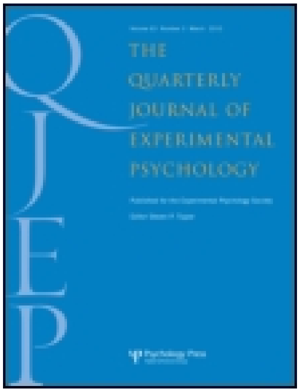

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Identifying the mechanisms underpinning recognition of structured sequences of action

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Identifying the mechanisms underpinning recognition of structured sequences of action

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We present three experiments to identify the specific information sources that skilled participants use to make recognition judgements when presented with dynamic, structured stimuli. A group of less skilled participants acted as controls. In all experiments, participants were presented with filmed stimuli containing structured action sequences. In a subsequent recognition phase, participants were presented with new and previously seen stimuli and were required to make judgements as to whether or not each sequence had been presented earlier (or were edited versions of earlier sequences). In Experiment 1, skilled participants demonstrated superior sensitivity in recognition when viewing dynamic clips compared with static images and clips where the frames were presented in a nonsequential, randomized manner, implicating the importance of motion information when identifying familiar or unfamiliar sequences. In Experiment 2, we presented normal and mirror-reversed sequences in order to distort access to absolute motion information. Skilled participants demonstrated superior recognition sensitivity, but no significant differences were observed across viewing conditions, leading to the suggestion that skilled participants are more likely to extract relative rather than absolute motion when making such judgements. In Experiment 3, we manipulated relative motion information by occluding several display features for the duration of each film sequence. A significant decrement in performance was reported when centrally located features were occluded compared to those located in more peripheral positions. Findings indicate that skilled participants are particularly sensitive to relative motion information when attempting to identify familiarity in dynamic, visual displays involving interaction between numerous features.

Keywords: Expertise; Pattern recognition; Relative motion; Absolute motion.

The ability to recognize visual stimuli is important in several tasks such as engaging in military combat (Williams, Ericsson, Ward, & Eccles, 2008), undertaking diagnostic imaging tasks (Nadine & Kundle, 1987), driving a car (McKenna & Horswill, 1999), playing board games (Charness, Reingold, Pomplun, & Strampe, 2001), and in competitive sport (Williams, Hodges, North, & Barton, 2006). This ability to recognize familiarity may be particularly important in tasks where there is considerable time pressure on performance, requiring individuals to selectively attend to only the most relevant sources of information, while disregarding irrelevant or nonregulatory cues. These

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situations may be particularly important in law enforcement, in military combat, and in sport and games such as speed chess, where the ability to detect familiarity early in an evolving sequence of action may provide a significant advantage over an opponent who is less effective at making such judgements. Several researchers have suggested that the ability to recognize familiarity may be an important precursor of anticipation in these types of situations (e.g., Cañal-Bruland & Williams, 2010; Chabris & Hearst, 2003; North, Williams, Hodges, Ward, & Ericsson, 2009).

Although the need to perceive familiarity may be crucial in many domains, as yet there have been relatively few attempts to identify how such judgements are made. More specifically, only a few published reports outline the mechanisms underlying skilled perception or the specific information that performers pick up when making such judgements. In this paper, we report three experiments that examine these issues. The sport of soccer is used as a vehicle given its dynamic nature and the complex interaction between numerous interactive features that are free to move independent of one another. We present film clips involving structured, offensive sequences of play and examine recognition performance under different experimental conditions. We examine whether skilled and less skilled participants process and recognize such stimuli as a function of specific features such as the locations of isolated or superficial display features, or whether it is the relative or absolute motions between features that are essential when making such familiarity-based judgements.

In Experiment 1, we test the importance of motion information in recognition judgements by comparing performance when viewing dynamic sequences, static/still images, and footage where the individual frames of the film sequence are presented randomly in a nonsequential order. The static/still images present no motion information yet access to relational information involving player locations and more superficial surface features such as the colour of players' uniforms and the condition of the field of play remains present. The condition in which individual frames are viewed in a random order distorts access to motion information and ensures that the amount of information presented remains consistent with the normal dynamic trials. The static condition differs from the random and dynamic condition in regard to both the absence of motion information and the amount of information presented over the duration of a trial. In Experiment 2, we mirror-reverse sequences of play such that the relational information between features, the relative motions between them, and superficial surface features do not differ, but the absolute motion (i.e., directional movement of individual features such as the ball) is reversed. In Experiment 3, we use a more subtle manipulation by removing certain features from the action sequences in order to disrupt access to more localized relative motions, while ensuring that superficial surface features, and to a lesser extent the locations of players, remain consistent. Our overall aim was to identify the processing mechanisms and the specific sources of information used when engaging in laboratory tests designed to examine recognition performance in dynamic, interactive, temporally constrained domains.

The recognition paradigm is rooted in cognitive psychology. Goldin (1978) reported that recognition of chess pieces was enhanced after players had chosen a move (i.e., a semantic task representative of chess playing) as opposed to counting the number of chess pieces (i.e., a superficial unrelated task). It was concluded that the processing of meaningful relations enhanced the accuracy of recognition. Allard, Graham, and Paarsalu (1980) were the first to use this paradigm in sport. They presented skilled and less skilled basketball players with a series of static slides showing either structured (images sampled from organized match play) or unstructured (images showing teams warming up or sampled from breaks in play) scenes, some of which had been presented to participants in an earlier viewing film and others that were novel. Participants were required to make a familiarity-based recognition judgement for each scene. Skilled basketball players demonstrated superior recognition accuracy on structured stimuli only. This finding has been replicated across numerous sports such as field hockey

(Smeeton, Ward, & Williams, 2004), American football (Garland & Barry, 1991), and soccer (Williams & Davids, 1995).

Only recently have researchers started to identify the specific information that skilled performers use when making successful recognition judgements. Williams et al. (2006, Experiment 2) examined the contributions of superficial low level surface features (e.g., shirt colour, body cues, or environmental or pitch conditions) and the relational information between these features (e.g., the positions or relative orientation of players) when making recognition judgements. Skilled and less skilled soccer players were required to make recognition judgements to sequences presented in both film and point-light display formats. In the latter condition, the locations and movements of players were presented as points of light against a black background, along with the position of the ball and an outline of the field of play, thereby removing access to superficial display features while preserving the relational information between players. The skilled performers reported better recognition performance under both viewing conditions, with their superiority over less skilled counterparts being maintained under the point light condition. In contrast, the less skilled players showed a significant decrement in performance under point light compared to normal viewing conditions.

Skilled participants detect familiarity based upon structural relations (e.g., positions of features or their relative orientations) and the higher order predicates they convey (e.g., tactical and/or strategic significance; cf., Gentner & Markman, 1997). According to the interactive encoding model proposed by Dittrich (1999), when viewing such sequences skilled performers initially extract information from the positions and temporal relationships between features and then match this stimulus representation with an internal semantic concept or template (cf., Charness et al., 2001; Didierjean & Marméche, 2005). A related proposal is the notion that skilled individuals develop elaborate task-specific retrieval structures, which aid the identification of future outcomes (Ericsson & Kintsch, 1995; Ericsson, Patel, & Kintsch, 2000). Superior retrieval is therefore achieved through better indexing and organization of information at encoding.

In previous work, Williams et al. (2006, Experiment 3) edited the film sequences such that the central attacking players were occluded during the recognition phase in an attempt to remove access to some of relational information between players. A significant decrement in the recognition accuracy of skilled participants was observed in the occluded conditions, suggesting that the relationships between central attackers and other features provide the critical structural information. Subsequent research using complimentary methodologies, such as eye movement recording and verbal protocol analysis, reinforced the findings and conclusions reported by Williams and colleagues (e.g., North et al., 2009; North, Williams, Ward, & Ericsson, 2011; Williams et al., 2006; Williams & North, 2009). Skilled perception is believed to combine low- and high-level processes. First, participants extract positional information and the temporal relationships between these features before matching this stimulus representation with an internal semantic concept or template developed through extended practice and engagement in the domain (see Didierjean & Marméche, 2005; Dittrich, 1999; Dittrich & Lea, 1994; Gobet & Simon, 1996). In contrast, less skilled performers lack experience within the domain, and, consequently, they will not have developed these high-level semantic concepts and are likely to be impaired in their ability to attribute meaning to this relational information. Less skilled performers will adopt a less sophisticated, low-level processing strategy focusing on more discrete or superficial elements and not on relational information (Dittrich, 1999). This literature provides evidence that skilled performers encode displays involving numerous features as a series of relationships arising in the final few moments preceding a critical event (North & Williams, 2008). However, it is not clear whether these relationships are encoded through motion information (i.e., relative, absolute, or common motion) or positional information, and, consequently, we attempt to shed more light on this issue in the current paper.

EXPERIMENT 1

In this experiment, we use a recognition paradigm to examine whether skilled participants perceive familiarity in the display through reference to the locations or positions of display features or via reference to the motions of these features (i.e., the players and/or the ball). In the initial viewing phase, participants are presented with structured stimuli, showing dynamic film footage occluded at the final frame prior to an attacking pass being made. In a later recognition phase, participants are presented with further clips, some of which were presented during the earlier viewing phase and others that are novel. In addition, the action sequences were edited to manipulate access to motion information by creating three different types of clips: dynamic, static, and randomized. Participants are required to decide whether or not they had seen each of these sequences (edited or otherwise) in the earlier viewing phase. The sensitivity of participants' recognition judgements and their response bias were taken as measures of performance.

We predicted that skilled participants would be more accurate when recognizing dynamic than both static and randomized stimuli (cf., Williams et al., 2006). In the static clips, motion is removed, and less information (only a single frame) is presented than in the dynamic and randomized sequences. The randomized sequences present the same amount of information as in the dynamic sequences, but in the former condition access to motion information is distorted. In the randomized clips, the different frames of action are presented in a nonsequential, random manner, rather than in the same sequential order as that employed in the dynamic condition. We predict that both the amount of information and access to motion cues are crucial when making familiarity-based judgements and that, consequently, the skilled players would perform better in the dynamic than in the randomized condition. In contrast, we predicted that less skilled participants would rely on superficial display features when encoding a display and that, consequently, there would be no differences in performance between the static, dynamic, and randomized conditions for this group. Although less skilled participants may attempt to extract some relational information based on the positions of players, when compared to skilled players they have less elaborate templates/cognitive representations to interpret the stimuli in a meaningful manner. Consequently, less skilled performers are likely to focus their attention on identifying any distinctive surface features (e.g., colour of players' uniforms, environmental conditions) present within the display.

Method

Participants

A total of 10 skilled and 10 less skilled male players participated. Skilled participants (M age = 20.30 years, $SD = 1.06$) had previously played at a professional club's Academy and/or were currently playing at a semiprofessional level, and all played in defensive positions. These participants had been playing soccer competitively for an average of 13.00 years ($SD = 2.45$). In contrast, less skilled participants (M age = 21.60 years, $SD = 3.50$) only played soccer at a recreational or amateur level and had been participating for an average of 11.60 years ($SD = 4.14$). In all three experiments presented in this paper, participants provided informed consent and were free to withdraw from testing at any stage. The research was carried out according to the ethical guidelines of the lead institution. All participants reported normal or corrected-to-normal levels of visual function.

Test stimuli

Participants were presented with two separate films of test stimuli: a viewing film and a recognition film. The films both contained structured offensive sequences of play. The stimuli were taken from matches involving the reserve or second teams of professional clubs and did not include any matches involving the participants or players with whom they were familiar. The sequences were filmed using a fixed, tripod-mounted camera (Canon XM-2, Tokyo, Japan) in an elevated position (approximate height 9 m) behind (approximate distance 15 m) the goal. The camera did not zoom or pan during recording. This camera position ensured that the entire field of play was visible and that information from wide areas of the field of play was not excluded. The action sequences were filmed from as close as possible to a central defender's position in the game, with all patterns of play emerging in the direction of the viewer. This viewing perspective has been shown to accurately capture expert performance (see Ripoll, Petit, & Le Troter, 2005), and construct validity has been established for the use of such clips in previously published reports (e.g., North et al., 2009, 2011; Ward & Williams, 2003; Williams et al., 2006). All sequences of play involved a number of passing manoeuvres mostly commencing in the defensive half of the pitch and ending with a pass being made into the offensive area of the pitch. Three expert soccer coaches independently rated each sequence as high or low in structure using a Likert-type scale from 0 to 10 (0 being very low in structure, 10 being very high in structure). The clips deemed high in structure were those that were viewed by the coaches to be most representative of the typical offensive sequences observed in match-play. Only sequences with a mean rating of 7 or above were included in the experiment. Only those clips in which there was complete agreement between coaches were used in the experiment. A still-frame from a typical film sequence is shown in Figure 1.

The viewing film contained 54 dynamic action sequences, each of which was 3 s in length. During this phase, participants were simply instructed to watch the clips with no response required. The recognition film contained 54 sequences, 36 of which had been presented previously in the viewing phase and 18 that were novel. Of the clips that had been presented previously, 12 were dynamic film sequences, 12 presented a static image of the last frame, and 12 involved dynamic sequences where the frames were presented in a nonsequential, random order. Of the 18 clips that were novel, 6 were dynamic, 6 were static, and 6 were randomized. The dynamic clips were the same as those in the viewing phase, where a 3-s attacking sequence was occluded when a pass or shot at goal was about to be made. In contrast, the static clips showed only the final frame prior to an attacking pass being made for 3 s. The randomized clips showed individual frames from a 3-s dynamic sequence presented in nonsequential, random order. A 5-s intertrial interval was employed to allow participants sufficient time to make a response and prepare for the next clip. The clips were presented in a random order that was kept constant across participants.

Apparatus

The viewing and recognition films were presented using a DVD player (Panasonic, DMR-E50, Osaka, Japan) and projector (Sharp, XG-NV2E, Manchester, UK) with images being presented onto a $9 \times 12''$ screen (Cinefold, Spiceland, IN, USA) at a rate of 25 frames per second with XGA resolution. The clips were edited using video-editing software (Adobe Premiere, Adobe Systems Incorporated, San Jose, CA, USA).

Procedure

Participants were tested individually and sat in a chair a distance of 3 metres from the projection screen such that the image subtended a viewing angle of approximately 40 degrees. During the viewing phase, participants were informed that they would be presented with a series of film clips from soccer matches showing sequences of play. Participants were informed that each clip lasted 3 s and would show an attacking pattern of play leading to a pass into an offensive area, although the action would be occluded at the final moment before this event occurred. Participants were instructed to watch the clips as if playing in the match, adopting the perspective of a central defender.

After presentation of the viewing film, there was a 10-min break during which participants completed a detailed practice history questionnaire. Participants were then asked to view a second series of clips, some of which had been presented previously in the viewing film and others that were novel. They were informed that some of the clips originally presented would now be shown as

Figure 1. *The viewing perspective presented in the three experiments. To view a colour version of this figure, please see the online issue of the Journal.*

edited versions of the same sequence in the recognition phase. Participants were instructed to watch each trial for its entire duration and then make a decision whether or not that clip had been presented previously in the viewing phase. Since several clips had now been edited, participants would technically be correct to indicate that these clips were different to those previously presented in the viewing phase and were thus novel. As such, participants were informed that their task was to respond "yes" to action sequences they believed were edited versions (static/random) of those presented earlier in the viewing phase and "yes" to those seen earlier, but not edited (dynamic). In contrast, they were instructed to respond "no" to video clips they believed to be novel and were therefore not presented in the viewing phase. A brief familiarization procedure was employed during which participants were shown three examples of each viewing condition. Participants responded using pen and paper.

Data analysis

Signal detection measures of sensitivity (d') and response bias (c) were used to measure recognition accuracy (Green & Swets, 1966). The data for d' and c were analysed separately using a mixed-design two-way analysis of variance (ANOVA) in which the between-participants factor was skill (skilled vs. less skilled), and the within-participants factor was display (dynamic vs. static vs. randomized). The assumption of normality was satisfied as determined using a Shapiro–Wilks test. Partial eta squared (η_p^2) values are provided as a measure of effect size. Cohen's d measures are reported where two means are compared. The alpha level for significance was set at $p < .05$.

Table 1. *The mean recognition sensitivity scores and criterion values for skilled and less skilled participants across the three experiments*

	Experiment 1				*Experiment 2*			*Experiment 3*				
Participant group	*Dynamic*	*Randomized*	*Static*	*Overall*	*Normal*	*Reversed*	*Overall*	*Condition 1*	*Condition 2*	*Condition 3*	*Condition 4*	*Overall*
Skilled *d′*	1.50	0.42	−0.43	0.49	0.51	0.71	0.61	1.44	0.35	0.26	1.15	0.80
	(0.52)	(0.75)	(0.51)	(0.90)	(0.55)	(0.45)	(0.05)	(0.64)	(0.69)	(0.79)	(0.46)	(0.81)
Less skilled *d′*	0.14	0	−0.10	0.02	−0.02	0.12	0.05	−0.01	0.19	0.07	0.59	0.21
	(0.55)	(0.75)	(0.94)	(0.70)	(0.38)	(0.40)	(0.39)	(0.32)	(0.53)	(0.39)	(0.82)	(0.58)
Overall *d′*	0.82	0.21	−0.26	0.26	0.24	0.42	0.33	0.71	0.27	0.17	0.87	0.51
	(0.87)	(0.76)	(0.76)	(0.89)	(0.53)	(0.51)	(0.52)	(0.89)	(0.60)	(0.61)	(0.71)	(0.76)
Skilled c	.11	.08	.08	.04	−.16	.10	−.03	−.15	.44	−.20	.29	.09
	(.42)	(.22)	(.39)	(.36)	(.40)	(.39)	(.41)	(.24)	(.38)	(.52)	(.27)	(.46)
Less skilled c	−.22	−.05	−.20	−.16	−.31	−.07	−.19	−.30	.27	−.29	.06	−.07
	(.51)	(.49)	(.39)	(.47)	(.16)	(.24)	(.23)	(.29)	(.44)	(.39)	(.45)	(.47)
Overall c	−.06	.02	−.14	−.06	−.23	.01	−.11	−.23	.35	−.24	.17	.01
	(.49)	(.39)	(.39)	(.43)	(.31)	(.33)	(.34)	(.28)	(.43)	(.48)	(.40)	(.47)

Note: d′ = recognition sensitivity. c = response bias. Standard deviations in parentheses.

Results

A summary of the descriptive statistics for all experiments is presented in Table 1. The analysis of d' revealed a significant Skill × Display interaction, $F(2, 36) = 3.58$, $p < .01$, $\eta_p^2 = .29$. Skilled participants were more sensitive in their recognition judgements for dynamic ($M = 1.50$, $SD = 0.52$) than for static ($M = -0.43$, $SD = 0.51$) and randomized ($M = 0.42$, $SD = 0.75$) clips, $d = 3.75$ and 1.67, respectively. In contrast, less skilled participants did not differ in recognition sensitivity across dynamic ($M = 0.14$, $SD = 0.55$), static ($M = -0.10$, $SD = 0.94$), and randomized ($M = 0$, $SD = 0.75$) clips, $d = 0.31$ and 0.21, respectively. This interaction is illustrated in Figure 2.

A main effect for skill was observed, $F(1, 18) = 10.10$, $p < .01$, $\eta_p^2 = .36$. Skilled participants ($M = 0.49$, $SD = 0.90$) were more sensitive in distinguishing previously seen from novel stimuli than their less skilled counterparts were ($M = 0.02$, $SD = 0.70$), $d = 0.54$. Finally, there was a significant main effect for display, $F(2, 36) = 12.22$, $p < .001$, $\eta_p^2 = .40$. Bonferroni-corrected pairwise comparisons showed that participants were more sensitive in their recognition judgements when viewing dynamic clips than under static ($d = 1.32$) and randomized ($d = 0.75$) conditions, $ps < .05$. There was no significant difference for response sensitivity between static and randomized clips, $p > .05$.

The analysis of c showed no main effect for skill, $F(1, 18) = 3.14$, $p > .05$, $\eta_p^2 = .15$, or display type,

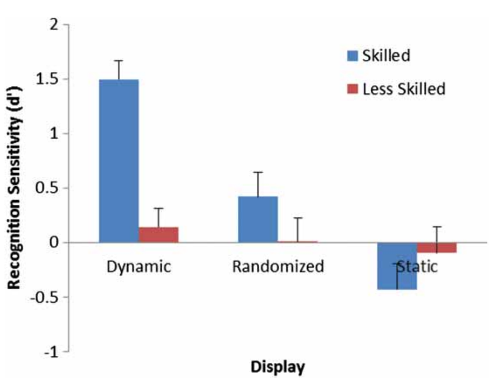

Figure 2. *The Skill × Display interaction for recognition accuracy (%) in Experiment 1.*

$F(2, 36) = 0.62$, $p > .05$, $\eta_p^2 = .03$. The Skill × Display interaction was not significant, $F(2, 36) = 0.36$, $p > .05$, $\eta_p^2 = .02$.

Discussion

We examined whether skilled participants perceive familiarity within a display by encoding display features and their positions or by perceiving motion information between these features. Although initial reports suggest that skilled performers perceive and process displays involving numerous elements as relational information (North et al., 2009; Williams et al., 2006), it has yet to be determined whether this relational information is picked up from positional or motion information. We presented participants with a series of structured displays either as dynamic playing patterns or as static images showing the final frame of an attacking sequence. Moreover, we presented participants with stimuli that showed a series of randomly ordered individual frames to control for the amount of information that was presented in the dynamic sequences. We predicted that skilled performers would demonstrate more sensitive recognition performance when viewing dynamic sequences rather than static slides. If skilled performance was underpinned by the perception of motion rather than the amount of information presented in dynamic sequences, then skilled participants would demonstrate superior recognition sensitivity for dynamic stimuli in comparison to clips where motion information was disrupted by presenting frames of action in a nonsequential, randomized manner. Less skilled participants were expected not to differ in recognition sensitivity across the dynamic, static, and randomized stimuli.

As predicted, skilled participants recorded more sensitive recognition performance when viewing sequences presented in dynamic ($M = 1.50$) rather than static ($M = -0.43$) and randomized format ($M = 0.42$), $d = 3.75$ and 1.67, respectively. The observed d' values demonstrate that skilled participants are much more sensitive when making recognition judgements in response to dynamic rather than static or randomized stimuli. Skilled participants are able to access the motion information maintained in dynamic sequences in order to perceive meaning and structure when making recognition decisions. The Skill × Display interaction and the descriptive values for d' provide evidence to support the notion that having access to motion information present in dynamic sequences is more important when making recognition judgements than the overall amount of information presented. It appears that skilled participants perceive the relational information mainly as a function of motion information. At this stage, we are unable to ascertain whether this motion information is extracted from the relative motions between players or the absolute motion of one or more features (Hill & Pollick, 2000).

It was hypothesized that less skilled participants would not differ in sensitivity across the dynamic, static, and randomized conditions. We predicted that they would process displays on the basis of superficial display information that was maintained across all conditions. The results reveal that, as predicted, there were no significant differences in recognition sensitivity for less skilled participants across the viewing conditions. A difficulty is that the overall level of performance for the less skilled participants was very low, as illustrated by the d' values presented in Figure 2. One possible explanation for the low d' scores exhibited for the less skilled participants across all conditions may be that their relatively impoverished cognitive knowledge structures makes it very difficult for them to encode and store information during the initial exposure when compared to their skilled counterparts. Subsequent memory-based judgements are therefore impaired as the participants are forced to guess rather than to make judgements against information stored in memory. An alternative explanation is that the recognition paradigm methodology may not be sufficiently sensitive: a notion discussed further in the General Discussion.

EXPERIMENT 2

In Experiment 1, we presented data to suggest that skilled participants rely on motion information when making recognition judgements. However, the specific nature of this motion information has yet to be ascertained. Cutting and Profitt (1982) differentiated between three different types of motion information—namely, absolute, common, and relative motion. Absolute motion describes the motion of a single element in a configuration relative to the person perceiving this information, whereas common motion describes the motion common to all elements in the configuration relative to the perceiver. Finally, relative motion refers to the motion of all the elements in the configuration relative to each other.

Although the relative importance of these three sources of motion information has been examined to some degree in the literature on observational learning and modelling (e.g., see Breslin, Hodges, Williams, Curran, & Kremer, 2005, 2006; Hodges, Williams, Horn, & Breslin, 2007), there have been no previous attempts to explore the relative importance of each source when making familiarity-based judgements in the area of perceptual–cognitive expertise. The majority of researchers have suggested that skilled participants extract relative motion rather than absolute or common motion information when making these types of judgement (e.g., North et al., 2009, 2011; Williams et al., 2006), but this issue has yet to be addressed directly by manipulating access to the different types of motion information.

In the context of structured sequences of play in soccer, it is very difficult to manipulate common motion information since the direction of play is always towards or away from the goal (i.e., up and down the pitch). In contrast, access to absolute motion may potentially be distorted by presenting clips in the recognition phase as mirror-reversed images of those sequences presented earlier in the viewing phase. In this mirror-reversed condition, the relative motions between players and their common motion remain constant, yet the absolute motion of key features is reversed, such as the direction of the pass or the runs of a player about to receive the ball. For example, in the initial viewing phase, an offensive sequence of play that ends with a pass being made to the right-hand side of the field of play would be replaced in the viewing phase by a sequence ending with a pass to the left side of the pitch. In this latter example, the common motion (i.e., movement towards the near end of the pitch) and the relative motions between display features do not differ, whereas the absolute motion of each individual feature differs from that presented originally. In this experiment, we mirror-reverse film sequences in the recognition phase in order to ascertain whether this manipulation leads to a decrement in response sensitivity in skilled and less skilled participants. If skilled participants rely on absolute motion information when making familiarity-based judgements, we predict a decrement in performance in the reversed condition compared to when viewing the normal (i.e., nonreversed) images. In contrast, we expected the less skilled participants not to differ in their performance across the two conditions given their reliance on more superficial display features rather than motion information when making these types of judgement.

Method

Participants

A total of 10 skilled and 10 less skilled male soccer players participated. None of the participants had taken part in Experiment 1. The skilled players ($M = 21.6$ years, $SD = 5.19$ years) had previously played at a professional club's Academy and/or were currently playing at a semiprofessional level, and all played in defensive positions. Participants had been playing soccer competitively for an average of 13.60 years ($SD = 3.60$ years). In contrast, less skilled players ($M = 20.50$ years, $SD = 1.58$ years) had played soccer at a recreational or amateur level only, typically for around 11.40 years ($SD = 3.40$ years). All participants reported normal or corrected-to-normal levels of visual function.

Test stimuli

Participants were presented with separate films of test stimuli involving a viewing phase and recognition phase, respectively. The action sequences were taken from a similar sample of matches to that used in Experiment 1. These matches were filmed from the same viewing perspective and using the same equipment as that in Experiment 1. The film sequences were made up of structured trials only and were chosen using the criteria and selection process outlined in Experiment 1.

The viewing phase included 60 film clips each involving 3 s of dynamic action, followed by an intertrial interval of 5 s. The recognition phase contained 40 clips taken from the viewing phase and 20 new action sequences that had not been seen previously by the participants. Of the 40 clips that had previously been presented, 20 were manipulated using software (Final Cut Pro 7, Apple, Cupertino, California, USA) that enabled the film to be mirror-reversed, while the other 20 remained exactly the same as they were in the viewing phase. The entire filmed image was reversed, creating a mirror image, with features that were previously on one side of the display now presented on the other. Of the 20 additional clips that had not previously been presented, 10 were reversed in the same way, whereas the remaining 10 were not edited.

Apparatus and procedure

The apparatus used to present the film clips and the procedure employed were the same as those in Experiment 1. However, participants were instructed that some of the clips originally presented in the viewing phase would now be shown as mirror-reversed images of the same sequence in the recognition phase. Since several clips had now been reversed, participants would technically be correct to indicate that these clips were different to those previously presented in the viewing phase and were thus novel. As such, participants were informed that their task was to respond "yes" to action sequences that they believed were reversed versions of those presented earlier in the viewing phase and "yes" to those seen earlier, but not reversed. In contrast, they were instructed to respond "no" to video clips that they believed to be novel and were therefore not presented in the viewing phase. A brief familiarization procedure was employed during which participants were presented with five examples of clips under normal and reversed viewing conditions, respectively.

Data analysis

The dependent measures and analysis procedures were the same as those in Experiment 1, except in this experiment the display condition compared normal versus reversed clips.

Results

The analysis of d' revealed a significant main effect for skill, $F(1, 18) = 18.08$, $p < .001$, $\eta_p^2 = .50$. Skilled participants ($M = 0.61$, $SD = 0.50$) were more sensitive in their recognition judgements than less skilled participants ($M = 0.05$, $SD = 0.39$), $d = 1.25$. The Skill × Display interaction, $F(1, 18) = 0.04$, $p > .05$, $\eta_p^2 = .002$, and the main effect for display, $F(1, 18) = 1.3$, $p > .05$, $\eta_p^2 = .07$, were not significant. The recognition sensitivity and criterion scores for skilled and less skilled participants across the two conditions are presented in Table 1.

The analysis of c revealed a significant main effect for display, $F(1, 18) = 9.78$, $p < .05$, $\eta_p^2 = .35$. Participants showed a significantly lower criterion threshold, and hence a bias toward responding "yes", for normal ($M = -.23$, $SD = .31$) than for reversed ($M = -.11$, $SD = .36$) stimuli, $d = 0.36$. The Skill × Display interaction, $F(1, 18) = 0.01$, $p > .05$, $\eta_p^2 = .001$, and the skill main effect, $F(1, 18) = 1.79$, $p > .05$, $\eta_p^2 = .09$, were not significant.

Discussion

We examined whether skilled participants perceive familiarity within a display by picking up absolute motion information from one or more display features or by perceiving relative motions between features. We mirror-reversed images such that the relative motions between features and the common motion of all features presented in the film sequences did not differ, whereas the absolute motion of the key features would be different (i.e., reversed). We predicted that the skilled participants would show a marked decrement in performance if they recognized clips based on absolute rather than on relative or common motion. In contrast, it has been reported previously (e.g., North et al., 2009, 2011; Williams et al., 2006) that less skilled participants rely on more superficial display features rather than motion information, and so when making recognition judgements, we expected that they would not differ in recognition sensitivity across the normal and reversed conditions.

Although there was a main effect for skill on recognition sensitivity, supporting the findings presented in Experiment 1 and elsewhere (e.g., North et al., 2009; Williams et al., 2006), there were no significant effects for display or the Skill × Display interaction, with very low effect sizes being reported for the latter comparisons. The skill advantage was demonstrated in the absence of any difference in response bias between skilled and less skilled participants. The descriptive statistics reveal that the d' values for the skilled participants were lower than those observed in Experiment 1, which suggests that even skilled participants found the task of distinguishing old from new stimuli in normal and reversed conditions difficult. Nevertheless, the values do indicate that skilled participants were able to successfully make these recognition judgements and could do so with significantly greater sensitivity than their less skilled counterparts across both normal and reversed conditions. These findings suggest that perturbing access to absolute motion does not negatively impact upon sensitivity when making recognition judgements.

When considered in conjunction with Experiment 1, findings suggest that skilled participants rely primarily on the relative motions between features when attempting to recognize previously viewed sequences. A caveat is that certain superficial display features were mirror invariant and thus unchanged by the reversal process (e.g., the stadium). It is therefore possible that skilled participants were using these features as well as the relative motions between display features. However, given findings from Williams et al. (2006) and North et al. (2009, 2011), where skill main effects were reported even when stimuli were presented as point-light displays where all superficial information was removed, it appears more plausible that skilled players were using relative motion rather than specific display features for recognition.

As with Experiment 1, it is important to note that less skilled participants recorded very low scores, and, consequently, it is difficult to draw conclusions about the nature of the processing undertaken by these participants when making recognition judgements.

EXPERIMENT 3

In Experiments 1 and 2, we presented data to suggest that when attempting to make recognition judgements, skilled participants perceive crucial information based upon relative motions between features. However, less is known about which features are particularly important when making these judgements. In a series of experiments, Williams and colleagues (e.g., Williams et al., 2006; Williams & North, 2009; North et al., 2009, 2011) used a number of different experimental techniques to try and address this issue. In one experiment, a digital editing technique was used to occlude the positions of the two central offensive features (i.e., the most advanced offensive players) and their corresponding defensive markers with the background information on structured sequences of play, whereas a control condition involved the removal of peripheral players (see Williams et al., 2006, Experiment 3). The occlusion of the central offensive features removed or distorted access to important relational information and had a detrimental effect on performance when compared to the control condition, implying that the central offensive features are important when attempting to detect familiarity.

In two further studies, North et al. (2009, 2011) examined the issue of which features are used to support recognition decisions using complementary methodologies. In one study, eye movement data were recorded as skilled and less skilled participants made familiarity-based recognition judgements to structured sequences, whereas in the latter study, think-aloud retrospective verbal reports were gathered immediately after each trial. The skilled participants recorded a higher number of fixations on the central offensive features and made more fixation transitions from the ball to an offensive feature and vice versa than did less skilled participants. In a similar vein, skilled participants made significantly more verbalizations involving the movements of offensive features "off the ball" than less skilled participants, with the central offensive features being particularly important for the skilled participants. These data suggest that the ability to pick up relative motion information between a few key features is crucial.

In this final experiment, in an effort to better identify the key features, or combination of features, that are important when making familiarity-based judgements, we manipulated different features and varying combinations of features to evaluate their impact on subsequent recognition sensitivity using structured sequences of play only. In the control condition (Condition 1), we occluded four players from peripheral positions (e.g., the offensive full-backs or centre backs as well as their corresponding defensive counterparts or the two opposing goalkeepers). In another condition (Condition 2), the two central offensive players and their corresponding defensive markers were occluded, while in another condition (Condition 3) two central midfield players as well as their defensive markers were occluded. In a final condition (Condition 4), one central offensive player and one central midfield player were occluded as well as their corresponding markers. It was hypothesized that skilled participants would show a reduction in response sensitivity on all three experimental conditions compared to the control condition; albeit given the partly exploratory nature of this experiment we were unable to predict the exact nature of any differences that may exist across the three experimental conditions. In contrast, the less skilled participants were expected not to differ in recognition sensitivity across the four conditions owing to their proposed reliance on superficial display features when making these judgements.

Method

Participants

A total of 10 skilled and 10 less skilled male soccer players participated. The skilled participants ($M =$ 20.20 years, $SD = 2.70$ years) had previously played at a professional club's Academy and/or were currently playing at semiprofessional level, and all played in defensive positions. These individuals had been playing soccer competitively for an average of 13.50 years ($SD = 2.40$ years). In contrast, the less skilled participants ($M = 19.50$ years, $SD = 2.50$ years) had played soccer competitively for an average of 10.30 years ($SD = 2.90$ years), albeit only at a recreational or amateur level. None of the participants had taken part in Experiment 1 or Experiment 2.

Test stimuli

Participants were presented with separate films of test stimuli involving a viewing phase and recognition phase, respectively. The action sequences were taken from a sample of two matches from Football Association Youth Cup matches, neither of which included players who participated in this experiment. These matches were filmed from the same viewing perspective and employing the same equipment as that in Experiment 1. The film sequences were made up of structured trials only. The same procedures as those outlined in Experiment 1 were used to select suitable clips for inclusion in this experiment.

The viewing phase included 60 film clips, with an intertrial interval of 5 s. The recognition phase contained 40 clips taken from the viewing phase, 10 from each viewing condition, and 20 new action sequences that had not been seen previously by the participants. The 40 clips that had previously been presented were manipulated using digital editing technology. The additional 20 clips that had not previously been presented were manipulated in the same way. In all, there were four edited conditions that acted to remove differing pieces of perceptual information from the film sequence for the entire duration of each clip. A panel of three expert coaches were consulted prior to the selection of occlusion conditions, and only those conditions and clips in which there was complete agreement were included. The four conditions were as follows:

Condition 1: a control condition where four peripheral players who did not play in central offensive or midfield roles (i.e., full backs, goalkeepers) were occluded;

Condition 2: where two central offensive players and their corresponding defensive markers were occluded;

Condition 3: where two central midfield players and their corresponding defensive markers were occluded;

Condition 4: where one central midfield player and one central offensive player were occluded, as well as their corresponding markers.

In total, there were 15 trials for each occluded condition in the recognition phase of the experiment. Of these 15 trials, 10 had previously been presented in the viewing phase, whereas 5 had not been presented earlier in the viewing phase. The order of presentation of video clips was randomly determined and was kept consistent across participants.

The procedure of occluding players was achieved by means of specialist editing software (Motion Key Analysis, Imagineer Systems Limited, New York, USA) that enabled the foreground (i.e., a player) to be replaced with the background (i.e., the playing surface/turf). Thus, display features were literally erased from each frame of action. Since attacking features are habitually marked by a defender, accompanying defensive markers were occluded for the duration of each trial.

Apparatus and procedure

The apparatus used to present the film clips and the experimental procedure were the same as those in Experiment 1. However, participants were informed that their task was to decide whether action sequences presented during the recognition phase were edited versions of video clips observed during the viewing phase, or completely novel clips that were not presented in the viewing phase. A brief familiarization procedure was employed, during which participants viewed five examples of clips under normal and occluded viewing conditions, respectively.

Data analysis
The dependent measures and analysis procedures were the same as those in Experiment 1, except that the within-participant factor had four levels (Conditions 1, 2, 3, and 4).

Results

The analysis of d' revealed a significant Skill × Display interaction, $F(3, 54) = 5.55$, $p < .01$, $\eta_p^2 = .24$. Skilled participants ($M = 1.44$, $SD = 0.64$) were significantly more sensitive when making recognition judgements in Condition 1 than their less skilled ($M = -0.01$, $SD = 0.32$) counterparts, $d = 2.87$. In contrast, there were no significant differences in recognition sensitivity between skilled ($M = 0.35$, $SD = 0.69$) and less skilled ($M = 0.19$, $SD = 0.53$) participants in Condition 2, $d = 0.26$, or between skilled ($M = 0.26$, $SD = 0.79$) and less skilled ($M = 0.07$, $SD = 0.39$) players in Condition 3, $d = 0.30$. In Condition 4, skilled participants ($M = 1.15$, $SD = 0.46$) showed superior recognition sensitivity when compared with less skilled participants ($M = 0.59$, $SD = 0.82$), $d = 0.84$. The Skill × Display interaction is illustrated in Figure 3. There was a significant main effect for skill, $F(1, 18) = 10.15$, $p < .01$, $\eta_p^2 = .36$. Skilled participants ($M = 0.80$, $SD = 0.81$) were more sensitive in making recognition judgements than their less skilled ($M = 0.21$, $SD = 0.58$) counterparts, $d = 0.84$. Finally, there was a significant main effect for display, $F(3, 54) = 8.94$, $p < .001$, $\eta_p^2 = .33$. The Bonferroni corrected pairwise comparisons showed that participants were significantly more sensitive at making recognition judgements in Conditions 1 and 4 than in Conditions 2 and 3, $p\text{s} < .05$, $d = 0.58$ and 0.71, respectively. There was no difference in recognition sensitivity between Conditions 1 and 4, $d = 0.20$, or between Conditions 2 and 3, $d = 0.17$, $p\text{s} > .05$.

The analysis of c showed a main effect for display type, $F(3, 54) = 12.02$, $p < .01$, $\eta_p^2 = .4$. Bonferroni corrected pairwise comparisons revealed that participants showed a significantly lower criterion threshold, and hence a bias toward responding "yes", in Condition 1 ($M = -.23$, $SD = .28$) than in Condition 4 ($M = .17$, $SD = .40$), $p < .05$, $d = 1.16$. Participants also demonstrated a lower criterion threshold for Condition 3 ($M = -.24$, $SD = .48$) than for Condition 2 ($M = .35$, $SD = .43$), $p < .05$, $d = 1.29$. There was no difference in criterion threshold between Conditions 1 and 3 or between Conditions 2 and 4, $p\text{s} > .05$, $d\text{s} = 0.03$ and 0.43, respectively. There was no main effect for skill, $F(1, 18) = 2.47$, $p > .05$, $\eta_p^2 = .12$, and no Skill × Display interaction, $F(3, 54) = 0.11$, $p > .05$, $\eta_p^2 = .01$.

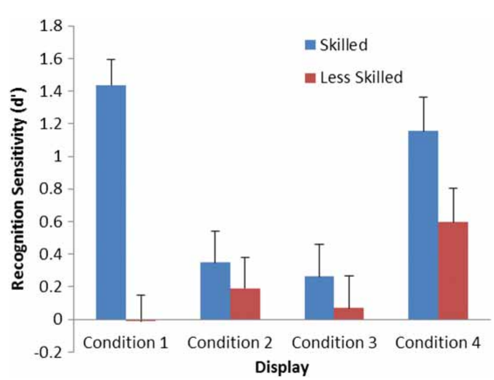

Figure 3. *The Skill × Display interaction for recognition accuracy (%) in Experiment 3.*

Discussion

In this experiment, we tried to identify the specific relative motion information that skilled participants extract from displays when making familiarity-based judgements. We predicted, based on previous work (e.g., Williams et al., 2006), that skilled participants would show a significant decrement in performance when specific central features were occluded or erased from the film sequences during the recognition phase. However, we were unable to make specific predictions as to the relative decrement in performance expected across the three experimental conditions. In contrast, we predicted that the less skilled participants would not differ in their recognition sensitivity across the different occlusion conditions owing to their reliance on superficial display features that remain consistent across conditions.

The skilled participants showed a significant decrement in recognition sensitivity in Conditions

2 and 3, when compared to the control condition (i.e., Condition 1, $d = 1.64$ and 1.64, respectively). The descriptive statistics reveal that the skilled performers found it very difficult to make successful recognition judgements in these conditions. It appears that either the two central offensive players or the two central midfield players, and their corresponding markers, provide important relative motion information that facilitates the recognition of familiar and unfamiliar playing sequences. When these sources of information are removed, skilled participants appear unable to perceive meaningful information and thus potentially revert to guessing. Skilled participants showed no significant difference in recognition sensitivity for Condition 4 when compared to the control condition, and they demonstrated better recognition sensitivity in this condition than their less skilled counterparts ($d = 0.83$). A slightly unusual observation is that less skilled participants seemed better able to make recognition decisions in Condition 4 than in the other three conditions, where they appeared unable to do so. Findings suggest that the relative motion information between features in complimentary, yet different, positional roles (i.e., forwards and midfield players) may be more important than the relative motions between features with shared positional responsibilities (i.e., pairs of offensive features or midfield features). In the case of less skilled participants it may be that removal of two features in different positional roles simplified the display and allowed them to access the important structural information with greater ease. Clearly, these latter propositions require confirmation in subsequent work.

GENERAL DISCUSSION AND CONCLUSIONS

We presented a series of experiments designed to investigate how skilled participants process stimuli and identify the information that is used when making recognition judgements in a time-constrained, dynamic environment involving interactions between numerous display features. In previous work, we established that skilled participants are more likely to use relational information either through the positions of display features or the motions that arise between them to make recognition judgements (see North et al., 2009, 2011; Williams et al., 2006). We therefore attempted to extend knowledge of this issue by manipulating access to positional and motion information in their various guises in three separate experiments. In Experiment 1, we examined whether participants rely on positional or motion information when making such judgements. In Experiment 2, we examined the relative importance of absolute and relative motion information. In Experiment 3, we attempted to identify the specific relative motions that participants use when making recognition judgements.

Our data provide a clearer and more complete understanding of how skilled performers make such judgements. In Experiment 1, skilled participants showed a significant decrement in recognition sensitivity when motion information was removed from the display, leaving behind only superficial display features and relational information from the positions of players. A significant decrement in recognition sensitivity was apparent for skilled participants when the same amount of information was presented as that contained in dynamic sequences, but motion information was removed by presenting the individual frames in a randomized order. In contrast, no differences were apparent in recognition sensitivity for the less skilled participants across these conditions, although the descriptive statistics suggested that they were unable to successfully complete the task and most likely reverted to guessing rather than extracting any specific type of information to inform their recognition decisions. So, the extraction of motion information appears a key mechanism underpinning successful recognition in skilled participants. In Experiment 2, we attempted to identify the specific motion information that may be of relevance. No decrements in performance were observed when we distorted absolute motion (by mirror-reversing stimuli) from individual display features (players and ball). Since we assumed that common motion would remain constant across all conditions, the only common movement between the players and the ball being up or down the pitch, our conclusion was that skilled participants pick up the key relative motions between display features when making these types of judgement. Although skilled participants outperformed their less skilled counterparts in both conditions, given the apparent inability of less skilled participants to complete the task and their seeming reliance on guessing, it is not possible to draw conclusions on the type of information used by less skilled participants to make these decisions. In Experiment 3, we showed that the relative motions between only a few key features are crucial, notably the relationships between the central offensive and central midfield players, whereas motions between pairs of offensive or midfield players as well as other more peripheral features are less important. In summary, the results provide evidence that skilled participants recognize dynamic displays showing interaction between multiple elements by perceiving motion and, specifically, relative motion within the display. Specifically, our findings suggest that maintaining the relative motions between features in two different central locations (midfield and offence) are critical for skilled participants to perceive meaning and structure to inform their recognition decisions.

Our findings provide support for the interactive encoding model proposed by Dittrich (1999; Dittrich & Lea, 1994). This model suggests that when recognizing familiarity in dynamic sequences, skilled observers rely upon the relational information between features—more specifically, based on this programme of work, the relative motions between only a few key features and the associated higher order strategic information conveyed by these relations. The use of relative motion information between a few key features (i.e., players) satisfies the initial low-level stage of processing outlined in the interactive encoding model. In this two-stage model, skilled participants initially extract low-level relational information between features. This low-level information is then matched against a high-level internal template/cognitive representation that skilled individuals have developed as a consequence of their extended experience within the domain (e.g., Ford, Ward, Hodges, & Williams, 2009; Ward, Hodges, Starkes, & Williams, 2007). A related proposal is that skilled participants develop complex retrieval structures in long-term memory as a function of experience (Ericsson & Kintsch, 1995). Once activated, the appropriate retrieval structure is employed to interpret and evaluate future situations and decide upon an appropriate response. We speculate that the relative motions between display features act as a cue to stimulate these complex retrieval structures in long-term memory. The skilled performer can judge the observed display in relation to previously encountered stimuli represented in the retrieval structure and make an appropriate decision.

One observation across experiments was that while skilled participants consistently outperformed their less skilled counterparts in their ability to distinguish between familiar and novel sequences, the less skilled participants were apparently unable to successfully complete the task. It is therefore not possible to draw conclusions about the type of information used by less skilled participants to make familiarity-based recognition decisions, and no additional support is presented for our earlier prediction that less skilled participants would use superficial surface-level features to make these decisions (e.g., see Williams et al., 2006). Previously, we (e.g., Williams et al., 2006) have reported that less skilled performers are able to successfully make recognition judgements (albeit significantly less accurately than skilled participants) to provide evidence for the type of information processed by this population. One explanation may be that given the subtle manipulations between conditions employed in this research, the less skilled participants were unable to perceive differences between new and old stimuli, and thus in the case of less skilled participants the recognition paradigm was not a sufficiently sensitive task. In their meta-analysis of research into perceptual–cognitive expertise, Mann, Williams, Ward, and Janelle (2007) concluded that methodologies requiring the same encoding, retrieval, and application of information such as predictive anticipation tasks and field-based methods were significantly more sensitive than recognition and recall-based measures, which is supported by the observed findings and the d' values reported in this paper.

It should be acknowledged that the specific importance of surface features and relational information in its various guises may differ as a function of scene properties (Goldstone, Medin, & Gentner, 1991) and the type of cognitive activity that may be engaged in the task (Holyoak & Koh, 1987). Consequently, it may be difficult to generalize existing findings across very different contexts or domains, albeit common underlying mechanisms are likely to be evident irrespective of the specific context or domain. An interesting issue is whether or not the ability to successfully recognize familiarity in the display may be improved through, for example, traditional concepts of imprinting (Goldstone, 1998). Several authors have argued that the ability to identify familiarity is an important component of anticipation skill. Consequently, now that we have a better understanding of the information that participants extract from the display when making such judgements, it should increase opportunity to develop systematic training programmes to try and improve this skill across domains (e.g., see Smeeton, Williams, Hodges, & Ward, 2005; Williams, Ward, Knowles, & Smeeton, 2002). We are currently exploring methods to highlight key relative motions for the purpose of performance enhancement.

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REFERENCES

Allard, F., Graham, S., & Paarsalu, M. L. (1980). Perception in sport: Basketball. *Journal of Sport Psychology*, *2,* 14–21.

Breslin, G., Hodges, N. J., Williams, A. M., Curran, W., & Kremer, J. (2005). Modelling relative motion to facilitate intra-limb coordination. *Human Movement Science*, *24,* 446–463.

Breslin, G., Hodges, N. J., Williams, A. M., Curran, W., & Kremer, J. (2006). A comparison of intra- and inter-limb relative motion information in modelling a novel motor skill. *Human Movement Science*, *25,* 753–766.

Cañal-Bruland, R., & Williams, A. M. (2010). Movement recognition and prediction of movement effects in biological motion perception. *Experimental Psychology*, *57*, 320–326.

Chabris, C. F., & Hearst, E. S. (2003). Visualization, pattern recognition, and forward search: Effects of playing speed and sight of the position on grandmaster chess errors. *Cognitive Science*, *27,* 637–648.

Charness, N., Reingold, E. M., Pomplun, M., & Strampe, D. M. (2001). The perceptual aspect of skilled performance in chess: Evidence from eye movements. *Memory and Cognition*, *29,* 1146–1152.

Cutting, J. E., & Profitt, D. R. (1982). The minimum principle and the perception of absolute, common and relative motion. *Cognitive Psychology*, *14,* 211–246.

Didierjean, A., & Marméche, E. (2005). Anticipatory representation of visual basketball scenes by novice and expert players. *Visual Cognition*, *12,* 265–283.

Dittrich, W. H. (1999). Seeing biological motion: Is there a role for cognitive strategies? In A. Braffort, R. Gherbi, S. Gibet, J. Richardson, & D. Teil (Eds.), *Gesture-based communication in human–computer interaction* (pp. 3–22). Berlin, Germany: Springer-Verlag.

Dittrich, W. H., & Lea, S. E. (1994). Visual perception of intentional motion. *Perception*, *23,* 253–268.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, *102,* 211–245.

Ericsson, K. A., Patel, V., & Kintsch, W. (2000). How experts' adaptations to representative task demands account for the expertise effect in memory recall: Comment on Vicente and Wang (1998). *Psychological Review*, *107,* 578–592.

Ford, P. R., Ward, P., Hodges, N. J., & Williams, A. M. (2009). The role of deliberate practice and play in career progression in sport: The early engagement hypothesis. *High Ability Studies*, *20,* 65–75.

Garland, D. J., & Barry, J. R. (1991). Cognitive advantage in sport: The nature of perceptual structures. *The American Journal of Psychology*, *104,* 211–228.

Gentner, D., & Markman, A. B. (1997). Structure mapping in analogy and similarity. *American Psychologist*, *52,* 45–56.

Gobet, F., & Simon, H. A. (1996). Recall of random and distorted positions: Implications for the theory of expertise. *Memory & Cognition*, *24,* 493–503.

Goldin, S. E. (1978). Effects of orienting tasks on recognition of chess positions. *American Journal of Psychology*, *91,* 659–671.

Goldstone, R. L. (1998). Perceptual learning. *Annual Review of Psychology*, *49,* 585–612.

Goldstone, R. L., Medin, D. L., & Gentner, D. (1991). Relational similarity and the non-independence of features in similarity judgments. *Cognitive Psychology*, *23,* 222–262.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.

Hill, H., & Pollick, F. E. (2000). Exaggerating temporal differences enhances recognition of individuals from point light displays. *Psychological Science*, *11,* 223–228.

Hodges, N. J., Williams, A. M., Horn, R. R., & Breslin, G. (2007). What is modelled during observational learning? *Journal of Sports Sciences*, *25*(5), 531–545.

Holyoak, K. J., & Koh, K. (1987). Surface and structural similarity in analogical transfer. *Memory and Cognition*, *15,* 332–340.

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

McKenna, F. P., & Horswill, M. S. (1999). Hazard perception and its relevance for driver licensing. *Journal of International Association of Traffic and Safety Sciences*, *23,* 36–41.

Nadine, C. F., & Kundle, H. L. (1987). Using eye movements to study visual search and to improve tumour detection. *Radiographics*, *7*(6), 1241–1250.

North, J. S., & Williams, A. M. (2008). The critical time period for information extraction when identifying patterns of play in soccer. *Research Quarterly for Exercise and Sport*, *79*(2), 268–273.

North, J. S., Williams, A. M., Hodges, N. J., Ward, P., & Ericsson, K. A. (2009). Perceiving patterns in dynamic action sequences: Investigating the processes underpinning stimulus recognition and anticipation skill. *Applied Cognitive Psychology*, *23,* 878–894.

North, J. S., Williams, A. M., Ward, P., & Ericsson, K. A. (2011). Identifying the critical information sources to skilled anticipation and recognition using retrospective verbal reports. *Memory, 19*, 155–168.

Ripoll, H., Petit, J.-P., & Le Troter, A. (2005). The relevance of using realistic simulated environments for the study of decision making in sport. In T. Morris, P. Terry, S. Gordon, S. Hanrahan, L. Ievleva, G. Kolt, & P. Tremayne (Eds.), *Proceedings of 11th ISSP World Congress of Sport Psychology*. Sydney, Australia: International Society of Sport Psychology.

Smeeton, N., Ward, P., & Williams, A. M. (2004). Transfer of perceptual skill in sport. *Journal of Sports Science*, *19,* 3–9.

Smeeton, N. J., Williams, A. M., Hodges, N. J., & Ward, P. (2005). The relative effectiveness of explicit instruction, guided-discovery and discovery learning techniques in enhancing perceptual skill in sport. *Journal of Experimental Psychology: Applied*, *11,* 98–110.

Ward, P., Hodges, N. J., Starkes, J., & Williams, A. M. (2007). The road to excellence: Deliberate practice and the development of expertise. *High Ability Studies*, *18,* 119–153.

Ward, P., & Williams, A. M. (2003). Perceptual and cognitive skill development in soccer: The multidimensional nature of expert performance. *Journal of Sport and Exercise Psychology*, *25,* 93–111.

Williams, A. M., & Davids, K. (1995). Declarative knowledge in sport: A by-product of experience or a characteristic of expertise? *Journal of Sport and Exercise Psychology*, *7,* 259–275.

Williams, A. M., Ericsson, K. A., Ward, P., & Eccles, D. (2008). Research on expertise in sport: Implications for the military. *Military Psychology* (pp. S1–S23).

Williams, A. M., Hodges, N. J., North, J. S., & Barton, G. (2006). Perceiving patterns of play in dynamic sport tasks: Identifying the essential information underlying skilled performance. *Perception*, *35,* 317–332.

Williams, A. M., & North, J. S. (2009). Identifying the minimal essential information underlying pattern recognition. In D. Arajuo, H. Ripoll, & M. Raab (Eds.), *Perspectives on cognition and action* (pp. 95–107). New York, NY: Nova Science Publishing.

Williams, A. M., Ward, P., Knowles, J. M., & Smeeton, N. J. (2002). Perceptual skill in a real-world task: Training, instruction, and transfer in tennis. *Journal of Experimental Psychology: Applied*, *8,* 259–270.