < 0.001$, $\eta p^2 = 0.86$, with significantly fewer transitions made during the post-*matte* preparation phase (5.88 ± 2.45) compared to the number of transitions made during the pre-*matte* preparation phase (12.91 ± 3.7; Table 9.1).

Within-group analysis identified that all groups made significantly fewer transitions post-*matte* compared to pre-*matte*. In the NJ group the number of transitions made during the pre-*matte* preparation phase was 14.14 ± 5.14 compared to 5.71 ± 1.06 during the post-*matte* preparation phase, $t(6) = 5.24$, $p < 0.01$, $d = 2.27$. During the pre-*matte* preparation phase the NAT coaches made 12.81 ± 2.63 transitions compared to 6.56 ± 2.18 transitions post-matte, $t(7) = 6.46$, $p < 0.001$, $d = 2.59$, and the INT coaches made 11.79 ± 3.17 transitions pre-*matte*, compared to 5.25 ± 2.56 transitions post-matte, $t(6) = 12.31$, $p < 0.001$, $d = 2.05$.

**Table 9.2. Pre- versus post-*matte* preparation phase ranking of frequency of transitions between areas of interest (AOIs)**

| | Ranking of frequency of transitions between AOIs (1 = most frequent; pre-*matte* ranking/post-*matte* ranking) | | | | | |
|---|---|---|---|---|---|---|
| **Group** | **WU-BU** | **WU-SP** | **BU-WU** | **BU-SP** | **SP-WU** | **SP-BU** |
| **NJ** | 4/1 | 2/6 | 1/3 | 6/14 | 3/13 | 5/7 |
| **NAT** | 3/1 | 4/6 | 2/2 | 5/13 | 1/24 | 6/3 |
| **INT** | 4/1 | 2/8 | 3/2 | 6/10 | 1/13 | 5/5 |

NJ = non-judo; NAT = national; INT = international; WU-BU = transition from white upper to blue upper; WU-SP = transition from white upper to space; BU-WU = transition from blue upper to white upper; BU-SP = transition from blue upper to space; SP-WU = transition from space to white upper; SP-BU = transition from space to blue upper

**9.3.9 Pre- versus post-*matte* preparation phase: relative number of transitions between each area of interest (AOI).** There was no significant phase × coaching level × transition interaction observed, $F(10, 95) = 0.28$, $p > 0.05$, $\eta p^2 = 0.03$. However, a significant phase × transition interaction was observed, $F(5, 95) = 10.49$, $p < 0.01$, $\eta p^2 = 0.36$. With the groups collapsed, follow-up comparisons identified that the relative number of transitions from WU to BU, $t(21) = - 2.82$, $p < 0.02$, $d = - 0.74$, and BU to WU, $t(21) = - 2.43$, $p < 0.03$, $d = - 0.56$, were significantly greater during the post-*matte* preparation phase (WU to BU: 16.83 ± 15.7 %; BU to WU: 13.91 ± 12.33 %) compared to during the pre-*matte* preparation phase (WU to BU: 7.82 ± 7.31 %; BU to WU: 8.62 ± 4.86 %). The relative number of transitions from WU to SP, $t(21) = 3.16$, $p < 0.01$, $d = 1$, BU to SP, $t(21) = 4.12$, $p > 0.001$, $d = 1.13$, and SP to WU, $t(21) = 7.79$, $p < 0.001$, $d = 2.46$, were significantly less during the post-*matte* preparation phase (WU to SP: 3.67 ± 4.62 %; BU to SP: 1.28 ± 3.2 %; SP to WU: 0.61 ± 1.82 %) compared to during the pre-*matte* preparation phase (WU to SP: 8.61 ± 5.21 %; BU to SP: 5.98 ± 4.92 %; SP to WU: 9.37 ± 4.69 %).

Within-group analysis found significant phase × transition interactions for the NJ group $F(5, 30) = 3.04$, $p < 0.03$, $\eta p^2 = 0.34$, and the NAT coaches $F(5, 35) = 5.1$, $p < 0.05$, $\eta p^2 = 0.42$. A significant phase × transition interaction was not observed in the INT coaches, $F(5, 30) = 3.25$, $p > 0.05$, $\eta p^2 = 0.35$. In the NJ group there were significantly more transitions from BU to SP during the pre-*matte* preparation phase (5.6 ± 4.54 %) compared to during the post-*matte* preparation phase (00.00 ± 00.00 %), $t(6) = 3.27$, $p < 0.02$, $d = 1.74$. Additionally, there were significantly more transitions from SP to WU pre-*matte* (7.75 ± 4.38 %) compared to post-*matte* (0.71 ± 1.89 %), $t(6) = 3.37$, $p > 0.02$, $d = 2.09$ (Figure 9.1). In the NAT coaches, the number of transitions from BU to SP was significantly greater $t(7) = 2.4$, $p < 0.05$, $d = 1.04$, during the pre-*matte* preparation phase (6.48 ± 5.05) compared to during the post-*matte* preparation phase (1.56 ± 4.42 %). The number of transitions from SP to WU were also significantly greater, $t(7) = 6.84$, $p < 0.001$, $d = 3.42$, during the pre-*matte* preparation phase (9.18 ± 3.8 %), compared to during the post-matte preparation phase (00.00 ± 00.00 %). Furthermore, in the NAT coaches, the number of transitions from BU to WU during the post-*matte* preparation phase (13.87 ± 9.86 %) was significantly greater, $t(7) = -2.51$, $p < 0.05$, $d = -0.78$, than during the pre-*matte* preparation phase (7.73 ± 5.17 %; Figure 9.2).

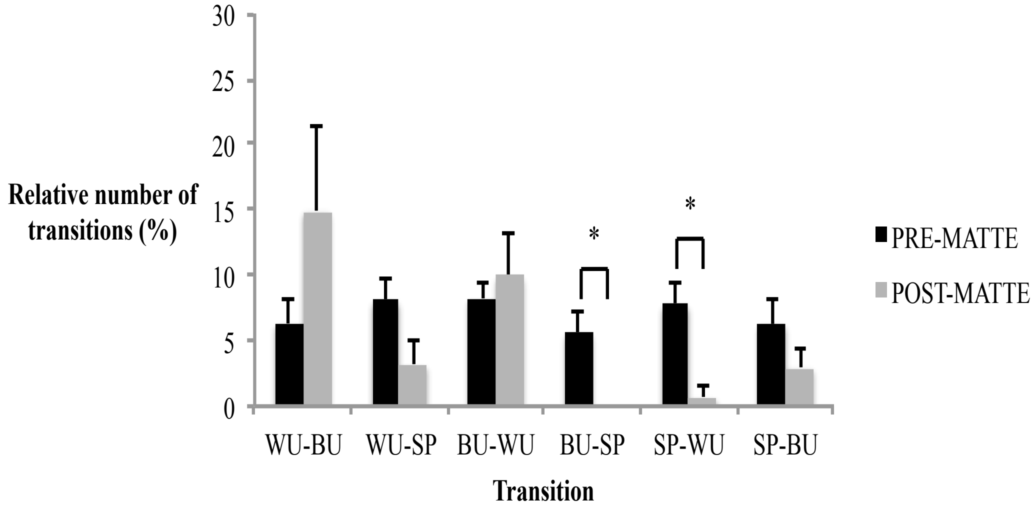


**Figure 9.1** Relative number of transitions (%) NJ group (mean + SE)

WU-BU = from white upper to blue upper; WU-SP = from white upper to space; BU-WU = from blue upper to white upper; BU-SP = from blue upper to space; SP-WU = from space to white upper; SP-BU = from space to blue upper; * denotes significant difference between pre-*matte* and post-*matte*

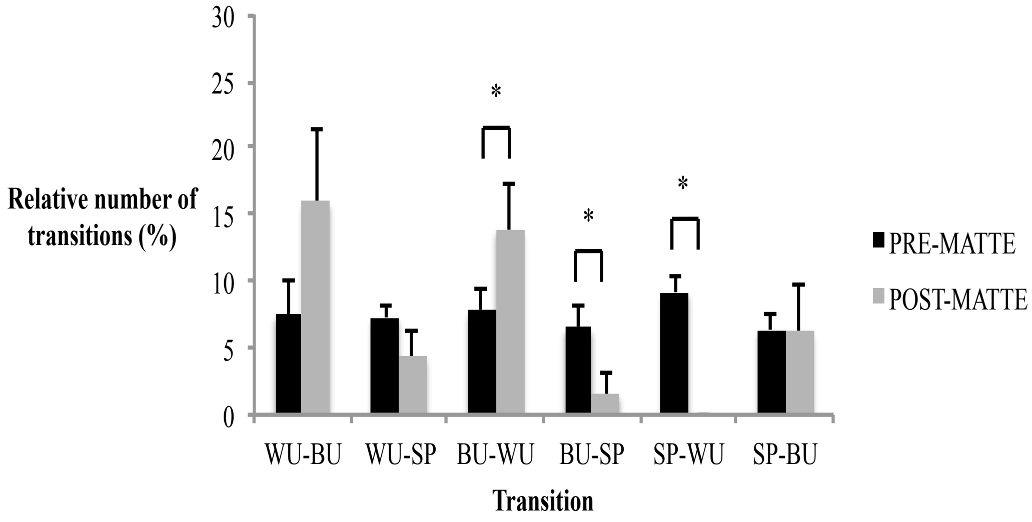


**Figure 9.2** Relative number of transitions (%) NAT coaches (mean + SE)

WU-BU = from white upper to blue upper; WU-SP = from white upper to space; BU-WU = from blue upper to white upper; BU-SP = from blue upper to space; SP-WU = from space to white upper; SP-BU = from space to blue upper; * denotes significant difference between pre-*matte* and post-*matte*

## 9.4 Discussion

The limited number of investigations into sport coaches' visual search strategies have analysed summary fixation data (e.g., Moreno et al., 2002). However, summary fixation data may not provide a complete understanding of individuals' search strategies (Button et al., 2011; Manzanres et al., 2015). Consequently, as an adjunct to summary fixation data, investigations have begun to analyse the frequency of transitions made between AOIs, and the randomness of individuals' search strategies (i.e., entropy; e.g., Allsop et al., 2017; Ryu et al., 2016). Therefore, the aim of the present chapter was to investigate the frequency of transitions between AOIs, and the entropy of sub-elite and elite judo coaches' (and participants with no judo experience) visual search strategies, when observing pre- and post-*matte* preparation phases of judo contests. By investigating the frequency of transitions between AOIs, and the entropy of judo coaches (and participants with no judo experience) search strategies, the present chapter has added to the understanding of judo coaches' search strategies gained from the previous experimental chapters that used summary fixation data.

Unexpectedly, findings from the present chapter suggest no between-group differences for search strategy predictability, with no significant expertise-based between-group differences for entropy, the total number of transitions, and relative number of transitions between the selected AOIs (i.e., WU, BU, SP) observed during either pre- or post-*matte* preparation phases. However, whilst not significant, during the pre-*matte* preparation phase entropy (0.78 ± 0.23 bits) and the total number of transitions (11.79 ± 3.17) were the lowest in the INT coaches, and the greatest in the NJ group (entropy = 1.09 ± 0.38 bits; total number of transitions = 14.14 ± 5.14), with the NAT coaches in-between (entropy = 0.88 ± 0.25 bits; total number of transitions = 12.81 ± 2.63). Similarly, during the post-*matte* preparation phase the lowest entropy (0.34 ± 0.22 bits) and total number of transitions (5.25 ± 2.56) was observed in the INT coaches, with greater entropy and total number of transitions observed in the NAT coaches (entropy = 0.47 ± 0.21 bits; total number of transitions = 6.56 ± 2.18) and NJ group (entropy = 0.42 ± 0.31 bits; total number of transitions = 5.71 ± 1.06). Although speculative, the lower entropy (i.e., reduced randomness) and fewer transitions observed in the INT coaches level suggests a possible influence of international coaching experience on the predictability of search strategies during judo contests. However, in the absence of statistical power calculations, any potential interpretation of the data as indicating between-group differences for entropy and the total number of transitions must be treated with caution. It is feasible that the experiment lacked statistical power due to the small sample size; therefore there is a possibility that an effect of coaching level was present (Button et al., 2013). In addition, the effect sizes observed ($\eta^2$ = 0.22 to 0.32) suggest a medium to large effect of level on entropy and the total number of transitions (Field, 2013). Nonetheless, future studies must address the issue of statistical power to establish if any differences in entropy and the total number of transitions do exist between judo coaches of different levels. Moreover, the alternative explanation of the visual scene presenting a limited number of potentially relevant AOIs (e.g., the *judokas'* upper bodies), with all participants looking at these AOIs must also be considered. The limited number of AOIs could have contributed to the lack of significant between-group differences for entropy and the total number of transitions, as there would have been limited opportunities for participants to engage in varied visual search strategies.

Within-group analysis of the pre-*matte* preparation phase found no significant differences between relative number of transitions between the selected AOIs in any group. However, during the post-*matte* preparation phase significant differences between the relative number of transitions between the selected AOIs were observed in the NAT coaches. Transitions by the NAT coaches from WU to BU (15.93 ± 15.78 %) were significantly greater than transitions from SP to WU (00.00 ± 00.00 %), whilst transitions from BU to WU (13.87 ± 9.86 %) were significantly greater than transitions from WU to SP (4.38 ± 5.21 %), BU to SP (1.56 ± 4.42 %), and SP to WU.

Further to the findings from the pre- and post-*matte* preparation phases, the findings from the comparison of the relative number of transitions made during the two phases indicate that the visual search strategies of the participants altered as the contest progressed. Both entropy and the total number of transitions were significantly less during the post-*matte* preparation phase compared to the pre-*matte* preparation phase. These findings are contrary to expectations that the NAT and INT coaches search strategies would remain consistent during the pre- and post-*matte* preparation phases, and that the NJ group would adopt a post-*matte* search strategy similar to that of the INT coaches.

Direct transitions between WU and BU (i.e., WU to BU, and BU to WU) were significantly greater post-*matte* compared to pre-*matte*, whilst three of the four transitions involving SP (i.e., WU to SP, BU to SP, and SP to WU) were significantly less post-*matte*. Furthermore, the within-group analyses suggest that the NJ group and NAT coaches decreased their use of transitions incorporating SP, with the NAT coaches increasing their use of direct transitions from BU to WU. Whilst the NJ group did not increase direct transitions between BU and WU, descriptively pre- to post-*matte* increases in transitions from WU to BU (pre-*matte*: 6.33 %; post-*matte*: 14.94 %), from OTH to WU (pre-*matte*: 1.85 %; post-*matte*: 12.08 %), WU to REF (pre-*matte*: 0.4 %; post-*matte*: 4.11 %), REF to WU (pre-*matte*: 0.65 %; post-*matte*: 5.18 %), and WU to TXT (pre-*matte*: 00.00 %; post-*matte*: 2.98 %) were observed. No significant pre- versus post-*matte* differences were observed in the INT coaches.

Collectively, the findings with regards to the relative number of transitions made during the pre- and post-*matte* preparation phases suggests that the NJ group and NAT coaches reduced their use of transitions involving SP, whilst the INT coaches did not significantly alter their use of transitions involving SP (or any of the other selected AOIs). Alongside their reduced use of transitions involving SP, the NJ group appears to have increased their use of transitions involving WU; however, caution is required, as the increases in transition involving WU observed are descriptive. Yet, unlike the NJ group, the NAT coaches appear to have increased their use of transitions from BU to WU, alongside their reduced use of transitions involving SP.

In all groups the total number of transitions was significantly greater during the pre-*matte* preparation phase compared to during the post-*matte* preparation phase (NJ group: 14.14 ± 5.14 versus 5.71 ± 1.06; NAT coaches: 12.81 ± 2.63 versus 6.56 ± 2.18; INT coaches: 11.79 ± 3.17 versus 5.25 ± 2.56). Whilst it is possible that fewer transitions between AOIs may be indicative of a more predictable search strategy (Manzanres et al., 2015), the fewer transitions made post-*matte* were likely due to post-*matte* preparation phase clips being shorter in duration than the clips used for the pre-*matte* preparation phases (pre-*matte*: ~ 7 – 8 s; post-*matte*: ~ 4 s). As with the total number of transitions, entropy (i.e., randomness, or alternatively predictability) was also significantly greater during the pre-*matte* preparation phase in comparison to the post-*matte* preparation phase. The NJ group demonstrated the greatest entropy of all the groups during the pre-*matte* preparation phase (1.09 ± 0.38 bits), with entropy decreasing to 0.42 ± 0.31 bits post-*matte*. The pre-*matte* entropy of the NAT (0.88 ± 0.25 bits) and INT (0.78 ± 0.23 bits) coaches decreased to 0.47 ± 0.21 bits and 0.34 ± 0.22 bits respectively post-*matte*. As relative measures were used to calculate entropy, differences in clip duration were accounted for; therefore entropy provides an indication of changes in search strategy predictability regardless of the differences in clip duration.

The reduced entropy observed for all groups during the post-*matte* preparation phase, compared to the pre-*matte* preparation phase, indicates that each group's search strategy became less random (more predictable) as contests progressed. It is possible that the visual information available during the *hajime-matte* block and *matte* period that separated the pre- and post-*matte* preparation phases may have contributed to the less random post-*matte* strategy. A less predictable search strategy may allow information to be obtained from more areas of a visual scene (Manzanares et al., 2015). Furthermore, when peripheral vision is not restricted (allowing the eyes to gather information using peripheral vision and subsequently move to all areas in a visual scene) entropy is greater (i.e., the search strategy is less predictable), than when peripheral vision is restricted (Ryu et al., 2016). Thus, a search strategy that incorporates multiple AOIs, compared to a strategy that uses fewer AOIs, will likely demonstrate greater entropy. Accordingly, it is possible that during the pre-*matte* preparation phase all groups used a strategy that incorporated several AOIs, possibly in an attempt to understand the visual scene that had just been presented to them. Yet, during the post-*matte* preparation phase fewer AOIs may have been required due to the information obtained during the intervening *hajime-matte* block and *matte* period.

The differences between the pre- and post-*matte* relative number of transitions between AOIs can provide further indication of how each group's search strategies changed, and became more predictable (i.e., demonstrated less entropy) during the post-*matte* preparation phase. In the NJ group, there was a pre- to post-*matte* decrease in the frequency of transitions from SP to WU (~ 7 %); alongside this decrease, there were pre- to post *matte* increases in the frequency of transitions from OTH to WU (~ 10 %), and from REF to WU (~ 4.5 %), with the frequency of transitions from other AOIs to WU (e.g., from BU to WU; from WL to WU; from BL to WU) remaining consistent. Whilst speculative, the results do suggest a net increase in the NJ group's frequency of transitions to WU, and hence a more predictable post-*matte* search strategy (i.e., they tended to return to WU from other AOIs), compared to their pre-*matte* search strategy.

Similar to the NJ group, the NAT coaches decreased their frequency of transitions involving SP during the post-*matte* preparation phase. Additionally, the NAT coaches also significantly increased their frequency of transitions from BU to WU by ~ 6 %. Furthermore, while not significant, the NAT coaches also demonstrated an increase of ~ 8.5 % in their frequency of transitions from WU to BU during the post-

*matte* preparation phase compared to during the pre-*matte* preparation phase. It is feasible that the reduction in transitions involving SP, and the increase in transitions between WU and BU, may account for the NAT coaches' more predictable post-*matte* search strategy (i.e., it was more likely they would transition from one upper body AOI to the other).

Unlike the NJ group and NAT coaches, no significant phase × transition interaction for the relative number of transitions between the selected AOIs was observed for the INT coaches. The lack of a significant phase × transition interaction suggests that the INT coaches adopted the same approach to transitioning between AOIs during the pre- and post-*matte* preparation phases. Such findings are congruent with the findings from chapter 7: Experiment 3 that indicate the use of a consistent search strategy by INT coaches during judo contest preparation phases regardless of prior exposure to contest-specific information. However, as with the NJ group and NAT coaches, a post-*matte* decrease in entropy was observed in the INT coaches, suggesting a more predictable post-*matte* search strategy. Despite the lack of a significant phase × transition interaction, a pre- to post-*matte* increase in the frequency of transitions from WU to BU (~ 10 %), and the frequency of transitions from BU to WU (~ 8 %) was observed. Additionally, pre- to post-*matte* decreases in the frequency of transitions from WU to SP (~ 10 %), and from SP to WU (~ 7 %) were also observed. Consequently, it is possible that the post-*matte* search strategy used by the INT coaches, as with the NAT coaches, may have been more predictable due to an increase in transitions between WU and BU, and a decrease in transitions between WU and SP (i.e., it was more likely that they would transition from one upper body AOI to the other).

The pre- to post-*matte* decrease in entropy, and pre- to post-*matte* changes in the relative number of transitions between AOIs, demonstrated by the NJ group, and NAT and INT coaches, appear to underpin the aspects of participants' search strategies identified in previous experimental chapters (using summary fixation data). Findings from chapter 7: Experiment 3 indicated that the NJ group adopted an alternative strategy during the post-*matte* preparation phase compared to during the pre-*matte* phase. Post-*matte,* the NJ group fixated on WU more frequently and for a longer duration compared to BU, whereas pre-*matte*, WU and BU were fixated by the NJ group in a comparable manner. Frequently transitioning to WU from other AOIs (e.g., BU, OTH) during the post-*matte* preparation phase, as observed in the present chapter, would have facilitated the increased post-*matte* frequency and fixation duration on WU. Furthermore, that the second most frequent transition was from OTH to WU, suggests the NJ group were not continually searching the scene for information relevant to the contest and task (i.e., provide coaching instructions to the *judoka* wearing white), or were not aware of where relevant information was located in the scene due to their lack of judo experience. As discussed in previous experimental chapters, the on-screen instructions (reiterating the task to participants) provided during the *matte* period may have acted as a cue (Knapp and Abrams, 2012; Kugler et al., 2015; Wood, Vine and Wilson, 2016) for the NJ group's subsequent post-*matte* search. Hence, in the absence of judo experience, the NJ group may have frequently transitioned back to WU from other AOIs, as WU was an AOI that had a clear relation to the task they had been asked to undertake (i.e., it was the upper body of the specified *judoka)*, and they had been reminded of its' relevance during the *matte* period.

As reported in previous experimental chapters, the NAT coaches appear to use a search strategy during the pre- and post-*matte* preparation phases that fixates the upper body AOIs (WU and BU) to a comparable extent. However, during the pre-*matte* preparation phase the fixation frequency on SP was not significantly different to the fixation frequency on BU, yet during the post-*matte* preparation phase the fixation frequency on SP was significantly less than the fixation frequency on BU. Furthermore, whilst no significant phase × AOI interaction was observed for the relative number of fixations or the relative total fixation duration in the NAT coaches, the number of fixations on SP decreased by ~ 8 % pre- to post-*matte*, whilst the total fixation duration on SP decreased by ~ 7 % pre- to post-*matte*. In addition to these findings from previous experimental chapters, in the present chapter transitions involving SP were less frequent during the post-*matte* preparation phase than during the pre-*matte* preparation phase, whilst transitions between the upper body AOIs increased. Together, the findings from previous experimental chapters, and the present chapter, suggest a reduced role for SP in the NAT coaches' post-*matte* search strategy. Moreover, it is feasible that the increase in transitions between the upper body AOIs facilitated the maintenance of the NAT coaches' strategy of fixating WU and BU in a comparable manner, despite the reduction in transitions involving SP.

As an AOI, SP was located between the *judokas*. Therefore, SP could have potentially acted as a visual pivot for participants' search strategies, enabling them to fixate on SP (using central vision), to use peripheral vision to monitor the movements of each *judoka*, and if necessary saccade to, and fixate, a *judoka's* upper body to obtain further information (e.g., Piras, Pierantozzi and Squatrito, 2014). It is possible that during the pre-*matte* preparation phase, the NAT coaches attempted to use SP as a visual pivot. However, due to their lesser experience of international level coaching (compared to the INT coaches), the NAT coaches may not have possessed the domain-specific knowledge to allow them to use relational information obtained from a visual pivot (e.g., North et al., 2009), and may not have been aware of the need to obtain accurate information about the handedness of the unfamiliar *judoka* they had been instructed to provide coaching points to (as discussed in chapter 6: Experiment 2). Thus, despite attempting to use SP as visual pivot, the NAT coaches may have had to frequently saccade from SP to fixate the upper bodies of the *judokas,* and use central vision to obtain information from surface features of the *judoka* (North et al., 2009). If the use of SP by the NAT coaches during the pre-*matte* preparation phase was an attempt at using a visual pivot, the reduced role of SP in the NAT coaches post-*matte* search strategy may have been recognition that it was not the most suitable approach to obtain the required information. Therefore, rather than attempting to use SP as a visual pivot and having to saccade to the upper body AOIs to obtain the required information, during the post-*matte* preparation phase the NAT coaches made transitions directly between upper body AOIs.

Further to its possible use as a visual pivot, SP could have acted as an intermediate location for participants' eyes to transition to when moving from WU to BU (or vice versa). The use of SP as intermediate location may have aided in limiting saccadic suppression and disruption to information processing (Vater, Kredel and Hossner, 2017) by dividing eye movements between upper body AOIs into two movements (e.g., from BU to SP, and then from SP to WU, rather than directly from BU to WU). Thus, due to the NAT coaches' need to obtain information from the upper body AOIs using central vision, SP may have been used as an intermediate location when moving the eyes between WU and BU during the pre-*matte* preparation phase. However, post-*matte*, less risk of saccadic suppression when moving the eyes between WU and BU may explain the reduced transitions involving SP.

Due to SP being located between the *judokas*, the size of the AOI could have varied during preparation phases as *judokas* aim to control (i.e., increase, decrease, or maintain) the space between them prior to engaging in the *kumi-kata* phase (i.e., taking grips; e.g., Miarka et al., 2012). If the *judoka* are closer to one another (i.e., SP decreases in size), then the distance to move the eyes between the upper body AOIs decreases. A decreased distance between the upper body AOIs would reduce the extent of saccadic suppression if moving the eyes directly from WU to BU (or vice versa), and possibly reduce the need for an intermediate location (i.e., SP). Furthermore, with the *judoka* closer to one another, the potential for SP to be used as a visual pivot is reduced, as an upper body AOI can be fixated, with peripheral vision used to monitor the opponent. Consequently, an alternative explanation for the NAT coaches' post-*matte* reduction in transitions involving SP, and increase in transitions between WU and BU, could be decreases in the size of SP during the post-*matte* preparation phase. The NAT coaches pre- to post-*matte* differences in transitions between AOIs could have facilitated the maintenance of their chosen strategy (i.e., fixate WU and BU in a comparable manner) despite possible differences in the context of the preparation phase. Future investigations could consider the possible effect of the context of contests on judo coaches' visual search strategies.

Unlike the NJ group and NAT coaches, the lack of a significant phase × transition interaction for the relative number of transitions in the INT coaches, suggests that they demonstrated consistency with regard to transitions between AOIs during the pre- and post-*matte* preparation phases. As previously identified in the present chapter, and in previous experimental chapters, the INT coaches also appear to adopt a consistent search strategy during the pre- and post-*matte* preparation phases with regard to fixation frequency and duration (i.e., they fixate on WU more frequently and for longer). As previously identified, a consistent search strategy may help to preserve cognitive resources, and may have developed as a consequence of task experience (Biggs et al., 2013; Dickinson and Zelinsky, 2007). However, the increases observed in the number of transitions between WU and BU, and the decreased frequency of transitions involving SP, suggests that caution is warranted when interpreting the present chapter's findings with regard to the consistency of the INT coaches' search strategy.

It is possible that the INT coaches, whilst maintaining their predominant use of WU pre- and post-*matte*, altered their use of transitions pre- to post-*matte* in a manner similar to the NAT coaches. The INT coaches' use of transitions to SP during the pre-*matte* preparation phase may indicate the use of SP as an intermediate location when moving the eyes between the upper body AOIs, or as a location from which to use peripheral vision to obtain information about the opponent, if this could not be done when using WU as a visual pivot (as discussed in chapter 6: Experiment 2 and chapter 7: Experiment 3). The possible post-*matte* reduction in transitions involving SP, and increase in transitions between WU and BU, suggest that the INT coaches did not have to use SP in the same manner as during the pre-*matte* preparation phase.

Being able to monitor the opponent (using peripheral vision) from WU, and less risk of saccadic suppression when moving the eyes between WU and BU may explain the changes in transitions involving SP, and transitions between the upper body AOIs. As with the NAT coaches, the INT coaches pre- to post-*matte* changes in transitions may have facilitated the maintenance of the INT coaches' strategy of predominantly fixating WU, despite a possible change in the context of the contest regarding the need to use SP.

**9.5 Conclusion**

The present chapter used Markov chain modelling to investigate the visual search strategies of sub-elite (NAT coaches) and elite (INT coaches) judo coaches (and participants with no judo experience) whilst observing pre- and post-*matte* preparation phases of judo contests. Markov chain modelling allowed the total number of transitions, the relative number of transitions between selected AOIs (i.e., WU, BU, and SP), and entropy to be calculated and analysed. The analysis of these variables supplements the summary fixation data analysed in the preceding experimental chapters. Furthermore, as the first investigation to utilise Markov chain modelling to investigate sport coaches' visual search strategies, the present chapter has the potential to inform further use of these methods, and the development of hypotheses, when investigating the search strategies of judo coaches, and coaches from other sports.

During the post-*matte* preparation phase the total number of transitions were fewer in all groups compared to during the pre-*matte* preparation phase. The shorter duration of the post-*matte* preparation phase clips compared to the pre-*matte* preparation phase clips provides an explanation for this observation, as participants had less time to transition between AOIs. Such a finding was expected, and the use of an absolute measure (i.e., total number of transitions) highlighted the need for the subsequent use of relative measures to account for variations in preparation phase duration.

The post-*matte* entropy (i.e., predictability) of all group's search strategies was less in comparison to their pre-*matte* entropy. Changes in the frequency of transitions between AOIs appear to account for the decrease in entropy observed in each group. In the NJ group, alongside a decrease in transitions involving SP, transitions to WU from other AOIs appeared to increase post-*matte*, thus contributing to an increase in the predictability (i.e., decreased entropy) of their post-*matte* search strategy (i.e., they tended to return to WU from other AOIs). Together with decreased transitions involving SP post-*matte*, the sub-elite coaches increased transitions between WU and BU, thus increasing the predictability of their post-*matte* search strategy (i.e., it was more likely they would transition from one upper body AOI to the other). Despite the lack of a significant phase × transitions interaction for the elite coaches, it is feasible that they increased the predictability of their post-*matte* search strategy in a manner similar to that of the sub-elite coaches.

The NJ group's increased transitions to WU during the post-*matte* preparation phase appear to have facilitated their post-*matte* search strategy of fixating predominantly on WU (as reported in chapter 7: Experiment 3). The sub-elite coaches post-*matte* decrease in transitions involving SP, and increase in transitions between WU and BU, together with a decrease in fixation frequency and duration on SP (as reported in chapter 7: Experiment 3), indicate a reduced role for SP in the sub-elite coaches post-*matte* search strategy. It is possible that the sub-elite coaches recognised that direct transitions between upper body AOIs, due to their need to use central vision to obtain information from surface features, was a more suitable strategy compared to attempting to use SP as a visual pivot, or as an intermediate location when moving the eyes between WU and BU. However, post-*matte* differences in the size of SP (due to changes in the proximity of the *judoka*) should be considered as an alternative explanation for the sub-elite coaches reduced use of SP during the post-*matte* preparation phase. The sub-elite coaches post-*matte* increase in transitions between WU and BU may have allowed them to maintain their strategy of fixating on the upper body AOIs in a comparable manner despite changes in the size of SP.

The lack of a significant phase × transition interaction in the elite group suggests that they were consistent in their use of transitions during the pre- and post-*matte* preparation phases. Such consistency is similar to that reported for the elite coaches in chapter 7: Experiment 3 regarding fixation frequencies and durations. However, the descriptive reduction in transitions involving SP, and increase in transitions between WU and BU observed post-*matte*, suggests a change in search strategy with regard to transitions between AOIs may have occurred. It is possible that during the post-*matte* preparation phase there was less need to use SP to monitor the opponent using peripheral vision, as this could be achieved from WU. Post-*matte* changes in the size of SP may explain the alteration in the elite coaches search strategy.

Future investigations should consider the influence of the context of the contest (e.g., availability of SP, duration of preparation phase) on judo coaches' visual search strategies. The use of Markov chain modelling can also be expanded to investigate the temporal sequencing (e.g., Button et al., 2011) of coaches' search strategies, and how coaches' search strategies develop in relation to changes in the context of the contest as it progresses.

# 10. General discussion and limitations

## 10.1 General discussion

The aim of the present series of experiments was to investigate the visual search strategies of judo coaches when observing judo contests. In the absence of investigations into judo coaches' search strategies, and the limited number of studies investigating sport coaches' search strategies, the current research was exploratory in nature. As the first investigation of judo coaches' search strategies, the current research aimed to contribute to the understanding of judo coaches' search strategies when observing contests, to inform the development of hypotheses for future investigations into judo coaches' (and other sport coaches') search strategies, and to add to the limited number of investigations of sport coaches' search strategies.

A single contest phase (i.e., the preparation phase) was selected for investigation. The preparation phase is the first phase of a *hajime-matte* block, and is where a *judoka* attempts to control the space between them and their opponent, and establish their first grip on the opponent whilst avoiding the opponent's attempts to grip. The search strategies of sub-elite and elite judo coaches, and participants with no judo experience, during the preparation phase were investigated without prior exposure to contest specific information (i.e., the pre-*matte* preparation phase), following prior exposure to contest specific information (i.e., the post-*matte* preparation phase), and during initial and repeated viewings of pre-*matte* preparation phases. Summary fixation data (i.e., number and duration of fixations on AOIs), and data obtained using Markov chain modelling (i.e., transitions between AOIs and entropy) were analysed.

Summary fixation data analysis indicated that elite coaches (INT coaches) adopted a consistent search strategy during pre- and post-*matte* preparation phases, and during initial and repeated viewings of pre-*matte* preparation phases, whereby they predominantly fixated on the upper body of the *judoka* they had been instructed to coach (i.e., WU). The sub-elite coaches (NAT coaches) also adopted a consistent search strategy; however, their search strategy fixated WU and the opponent's upper body (i.e., BU) in a comparable manner. Participants with no judo experience (NJ group) did not demonstrate consistency in their search strategies to the same extent as the sub-elite and elite coaches. During the pre-*matte* preparation phases the NJ group fixated WU and BU in a comparable manner, yet during the post-*matte* preparation phase they predominantly fixated WU.

The elite coaches' consistent predominant use of WU may have been a consequence of their experience of international coaching. Top-down, goal-orientated signals would have driven their visual search to obtain information about the *judoka* they were instructed to provide coaching instructions for. Furthermore, due to their experience, the elite coaches would have been able to use WU as a visual pivot, using peripheral vision and relational information to obtain information about the opponent. The sub-elite coaches' search strategy may also have been driven by top-down, goal-orientated signals, yet due to their lack of experience of international level coaching they had to obtain information from surface features (rather than relational information), hence their comparable use of WU and BU. For the NJ group, the need to understand an unfamiliar scene may have contributed to their pre-*matte* use of WU and BU, as heads and faces (located within upper body AOIs) may provide information about individuals' intentions. The post-*matte* change in the NJ group's search strategy possibly resulted from on-screen text during the *matte* period acting as cue for their subsequent visual search. In contrast, the consistency of the sub-elite and elite coaches' search strategies indicates that information between the two preparation phases did not influence their search strategy.

Whilst the summary fixation data suggested consistency in the sub-elite and elite coaches' pre- and post-*matte* search strategies, and a pre- to post-*matte* change in the NJ group's search strategy, analysis of transition and entropy data indicated that there were pre- to post-*matte* changes in the search strategies of all groups. Post-*matte*, a decrease in the total number of transitions between AOIs and entropy (i.e., increased predictability) was observed in all groups. The shorter post-*matte* preparation phase possibly accounts for the reduction in transitions between AOIs, whilst post-*matte* changes in the frequency of transitions between AOIs appear to account for the decrease in entropy. Post-*matte*, the NJ group decreased the number transitions involving SP, whilst increasing transitions to WU from other AOIs. The sub-elite coaches also decreased the number of transitions involving SP, but increased the number of transitions between WU and BU. Whilst not significant, the results suggest that the elite coaches may have altered their transitions in a manner similar to the sub-elite coaches.

It is possible that the pre- to post-*matte* differences in the frequency of transitions between AOIs acted to underpin the consistency of the sub-elite and elite coaches' search strategies, and the change in the NJ group's search strategy. Less need to use SP, or a reduction in the size of SP available, during the post-*matte* preparation phase may explain the reduction in transitions involving SP. Therefore, the sub-elite and elite coaches increased the number of transitions involving the upper body AOIs during the post-*matte* preparation phase to maintain their comparable use of WU and BU (sub-elite coaches), and predominant use of WU (elite coaches). For the NJ group, the increase in transitions to WU would have contributed to their predominant use of WU post-*matte*.

**10.2 Limitations**

The series of exploratory experiments in this thesis have provided the first investigations into the visual search strategies of judo coaches. However, there are several limitations with this research that should be considered and addressed in future studies. A priori power analyses were not carried out. Furthermore, the use of convenience sampling, and the challenges of recruiting higher-level (i.e., national and international level) judo coaches led to a small sample size, which whilst similar to other studies of coaches' visual search strategies (e.g., Moreno et al., 2006), could have contributed to a lack of statistical power. The absence of a priori power analyses, and the use of small sample sizes are not uncommon in sport and exercise science research, and the associated issues have received attention in the literature (e.g., Atkinson and Nevill, 2001; Bernards et al., 2017; Heneghan at al., 2012). The small sample size in the present series of experiments may have led to insufficient statistical power; therefore, the true effect of coaching level on the variables analysed may not have been found (Bernards et al., 2017). Alternatively, the small sample size could have led to an overestimation of the significant within-group effects found (Button et al., 2013). Attempting to recruit a large number of higher-level judo coaches to address the issue of statistical power will remain challenging. Future research should consider alternative approaches to the nullhypothesis significance testing (NHST; as used in the present research) such as a Bayesian framework that may be able to tolerate smaller sample sizes (Bernards et al., 2017).

Alongside considerations regarding statistical power and sample size, consideration should be given to the analytical approach used. ANOVAs (one-way and multiway) were used throughout the series of experiments reported in this thesis. Whilst ANOVAs may be considered robust to violations of assumptions (as occurred with aspects of the present data set; Field, 2013), and are often used in exploratory experiments where researchers could be considered to be "taking a look to see what they might find" in a data set (Craemer et al., 2016), multiway ANOVAs are susceptible to familywise error, and therefore inflation of the alpha level. Consequently, it is possible that in the absence of the use of a correction to address any familywise errors in the present research, inflation of the alpha level may have occurred, thus increasing the probability that type I errors could have been made when using multiway ANOVAs. Future investigations, if continuing to use NHST and multiway ANOVAs, must address familywise errors through the use appropriate corrections (e.g., Bonferroni-Holm; Cramer et al., 2016).

Further to the possible limitations of the statistical approach used in the present research, are considerations concerning aspects of the study design. Coaching expertise was established using composite criteria (i.e., qualifications, experience, level of coaching; Nash et al., 2012), and the INT coaches demonstrated characteristics of elite judo coaches as previously described in Santos et al. (2015). However, using such composite criteria may not effectively establish coaching expertise, and additional criteria including coaches' declarative knowledge base, perceptual skills, use of routines, and ability to problem-solve and reflect on practice have been proposed to further assess coaching expertise (Nash et al., 2012). Yet, the use of such criteria in the present research would have required long-term of observation of the coaches' practice, and therefore was not feasible. In investigations of athletes' and officials' visual search strategies concerns with defining expertise have been addressed by grouping participants based on the level of performance they demonstrate in the specific task being investigated (e.g., median-split technique; Cattuew et al., 2010). Grouping participants based on performance, rather than reported level, in the task being investigated controls for participants' competency in the different components of performance that can contribute to reaching a high level of performance (Vaeyens et al., 2007b; Williams and Ericsson, 2005). However, in the present research a coaching-based task was not included, hence coaches could not be grouped based on task performance. In addition to grouping participants, the inclusion of a coaching-based task (e.g., establish handedness) would have been beneficial in establishing if expertise-based differences in performance were present despite the absence of significant between-group differences in visual search. Furthermore, the use of a recognition task in chapter 8: Experiment 4 would have added to the findings regarding the initial and repeated viewings by establishing if participants did recognise they were viewing a repeated contest.

Alongside the considerations about how expertise was defined, and the absence of a coaching-based task, the broadness of the AOIs used presents a further limitation. Whilst participants appeared to predominantly utilise the upper body AOIs (i.e., WU and BU) in their visual search strategies, it is not known if participants were looking at different areas within the upper body AOIs. Whilst the experimental set-up and equipment used meant that more specific AOIs could not be used, the use of an adjunct measure such as verbal reports of thinking (e.g., Afonso et al., 2012) would have allowed additional information about participants' search strategies with regard to the upper body AOIs to be obtained (Afonso et al., 2012). Moreover, verbal reports could have provided information regarding any covert shifts of attention made by participants (i.e., use of peripheral vision that would not have been identified using the eye tracking glasses), and why participants looked at the upper body AOIs.

# 11. Conclusion

This thesis provides the first investigation of judo coaches' visual search strategies, and adds to the limited number of investigations of sport coaches' visual search strategies. The findings suggest that elite judo coaches adopt an alternative search strategy to sub-elite judo coaches during the preparation phase of judo contests, and that they use this strategy consistently throughout the contest. It is possible that the search strategy used by elite coaches (i.e., predominant fixation of the upper body of the *judoka* they are coaching), as a consequence of their experience, represents an advantageous strategy for obtaining visual information during the preparation phase of judo contests. If the strategy is advantageous, it may be beneficial for sub-elite judo coaches to be trained to develop such a search strategy as part of their coach education. Training similar to that used to develop QE duration (Vine, Moore and Wilson, 2011; Vine et al., 2013) could be used to help sub-elite coaches to increase their top-down, goal-directed drive to fixate the upper body of the *judoka* they are coaching. However, limitations of the present research, and directions for further research, must be considered before attempting to apply the findings.

The findings from the present research represent a specific situation. Contest footage was presented via video, only the preparation phase was analysed, and the *judoka* to be coached was unfamiliar to the coaches. In addition, only a single *hajime-matte* block separated the contest phases analysed. Future research should investigate if differences exist between coaches' search strategies when coaching in live situations and when coaching via video. Findings from such studies could inform the experimental set-up used in subsequent investigations. Additionally, studies should consider coaches' search strategies during other contest phases (e.g., *kumi-kata*), and when coaching *judoka* with whom they are familiar. Contest phases separated by multiple *hajime-matte* blocks should also be considered to investigate the influence of accumulated contest specific information on subsequent search strategies.

Further to investigating other contest situations, future research should consider investigating the relationship between coaches' prior motor experience (i.e., as a *judoka*) and their visual search. Additionally, the relationship between visual search and performance of specific coaching tasks (e.g., identifying *judoka* handedness, contest recognition, pattern recall) should be considered. The inclusion of a task may also allow the creation of groups based upon task performance (e.g., median-split technique), and address issues with defining the expertise of participants based on aspects such as years of experience and qualifications. Furthermore, any future investigations should also attempt to use more specific AOIs. Whilst the present research identified consistency in judo coaches' search strategies during the preparation phase with regard to WU and BU, the use of broad AOIs means that it is not known how the coaches' searched within the upper body AOIs, and whether this was also consistent. The use of more specific AOIs may also help to identify expertise-based differences not identified in the present research, and aspects of coaches' visual search that may vary dependent on the contest phase or coaching task being performed. The use of adjunct measures, such as verbal reports of thinking, may provide additional insight into how coaches process information and make decisions during different contest phases and coaching tasks.

# 12. References


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# 13. Appendices

## Appendix A

**PARTICIPANT NUMBER:**

**Pre-participation questionnaire for visual health**

Thank you for volunteering to take part in this study. The study involves viewing clips of judo contests on a large screen from a close distance. The large screen and close distance allow the study to replicate as closely as possible the visual environment that a judo coach experiences when viewing live judo contests. Viewing the video footage on a large screen from a close distance is very safe for most people, but having underlying medical conditions may raise the level of risk. The purpose of this questionnaire is to reduce the risk to participants by identifying any medical conditions that may increase the risk and affect participation in the study.

**Please answer all questions below.**

**Section A**

1. Do you wear glasses?

   Please circle: Yes No

2. Do you wear contact lenses?

   Please circle: Yes No

3. When was the last time you had your eyes tested?

   ______________________________

4. To your knowledge do you have normal vision (i.e., 20/20 vision) without glasses/contact lenses, or when wearing glasses/contact lenses?

   Please circle: Yes – without glasses/contact lenses Yes – with glasses/contact lenses No

**If you require glasses to correct your vision you will not be able to participate in the study. Please inform the main investigator if this is the case.**

**Section B**

5. As far as you are aware do you suffer, or have you suffered, from photosensitive epilepsy?

   Please circle: Yes No

**Figure A1** Participant visual health questionnaire

6. Have you ever suffered a seizure when viewing images (e.g., photographs, television, video game, film etc.) on a screen of any size?

   Please circle: Yes No

7. Have you ever experienced visual disturbances (e.g., blurred vision, double vision, pain etc.) when viewing images (e.g., photographs, television, video game, film etc.) on a screen of any size?

   Please circle: Yes No

8. Have you ever suffered from migraines when viewing images (e.g., photographs, television, video game, film etc.) on a screen of any size?

   Please circle: Yes No

9. As far as you are aware do you have any other medical condition that may affect your ability to participate in this study?

   Please circle: Yes No

   **If you answered Yes to any question in Section B please speak to the main investigator.**

**If your health changes whilst you are still participating in this study so that you would answer the above questions differently please inform the main investigator.**

**I have read, understood and completed this questionnaire. I was able to ask questions and any questions I asked were answered to my satisfaction.**

**Name:**

**Signature:**

**Date:**

**Figure A1** Participant visual health questionnaire (continued)

## Judo experience questionnaire

**PARTICIPANT NUMBER:** **DOB:**

**Questionnaire to establish your judo coaching experience**

1. How many years have you been doing judo?

_______________________________________________

2. Do you hold a judo coaching qualification?

   Please circle: Yes No

3. What judo coaching qualification do you hold?

_______________________________________________

4. What is your judo grade?

_______________________________________________

5. Which body awarded your judo grade?

_______________________________________________

6. How many years have you been coaching judo?

_______________________________________________

7. What is the highest level of judo you have coached at?

   Please circle: Recreational Regional National International

8. Have you ever competed in judo?

   Please circle: Yes No

**If you answered No to question 8 please go to question 10.**

8. What was the highest level of judo competition that you competed at?

   Please circle: Recreational Regional National International

9. When did you last compete in judo competition?

_______________________________________________

**Figure A2** Participant judo experience questionnaire

10. Do you still actively participate in judo training (e.g., randori)?

Please circle: Yes No

**If you answered No to question 10 you do not need to answer any further questions.**

11. How many times per week do you actively participate in judo training?

______________________________________________

**Thank you for your time.**

**I have read, understood and completed this questionnaire. I was able to ask questions and any questions I asked were answered to my satisfaction.**

**Name:**

**Signature:**

**Date:**

**Figure A2** Participant judo experience questionnaire (continued)

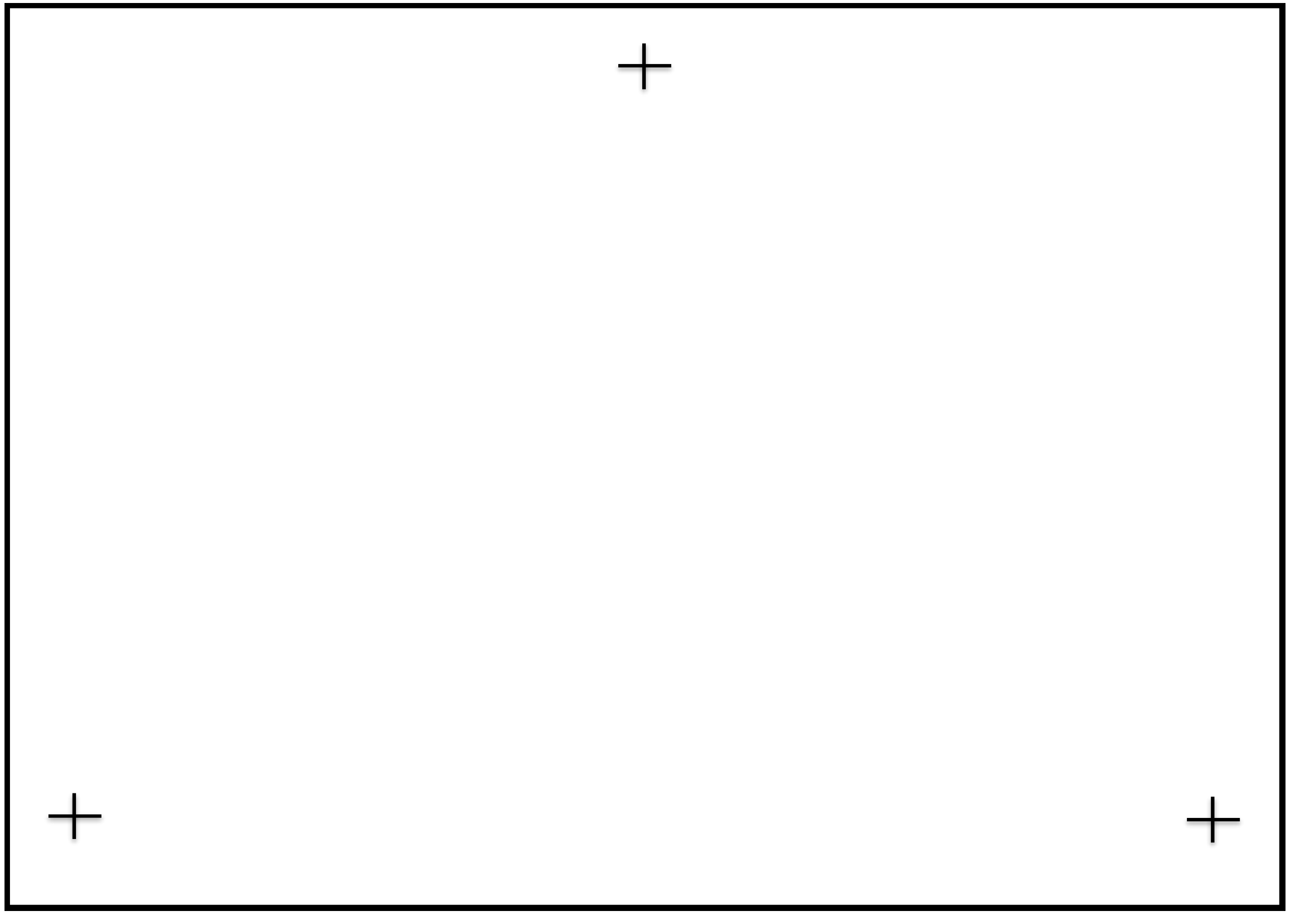

**Figure A3** Three-point calibration image

| | | | | | |
|---|---|---|---|---|---|
| POST-MATTE MACRO 1 | Start Here | PR001 | | | 0 |
| | | PR006 | PR001 4 post-matte.txt | PR001 4 post-matte.xlsx | 0 |
| | *Increment Line_Nb* | PR007 | PR001 6 post-matte.txt | PR001 6 post-matte.xlsx | |
| | =SELECT("Loop_1") | PR008 | PR006 4 post-matte.txt | PR006 4 post-matte.xlsx | |
| | =FORMULA(Loop_1+1) | PR009 | PR006 6 post-matte.txt | PR006 6 post-matte.xlsx | |
| | =SELECT("Loop_2") | PR010 | PR007 4 post-matte.txt | PR007 4 post-matte.xlsx | |
| | =FORMULA(loop_2+1) | PR011 | PR007 6 post-matte.txt | PR007 6 post-matte.xlsx | |
| | | PR013 | PR008 4 post-matte.txt | PR008 4 post-matte.xlsx | |
| | | PR020 | PR008 6 post-matte.txt | PR008 6 post-matte.xlsx | |
| Subject_Name | =INDEX(C1:C21,loop_2) | PR021 | PR009 4 post-matte.txt | PR009 4 post-matte.xlsx | |
| File_Name_text | =INDEX(E2:E43,Loop_1) | PR022 | PR009 6 post-matte.txt | PR009 6 post-matte.xlsx | |
| original_file | =INDEX(D2:D43,Loop_1) | PR023 | PR010 4 post-matte.txt | PR010 4 post-matte.xlsx | |
| | =DIRECTORY("F:\PhD\Data\Post-matte BeGaze output\") | PR024 | PR010 6 post-matte.txt | PR010 6 post-matte.xlsx | |
| | =OPEN(original_file) | PR025 | PR011 4 post-matte.txt | PR011 4 post-matte.xlsx | |
| | | PR026 | PR011 6 post-matte.txt | PR011 6 post-matte.xlsx | |
| | =NEW(5) | PR027 | PR013 4 post-matte.txt | PR013 4 post-matte.xlsx | |
| | =DIRECTORY("F:\PhD\Data\Post-matte BeGaze output\") | PR028 | PR013 6 post-matte.txt | PR013 6 post-matte.xlsx | |
| | =SAVE.AS("Results\"&File_Name_text) | PR029 | PR020 4 post-matte.txt | PR020 4 post-matte.xlsx | |
| | | PR030 | PR020 6 post-matte.txt | PR020 6 post-matte.xlsx | |
| | =ACTIVATE(original_file) | PR031 | PR021 4 post-matte.txt | PR021 4 post-matte.xlsx | |
| | =SELECT("R34") | PR033 | PR021 6 post-matte.txt | PR021 6 post-matte.xlsx | |
| | =FORMULA.FIND("B AOI Hit",1,2,1,1,FALSE) | | PR022 4 post-matte.txt | PR022 4 post-matte.xlsx | |
| | =SELECT("c") | | PR022 6 post-matte.txt | PR022 6 post-matte.xlsx | |
| | =COPY() | | PR023 4 post-matte.txt | PR023 4 post-matte.xlsx | |
| | =ACTIVATE(File_Name_text) | | PR023 6 post-matte.txt | PR023 6 post-matte.xlsx | |
| | =SELECT("c1") | | PR024 4 post-matte.txt | PR024 4 post-matte.xlsx | |
| | =PASTE.SPECIAL(3,1,FALSE,FALSE) | | PR024 6 post-matte.txt | PR024 6 post-matte.xlsx | |
| | | | PR025 4 post-matte.txt | PR025 4 post-matte.xlsx | |
| | | | PR025 6 post-matte.txt | PR025 6 post-matte.xlsx | |
| | =SELECT("R34c1") | | PR026 4 post-matte.txt | PR026 4 post-matte.xlsx | |
| start_fixation | =ROW(ACTIVE.CELL()) | | PR026 6 post-matte.txt | PR026 6 post-matte.xlsx | |
| | =SELECT("R"&start_fixation&"c3") | | PR027 4 post-matte.txt | PR027 4 post-matte.xlsx | |
| | =FORMULA("white upper 1") | | PR027 6 post-matte.txt | PR027 6 post-matte.xlsx | |
| | =SELECT("Rc[1]") | | PR028 4 post-matte.txt | PR028 4 post-matte.xlsx | |
| | =FORMULA("white upper 2") | | PR028 6 post-matte.txt | PR028 6 post-matte.xlsx | |
| | =SELECT("Rc[1]") | | PR029 4 post-matte.txt | PR029 4 post-matte.xlsx | |
| | =FORMULA("white upper 1 & white upper 2") | | PR029 6 post-matte.txt | PR029 6 post-matte.xlsx | |
| | =SELECT("Rc[1]") | | PR030 4 post-matte.txt | PR030 4 post-matte.xlsx | |
| | =FORMULA("white lower 1") | | PR030 6 post-matte.txt | PR030 6 post-matte.xlsx | |
| | =SELECT("Rc[1]") | | PR031 4 post-matte.txt | PR031 4 post-matte.xlsx | |
| | =FORMULA("white lower 2") | | PR031 6 post-matte.txt | PR031 6 post-matte.xlsx | |
| | =SELECT("Rc[1]") | | PR033 4 post-matte.txt | PR033 4 post-matte.xlsx | |
| | =FORMULA("white lower 1 & white lower 2") | | PR033 6 post-matte.txt | PR033 6 post-matte.xlsx | |

**Figure A4** Bespoke macro script example

| | |
|---|---|
| | =SELECT("Rc[1]") |
| | =FORMULA("white total") |
| | =SELECT("Rc[1]") |
| | =FORMULA("blue upper 1") |
| | =SELECT("Rc[1]") |
| | =FORMULA("blue upper 2") |
| | =SELECT("Rc[1]") |
| | =FORMULA("blue upper 1 & blue upper 2") |
| | =SELECT("Rc[1]") |
| | =FORMULA("blue lower 1") |
| | =SELECT("Rc[1]") |
| | =FORMULA("blue lower 2") |
| | =SELECT("Rc[1]") |
| | =FORMULA("blue lower 1 & blue lower 2") |
| | =SELECT("Rc[1]") |
| | =FORMULA("blue total") |
| | =SELECT("Rc[1]") |
| | =FORMULA("other 1") |
| | =SELECT("Rc[1]") |
| | =FORMULA("other 2") |
| | =SELECT("Rc[1]") |
| | =FORMULA("other 1 and other 2") |
| | =SELECT("Rc[1]") |
| | =FORMULA("referee") |
| | =SELECT("Rc[1]") |
| | =FORMULA("scoreboard") |
| | =SELECT("Rc[1]") |
| | =FORMULA("screen text") |
| | =SELECT("Rc[1]") |
| | =FORMULA("space 1") |
| | =SELECT("Rc[1]") |
| | =FORMULA("space 2") |
| | =SELECT("Rc[1]") |
| | =FORMULA("space 1 & space 2") |
| | =SELECT("Rc[1]") |
| | =FORMULA("no fixation") |
| | =SELECT("Rc[1]") |
| | =FORMULA("total") |
| | =ACTIVATE(File_Name_text) |
| | =SELECT("c1") |
| Data | =COLUMN(ACTIVE.CELL()) |
| | |
| | =SELECT("R"&start_fixation+2&"c1") |
| | =SELECT.END(4) |
| End_data | =ROW(ACTIVE.CELL()) |
| | =SELECT("R[4]c") |
| | =FORMULA("END") |
| | =FILL.AUTO("rc:"&"rc[27]") |
| | |
| | |
| | =ACTIVATE(File_Name_text) |
| | =SELECT("R"&start_fixation&"c1") |
| | =SELECT("R[1]c") |
| Start_trial | Start_trial |

**Figure A4** Bespoke macro script example (continued)

## Appendix B

**Table B1** Post-hoc analysis of relative number of fixations on AOIs, total relative fixation durations on AOIs, and average fixation duration on AOIs (mean ± SE)

| | WU | WL | BU | BL | SP | SB | REF | TXT | OTH |
|---|---|---|---|---|---|---|---|---|---|
| **RELFIX (%)** | 44.24 ± 3.45<br>b, c, d, e, f, g, h, i | 2.52 ± 0.64<br>a, c, e, f, i | 26.16 ± 2.50<br>a, b, d, e, f, g, h, i | 4.66 ± 1.26<br>a, c, e, g, i | 11.19 ± 2.09<br>a, b, c, d, f, g, h, i | 5.54 ± 0.99<br>a, b, c, e, g, i | 1.52 ± 0.44<br>a, c, d, e, f, i | 3.13 ± 0.54<br>a, c, e, i | 0.28 ± 0.54<br>a, b, c, d, e, f, g, h |
| **TOTALFIX (%)** | 41.70 ± 3.57<br>b, c, d, e, f, g, h, i | 1.99 ± 0.52<br>a, c, e, f, h, i | 25.71 ± 2.74<br>a, b, d, e, f, g, h, i | 3.86 ± 1.05<br>a, c, f, g, h, i | 8.63 ± 2.41<br>a, b, c, g, h, i | 8.34 ± 1.59<br>a, b, c, d, g, h, i | 1.05 ± 0.26<br>a, c, d, e, f, h | 1.82 ± 0.32<br>a, c, e, f, i | 0.21 ± 0.1<br>a, b, c, d, e, f, g, h |
| **AVFIX (secs)** | 0.85 ± 0.07<br>b, d, e, f, g, h, i | 0.24 ± 0.06<br>a, c, f, i | 0.81 ± 0.09<br>b, d, e, g, h, i | 0.29 ± 0.07<br>a, c, e, f, g, i | 0.46 ± 0.08<br>a, c, d, g, h, i | 0.54 ± 0.12<br>a, b, d, g, h, i | 0.12 ± 0.04<br>a, c, d, e, f | 0.2 ± 0.03<br>a, c, e, f, i | 0.05 ± 0.02<br>a, b, c, d, e, f, h |

AOI = area of interest; RELFIX = relative number of fixations; TOTALFIX = relative total fixation duration; AVFIX = average fixation duration; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard; REF = referee; TXT = screen text; OTH = other; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to TXT; [i] = significantly different ($p < 0.05$) to OTH

**Table B2** Within-group post-hoc analysis of relative number of fixations on secondary AOIs (%; mean ± SD)

| | REF | TXT | OTH |
|---|---|---|---|
| **NJ** | 2.01 ± 1.97 [a, c] | 3.87 ± 1.85 [a, c] | 0.00 ± 0.00 [NA] |
| **NAT** | 1.72 ± 2.57 [a, c, d, e, f] | 3.32 ± 2.82 [a, c, e, h,] | 0.86 ± 1.60 [a, c, e, f, i] |
| **INT** | 0.84 ± 1.44 [a, c, e, f] | 2.70 ± 2.80 [a, c] | 0.84 ± 1.44 [a, c, e, f] |

AOI = area of interest; NJ = non-judo; NAT = national; INT = international; REF = referee; OTH = other; TXT = screen text; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to OTH; [i] = significantly different ($p < 0.05$) to TXT; [NA] = not included in within-group analysis

**Table B3** Within-group post-hoc analysis of relative total fixation duration on secondary AOIs (%; mean ± SD)

| | REF | TXT | OTH |
|---|---|---|---|
| **NJ** | $1.39 \pm 1.61^{a, c}$ | $2.22 \pm 1.34^{a, c}$ | $0.00 \pm 0.00^{NA}$ |
| **NAT** | $1.16 \pm 1.03^{a, c, e, f}$ | $1.79 \pm 1.38^{a, c, e, f, h}$ | $0.24 \pm 0.41^{a, c, e, f, i}$ |
| **INT** | $0.59 \pm 0.92^{a, c, e, f}$ | $1.46 \pm 1.63^{a, c, f}$ | $0.39 \pm 0.66^{a, c, e, f}$ |

AOI = area of interest; NJ = non-judo; NAT = national; INT = international; REF = referee; OTH = other; TXT = screen text; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to OTH; [i] = significantly different ($p < 0.05$) to TXT; [NA] = not included in within-group analysis

**Table B4** Within-group post-hoc analysis of average fixation duration on secondary AOIs (secs; mean ± SD)

| | **REF** | **TXT** | **OTH** |
|---|---|---|---|
| **NJ** | 0.20 ± 0.23 [a, c] | 0.28 ± 0.16 [c, h, j] | 0.02 ±0.05 [a, c, d, e, i] |
| **NAT** | 0.09 ± 0.14 [a, c, d, e, f] | 0.19 ± 0.13 [a, c, f, h, j] | 0.04 ± 0.08 [a, c, e, f, i] |
| **INT** | 0.08 ± 0.14 [a, c, e, f] | 0.14 ± 0.13 [a, c, f] | 0.08 ± 0.10 [a, c, e, f] |

AOI = area of interest; NJ = non-judo; NAT = national; INT = international; REF = referee; OTH = other; TXT = screen text; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to OTH; [i] = significantly different ($p < 0.05$) to TXT; [NA] = not included in within-group analysis

## Appendix C

**Table C1** Post-*matte* post-hoc analysis of relative number of fixations on AOIs and total relative fixation durations on AOIs (mean ± SE)

| | **WU** | **WL** | **BU** | **BL** | **SP** | **SB** | **REF** | **TXT** | **OTH** |
|---|---|---|---|---|---|---|---|---|---|
| **RELFIX (%)** | 51.19 ± 3.83 [b, c, d, e, f, g, h, i] | 2.91 ± 1.4 [a, c] | 26.74 ± 3.12 [a, b, d, e, f, g, h, i] | 1.77 ± 0.67 [a, c, h] | 3.41 ± 0.97 [a, c] | 4.04 ± 1.62 [a, c] | 1.37 ± 0.58 [a, c, h] | 4.2 ± 1.01 [a, c, d, g] | 4.02 ± 2.0 [a, c] |
| **TOTALFIX (%)** | 53.63 ± 3.77 [b, c, d, e, f, g, h, i] | 2.69 ± 1.36 [a, c] | 24.17 ± 3.65 [a, b, d, e, f, g, h, i] | 1.1 ± 0.46 [a, c, h] | 1.86 ± 0.57 [a, c] | 3.42 ± 1.38 [a, c] | 1.02 ± 0.43 [a, c, h] | 3.1 ± 0.82 [a, c, d, g] | 2.94 ± 1.46 [a, c] |

AOI = area of interest; RELFIX = relative number of fixations; TOTALFIX = relative total fixation duration; AVFIX = average fixation duration; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard; REF = referee; TXT = screen text; OTH = other; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to TXT; [i] = significantly different ($p < 0.05$) to OTH

**Table C2** Post-*matte* within-group post-hoc analysis of relative number of fixations on secondary AOIs (%; mean ± SD)

| | **REF** | **TXT** | **OTH** |
|---|---|---|---|
| **NJ** | 1.02 ± 2.7 [a, c] | 3.16 ± 4.2 [a, c] | 3.97 ± 10.5 [a, c] |
| **NAT** | 1.35 ± 2.54 [a, c] | 4.45 ± 4.11 [a, c, d] | 2.71 ± 7.66 [a, c] |
| **INT** | 1.74 ± 2.77 [a, c] | 4.98 ± 5.56 [a, c] | 5.37 ± 9.17 [a, c] |

AOI = area of interest; NJ = non-judo; NAT = national; INT = international; REF = referee; OTH = other; TXT = screen text; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to OTH; [i] = significantly different ($p < 0.05$) to TXT; [i] = significantly different ($p < 0.05$) to OTH

**Table C3** Post-*matte* within-group post-hoc analysis of relative total fixation duration on secondary AOIs (%; mean ± SD)

| | **REF** | **TXT** | **OTH** |
|---|---|---|---|
| **NJ** | 0.82 ± 2.16 [a, c] | 1.85 ± 2.51 [a, c] | 3.07 ± 8.12 [a, c] |
| **NAT** | 0.66 ± 1.23 [a, c,] | 3.68 ± 3.67 [a, c,] | 1.56 ± 4.4 [a, c] |
| **INT** | 1.57 ± 2.47 [a, c] | 3.76 ± 4.87 [a, c] | 4.21 ± 7.24 [a, c] |

AOI = area of interest; NJ = non-judo; NAT = national; INT = international; REF = referee; OTH = other; TXT = screen text; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to OTH; [i] = significantly different ($p < 0.05$) to TXT; [NA] = not included in within-group analysis

## Appendix D

**Table D1** Initial viewing post-hoc analysis of relative number of fixations on AOIs, total relative fixation durations on AOIs, and average fixation duration on AOIs (mean ± SE)

| | WU | WL | BU | BL | SP | SB | REF | TXT | OTH |
|---|---|---|---|---|---|---|---|---|---|
| **RELFIX (%)** | 40.62 ± 3.14 b, c, d, e, f, g, h, i | 6.71 ± 1.55 a, c, f, g, i | 28.52 ± 2.21 a, b, d, e, f, g, h, i | 5.76 ± 1.57 a, c, i | 8.55 ± 1.78 a, c, f, g, h, i | 2.75 ± 0.81 a, b, c, e | 2.14 ± 0.65 a, b, c, e | 3.54 ± 0.63 a, c, e, i | 1.42 ± 0.96 a, b, c, d, e |
| **TOTALFIX (%)** | 42.66 ± 3.54 b, c, d, e, f, g, h, i | 5.31 ± 1.37 a, c, g, h, i | 28.39 ± 2.59 a, b, d, e, f, g, h, i | 5.5 ± 1.63 a, c, g, h, i | 6.57 ± 1.48 a, c, f, g, h, i | 2.18 ± 0.56 a, c, e | 1.28 ± 0.48 a, b, c, d, e | 1.61 ± 0.28 a, b, c, d, e | 0.87 ± 0.74 a, b, c, d, e |

AOI = area of interest; RELFIX = relative number of fixations; TOTALFIX = relative total fixation duration; AVFIX = average fixation duration; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard; REF = referee; TXT = screen text; OTH = other; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to TXT; [i] = significantly different ($p < 0.05$) to OTH

**Table D2** Initial viewing within-group post-hoc analysis of relative number of fixations on secondary AOIs (%; mean ± SD)

| | **REF** | **TXT** | **OTH** |
|---|---|---|---|
| **NJ** | 1.43 ± 2.63 [a, b, c] | 2.45 ± 2.52 [a, c] | 0.98 ± 1.69 [a, b, c] |
| **NAT** | 3.52 ± 3.46 [a, c] | 3.65 ± 2.26 [a, c] | 2.77 ± 6.77 [a, c] |
| **INT** | 1.46 ± 2.55 [a, c] | 4.5 ± 3.8 [a, c, i] | 0.49 ± 1.2 [a, c, h] |

AOI = area of interest; NJ = non-judo; NAT = national; INT = international; REF = referee; OTH = other; TXT = screen text; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to OTH; [i] = significantly different ($p < 0.05$) to TXT; [i] = significantly different ($p < 0.05$) to OTH

**Table D3** Initial viewing within-group post-hoc analysis of relative total fixation duration on secondary AOIs (%; mean ± SD)

| | **REF** | **TXT** | **OTH** |
|---|---|---|---|
| **NJ** | $0.81 \pm 1.61^{a, c}$ | $1.04 \pm 1.1^{a, c, e}$ | $0.37 \pm 0.63^{a, c, e}$ |
| **NAT** | $2.4 \pm 3.08^{a, c}$ | $1.71 \pm 0.9^{a, c}$ | $2.08 \pm 5.34^{a, c}$ |
| **INT** | $0.62 \pm 0.96^{a, c}$ | $2.08 \pm 1.82^{a, c, i}$ | $0.17 \pm 0.43^{a, c, h}$ |

AOI = area of interest; NJ = non-judo; NAT = national; INT = international; REF = referee; OTH = other; TXT = screen text; $^{a}$ = significantly different ($p < 0.05$) to WU; $^{b}$ = significantly different ($p < 0.05$) to WL; $^{c}$ = significantly different ($p < 0.05$) to BU; $^{d}$ = significantly different ($p < 0.05$) to BL; $^{e}$ = significantly different ($p < 0.05$) to SP; $^{f}$ = significantly different ($p < 0.05$) to SB; $^{g}$ = significantly different ($p < 0.05$) to REF; $^{h}$ = significantly different ($p < 0.05$) to OTH; $^{i}$ = significantly different ($p < 0.05$) to TXT; $^{i}$ = significantly different ($p < 0.05$) to OTH

**Table D4** Repeat viewing post-hoc analysis of relative number of fixations on AOIs, total relative fixation durations on AOIs, and average fixation duration on AOIs (mean ± SE)

| | WU | WL | BU | BL | SP | SB | REF | TXT | OTH |
|---|---|---|---|---|---|---|---|---|---|
| **RELFIX (%)** | 40.21 ± 2.98 b, d, e, f, g, h, i | 5.4 ± 1.86 a, c | 31.89 ± 2.62 b, d, e, f, g, h, i | 3.74 ± 1.61 a, c | 6.55 ± 1.06 a, c, f, g, i | 2.98 ± 0.59 a, c, e | 2.72 ± 0.84 a, c, e | 4.37 ± 0.74 a, c | 1.95 ± 1.04 a, c, e |
| **TOTALFIX (%)** | 39.44 ± 3.21 b, d, e, f, g, h, i | 4.21 ± 1.76 a, c | 33.98 ± 2.65 b, d, e, f, g, h, i | 3.45 ± 1.36 a, c | 4.4 ± 0.97 a, c, g, h, i | 4.12 ± 0.96 a, c, g, i | 1.62 ± 0.69 a, c, e, f | 1.94 ± 0.32 a, c, e, i | 0.87 ± 0.38 a, c, e, f, h |

AOI = area of interest; RELFIX = relative number of fixations; TOTALFIX = relative total fixation duration; AVFIX = average fixation duration; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard; REF = referee; TXT = screen text; OTH = other; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to TXT; [i] = significantly different ($p < 0.05$) to OTH

**Table D5** Repeat viewing within-group post-hoc analysis of relative number of fixations on secondary AOIs (%; mean ± SD)

| | REF | TXT | OTH |
|---|---|---|---|
| **NJ** | 4.4 ± 5.59 [a, c] | 2.16 ± 2.33 [a, c] | 1.29 ± 1.62 [a, c, e] |
| **NAT** | 0.85 ± 1.63 [a, c, e, f, h] | 5.12 ± 3.11 [a, c, g] | 2.76 ± 7.0 [a, c] |
| **INT** | 2.93 ± 3.35 [a, c] | 5.82 ± 4.49 [a, c] | 1.8 ± 2.84 [a, c] |

AOI = area of interest; NJ = non-judo; NAT = national; INT = international; REF = referee; OTH = other; TXT = screen text; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to OTH; [i] = significantly different ($p < 0.05$) to TXT; [i] = significantly different ($p < 0.05$) to OTH

**Table D6** Repeat viewing within-group post-hoc analysis of relative total fixation duration on secondary AOIs (%; mean ± SD)

| | **REF** | **TXT** | **OTH** |
|---|---|---|---|
| **NJ** | 2.68 ± 4.71 [a, c] | 1.15 ± 1.32 [a, c] | 0.64 ± 0.91 [a, c] |
| **NAT** | 0.36 ± 0.74 [a, c, e, f, h] | 2.62 ± 1.76 [a, c, g] | 0.96 ± 2.28 [a, c, e] |
| **INT** | 1.8 ± 2.77 [a, c] | 2.04 ± 1.19 [a, c] | 1.0 ± 1.56 [a, c] |

AOI = area of interest; NJ = non-judo; NAT = national; INT = international; REF = referee; OTH = other; TXT = screen text; [a] = significantly different ($p < 0.05$) to WU; [b] = significantly different ($p < 0.05$) to WL; [c] = significantly different ($p < 0.05$) to BU; [d] = significantly different ($p < 0.05$) to BL; [e] = significantly different ($p < 0.05$) to SP; [f] = significantly different ($p < 0.05$) to SB; [g] = significantly different ($p < 0.05$) to REF; [h] = significantly different ($p < 0.05$) to OTH; [i] = significantly different ($p < 0.05$) to TXT; [i] = significantly different ($p < 0.05$) to OTH

## Appendix E

| | | Present AOI | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | WU | WL | BU | BL | SP | SB | REF | TXT | OTH |
| | WU | | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| | WL | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | BU | 1 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 |
| | BL | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 |
| Prior AOI | SP | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 |
| | SB | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |
| | REF | 1 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| | TXT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| | OTH | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

AOI = area of interest; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard; REF = referee; TXT = screen text; OTH = other

**Figure E1** Example of a first order transition matrix

| | | Present AOI | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **WU** | **WL** | **BU** | **BL** | **SP** | **SB** | **REF** | **TXT** | **OTH** |
| | **WU** | | 0 | 0.5 | 0 | 0.5 | 0 | 0 | 0 | 0 |
| | **WL** | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **BU** | 1 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 |
| | **BL** | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 |
| **Prior AOI** | **SP** | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 |
| | **SB** | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |
| | **REF** | 1 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| | **TXT** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| | **OTH** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

AOI = area of interest; WU = white upper; WL = white lower; BU = blue upper; BL = blue lower; SP = space; SB = scoreboard; REF = referee; TXT = screen text; OTH = other

**Figure E2** Example of a conditional transitional probability matrix

SUM | $fx$ =-((((LOG(S3,2)*(S3))+((LOG(U3,2)*(U3)))))

| | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AB | AC | AD | AE | AF | AG | AH | AI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | Present state | | | | | | | | | | | | | | |
| 2 | | | WU | WL | BU | BL | SP | SB | REF | TXT | OTH | | Total check | | %dwell | %dwell/100 | | | | %dwell | |
| 3 | | WU | | 0 | 0.5 | 0 | 0.5 | 0 | 0 | 0 | 0 | | 1 | | 75.5556 | 0.75556 | | WU | ) | 0.75556 | 0.75556 |
| 4 | | WL | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | 0 | | WL | 0 | 0 | 0 |
| 5 | | BU | 1 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | | 17.037 | 0.17037 | | BU | 0 | 0.17037 | 0 |
| 6 | | BL | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | 0 | | BL | 0 | 0 | 0 |
| 7 | Prior state | SP | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | | 0.74074 | 0.00741 | | SP | 0 | 0.00741 | 0 |
| 8 | | SB | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | | 0 | | 0 | 0 | | SB | 0 | 0 | 0 |
| 9 | | REF | 1 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | | 1 | | 5.92593 | 0.05926 | | REF | 0 | 0.05926 | 0 |
| 10 | | TXT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | | 0 | 0 | | TXT | 0 | 0 | 0 |
| 11 | | OTH | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | 1 | | 0.74074 | 0.00741 | | OTH | 0 | 0.00741 | 0 |
| 12 | | | | | | | | | | | | | | | 100 | 1 | | | | Entropy | 0.75556 |

**Figure E3a** Example of step 1 of an entropy calculation from a conditional transitional-probability matrix: $\sum_{j=1}^{n} p(j/i) \log_2 p(j/i)$

SUM | $fx$ =AG3*AH3

| | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AB | AC | AD | AE | AF | AG | AH | AI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | Present state | | | | | | | | | | | | | | |
| 2 | | | WU | WL | BU | BL | SP | SB | REF | TXT | OTH | | Total check | | %dwell | %dwell/100 | | | | %dwell | |
| 3 | | WU | | 0 | 0.5 | 0 | 0.5 | 0 | 0 | 0 | 0 | | 1 | | 75.5556 | 0.75556 | | WU | 1 | 0.75556 | =AG3*AH3 |
| 4 | | WL | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | 0 | | WL | 0 | 0 | 0 |
| 5 | | BU | 1 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | | 17.037 | 0.17037 | | BU | 0 | 0.17037 | 0 |
| 6 | | BL | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | 0 | | BL | 0 | 0 | 0 |
| 7 | Prior state | SP | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | | 0.74074 | 0.00741 | | SP | 0 | 0.00741 | 0 |
| 8 | | SB | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | | 0 | | 0 | 0 | | SB | 0 | 0 | 0 |
| 9 | | REF | 1 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | | 1 | | 5.92593 | 0.05926 | | REF | 0 | 0.05926 | 0 |
| 10 | | TXT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | | 0 | 0 | | TXT | 0 | 0 | 0 |
| 11 | | OTH | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | 1 | | 0.74074 | 0.00741 | | OTH | 0 | 0.00741 | 0 |
| 12 | | | | | | | | | | | | | | | 100 | 1 | | | | Entropy | 0.75556 |

**Figure E3b** Example of step 2 of an entropy calculation from a conditional transitional-probability matrix: $p(i)$

SUM | =SUM(AI3:AI11)

| | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AB | AC | AD | AE | AF | AG | AH | AI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | Present state | | | | | | | | | | | | | | |
| 2 | | | WU | WL | BU | BL | SP | SB | REF | TXT | OTH | | Total check | | %dwell | %dwell/100 | | | | %dwell | |
| 3 | | WU | | 0 | 0.5 | 0 | 0.5 | 0 | 0 | 0 | 0 | | 1 | | 75.5556 | 0.75556 | | WU | 1 | 0.75556 | 0.75556 |
| 4 | | WL | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | 0 | | WL | 0 | 0 | 0 |
| 5 | | BU | 1 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | | 1 | | 17.037 | 0.17037 | | BU | 0 | 0.17037 | 0 |
| 6 | | BL | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | 0 | | BL | 0 | 0 | 0 |
| 7 | Prior state | SP | 0 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | | 1 | | 0.74074 | 0.00741 | | SP | 0 | 0.00741 | 0 |
| 8 | | SB | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 | | 0 | | 0 | 0 | | SB | 0 | 0 | 0 |
| 9 | | REF | 1 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | | 1 | | 5.92593 | 0.05926 | | REF | 0 | 0.05926 | 0 |
| 10 | | TXT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | | 0 | 0 | | TXT | 0 | 0 | 0 |
| 11 | | OTH | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | 1 | | 0.74074 | 0.00741 | | OTH | 0 | 0.00741 | 0 |
| 12 | | | | | | | | | | | | | | | 100 | 1 | | | | Entropy | AI11) |

**Figure E3c** Example of step 3 of an entropy calculation from a conditional transitional-probability matrix: $\sum_{i=1}^{n} p(i)$