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EXPERT–NOVICE DIFFERENCES IN BRAIN FUNCTION OF FIELD HOCKEY PLAYERS

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Abstract—The aims of this study were to use functional magnetic resonance imaging to examine the neural bases for perceptual-cognitive superiority in a hockey anticipation task. Thirty participants (15 hockey players, 15 non-hockey players) lay in an MRI scanner while performing a video-based task in which they predicted the direction of an oncoming shot in either a hockey or a badminton scenario. Video clips were temporally occluded either 160 ms before the shot was made or 60 ms after the ball/shuttle left the stick/racquet. Behavioral data showed a significant hockey expertise × video-type interaction in which hockey experts were superior to novices with hockey clips but there were no significant differences with badminton clips. The imaging data on the other hand showed a significant main effect of hockey expertise and of video type (hockey vs. badminton), but the expertise × video-type interaction did not survive either a whole-brain or a small-volume correction for multiple comparisons. Further analysis of the expertise main effect revealed that when watching hockey clips, experts showed greater activation in the rostral inferior parietal lobule, which has been associated with an action observation network, and greater activation than novices in Brodmann areas 17 and 18 and middle frontal gyrus when watching badminton videos. The results provide partial support both for domain-specific and domain-general expertise effects in an action anticipation task. © 2015 The Authors. Published by Elsevier Ltd. on behalf of IBRO. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Key words: fMRI, sport, action observation network, action anticipation, hockey, badminton.

INTRODUCTION

Research has indicated that expert athletes have better visual and motor skills than novices (e.g. Kato and Fukida, 2002; Ward and Williams, 2003; Le Runigo et al., 2010; Cañal-Bruland et al., 2011; Piras et al., 2014). Further, advanced cue utilization research has found that a key component of elite sports performance involves the ability to predict and anticipate the behavior of other players. This has been shown in sports including football (Dicks et al., 2010), cricket (Müller et al., 2006), volleyball (Schorer et al., 2013), squash (Abernethy, 1990), tennis (Loffing and Hagemann, 2014) and badminton (Abernethy, 1988).

The neural underpinnings of perceptual-motor expertise have been studied in many domains including imitation of hand actions in guitarists (Vogt et al., 2007), motor imagery (Guillet et al., 2008), learning of action sequences in pianists (Landau and D'Esposito, 2006) and dance (Calvo-Merino et al., 2005). Recently, there have been several functional magnetic resonance imaging (fMRI) studies of the superior perceptual-motor abilities of expert sports players. Wright et al. (2010) found that expert badminton players, when predicting the part of the court to which a shot was aimed, exhibited greater activity than novices in a set of brain areas integral to action observation, imagery and execution, often referred to as the action observation network (AON). A further experiment using point-light stimuli showed essentially similar results (Wright et al., 2011). Likewise, AON activation and expertise effects have been reported for tennis (Balser et al. 2014a), basketball (Abreu et al., 2012) and football (Bishop et al., 2013; Wright et al., 2013). One crucial skill component common to such sports is the ability to anticipate what an opponent is going to do next and this is one skill which sets experts apart from novices (e.g. Abernethy, 1990; Abernethy et al., 2008). Often these studies employ temporal occlusion techniques and experts seem to be constantly superior at using the earliest information available from an opponent's body kinematics (e.g. Jones and Miles, 1978; Jackson, 1986; Houlston and Lowes, 1993). Thus, in the present work, a temporal occlusion paradigm will be used to explore expert–novice differences in the brain mechanisms underlying advance cue utilization as participants make judgements of shot direction in the sport of field hockey.

A second area for investigation in the present study is to see whether the 'expert brain' also functions differently from the 'novice brain' when performing a task in which neither group of participants has any experience. There

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Abbreviations: ANOVAs, analysis of variances; AON, action observation network; BC, badminton control; BL, badminton long; fMRI, functional magnetic resonance imaging; FWE, family-wise error; HC, hockey control; HL, hockey long; HS, hockey short; MEPs, motor-evoked potentials; MNI, Montreal Neurological Institute.

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has been very little work to explore this possibility. The only behavioral studies currently in this area focus on pattern recognition. Smeeton et al. (2004) found that the skilled footballers and hockey players were able to transfer perceptual information or strategies between their respective sports. In a similar paper (Abernethy et al., 2005), expert netball, basketball and hockey players and a control group performed a recall task for patterns of play derived from each of these sports. Experts consistently outperformed the non-expert controls in their recall of defensive player positions in their non-preferred sports, suggesting some selective transfer of pattern recall skills.

However, other studies suggest domain-specific rather than domain-general expertise. Calvo-Merino et al. (2005) investigated whether the action observation system is specifically tuned to an individual's motor repertoire by including two differing types of dancer, experts in classical ballet and experts in capoeira, as well as inexpert control subjects. Their results showed that there were greater bilateral activations in AON areas when an expert viewed movements that they had been trained to perform compared to movements they had not. Aglioti et al. (2008) asked athletes (basketball players), expert watchers (coaches and sports journalists involved with basketball) and novices to predict the outcome of free throws in basketball or kicks at goal in football. They found that basketball players could predict the outcome of free throws in basketball earlier and more accurately than either novices or expert watchers. Using single-pulse transcranial magnetic stimulation (TMS) they found an increase in motor-evoked potentials (MEPs) in athletes when they were observing the basketball free throw but not the football kick, suggesting that the brain sends out different messages when watching a clip of a sport in which an athlete actively competes. Balser et al. (2014b) compared expert tennis players and expert volleyball players using video clips of both sports, with each group acting as novice controls in the sports for which they were not expert. This meant that the 'novice' groups still had high levels of anticipation experience as well being used to making decisions under time pressure. Their results nevertheless maintained a difference between the two groups with domain-specific stimulus material; experts experiencing increased activation within the AON, particularly the pre-supplementary motor area, the superior parietal lobule, as well as broad sections of the cerebellum.

However, in a recent critique, Press and Cook (2015) argue that the case for domain-specific motor effects on action observation is weaker than is commonly supposed. They point out that many domain-general effects of motor processes on perception have been identified, and argue that the apparent domain-specific effects reported could be mediated by low-level properties of the stimuli and task such as spatiotemporal perception and attention.

Thus, the present study further explores whether expertise in one sporting domain confers an advantage in a different, non-expert, domain and whether experts show differences in brain activation patterns from novices in this non-expert sporting domain. Instead of using two groups of experts as in the above-mentioned Balser et al. (2014b) study, it was decided to have experts and novices, but to include a task in which both groups would be novices in order to see if differences in activation still occurred. From the little behavioral research carried out in this area it would seem that some transfer of perceptual skills is possible. However, if research on the importance of specific motor expertise in action observation (Calvo-Merino et al., 2005; Aglioti et al., 2008; Balser et al., 2014b) is taken into account it may be expected that brain function of expert hockey players may not differ from novice hockey players when watching badminton clips. This is because, as the study by Calvo-Merino and colleagues shows, the action observation system is very specific in its activation. Finally it should be noted that domain-specific and domain-general effects are not mutually exclusive, and that both may occur.

This study therefore set out to test four main hypotheses: (a) that there are domain-specific effects of hockey expertise on prediction accuracy in hockey and badminton video stimuli, (b) that there are domain-specific effects of hockey expertise on fMRI activations in the same task, (c) that there are domain-general effects of hockey expertise on prediction accuracy and (d) that there are domain-general effects on fMRI activations.

EXPERIMENTAL PROCEDURES

Participants

Fifteen hockey players, ranging in ability from club level to senior international (mean age 28.7, SD 7.3, 10 male and 5 female, average years' experience of competitive hockey = 8.86, SD 5.6), and 15 non-hockey players (mean age 22.1, SD 3.5, 9 male and 6 female) took part in the study. All participants had a minimum education level of having at least begun a university degree. The hockey players were recruited through the first author's contacts in various hockey teams and clubs. The non-hockey players were recruited through the university or were friends of the hockey players who also wanted to take part. No participants from either group had any experience playing badminton beyond school PE lessons. None of the participants reported regularly watching badminton and none of the non-hockey players reported regularly watching hockey. All had normal or corrected to normal vision. All participants were fully briefed on the experiment and the use of fMRI. All participants signed a consent form and were free to withdraw at any point.

Stimuli and design

Continuous fMRI data were acquired as participants viewed 2-s video clips of either an opposing badminton player or an opposing hockey player making a shot/pass either left or right. Participants pressed one of two buttons, during a 2-s luminance-matched screen after each clip, to predict to which side they believed the shuttlecock/ball to be traveling. The actors in the video clips were national-level players in each respective sport, and the hockey and badminton clips were approximately matched in terms of the filming distance, mean luminance, and the height on the screen of the players. Although both hockey and badminton stimuli involved a strike to the left or right, there are both similarities and differences between the strike played in the badminton clips and those played in the hockey clips. Both shots are played by an implement (hockey stick/badminton racquet) that is held by the athlete being observed. However, the badminton racquet is held in just one hand and is positioned above the head, whereas the hockey stick is held in both hands (left hand at the top of the stick, right hand approximately one third of the way down), with the head of the stick in contact with the floor. Further, while both implements are used to propel an object (the shuttlecock in badminton, the ball in hockey) toward the camera, this is also achieved in different ways. The badminton shot consists of one motion, with the shuttlecock in contact with the racquet for minimal time as the athlete volleys the shuttlecock in one immediate motion. In contrast, the hockey stick is first used to bring the ball to a near stop, often the ball is touched again to put it into a more suitable position, the stick head is then drawn away from the ball and then swung to propel the ball forward.

Each block comprised five video clips and five blank intervals. There were six different block conditions: hockey long (HL), in which the action of a hockey clip was cut to 60 ms after the ball was last in contact with the stick; hockey short (HS) in which the action of a hockey clip was cut to 160 ms before the ball was released from the stick; hockey control (HC) in which no ball appeared on the screen but the participant had to judge in which hand the hockey player was holding their stick; badminton long (BL), the action of the badminton clip was cut to 60 ms after the shuttlecock left the racquet; badminton short (BS), where the action was cut at 160 ms before the shuttlecock hit the racquet, and badminton control (BC) where there was no shuttlecock or shot played but the participant had to judge in which hand the player was holding their racquet. The participant's task on the control tasks was the same as on the experimental blocks in terms of having to make a directional judgement and respond using a button press but different in that they did not have to anticipate the shot direction. Additionally there were two rest blocks of equal length to the experimental blocks in which a gray screen was visible and the participant was not required to respond.

Procedure

Following a safety briefing and completing the necessary consent and medical forms participants were taken to the scanner where they lay supine with their head held still within a surface coil. Images were viewed via a mirror which was aligned to a monitor outside of the machine and they held a button box in their hands on which they had been instructed to push one button to signal 'left' and one button to signal 'right'. Participants viewed the hockey/badminton clips first with the blocks presented in a randomized order. This was followed by a structural scan.

Data acquisition

Brain images were acquired with a 3T MRI scanner (Magnetom Trio, Siemens, Erlangen, Germany) equipped with an eight-channel array headcoil. Functional images of the entire brain were acquired with a standard gradient-echo, echoplanar sequence (TR = 4000 ms, TE = 35 ms, Flip angle 90°, 41 slices, voxel size $3 \times 3 \times 3$ mm, 64×64 matrix). A whole-brain anatomical scan (176 slices, $1 \times 1 \times 1$-mm voxel size, MP-RAGE T1-weighted sequence) was also acquired.

Data analysis

SPM8 was used to carry out the image pre-processing. Each EPI volume was realigned to the first image in the sequence to correct for head motion, and structural and mean functional images were co-registered. In order to allow group data analysis, functional and structural images were spatially normalized to the Montreal Neurological Institute (MNI) template. Spatial smoothing with a 6-mm three-dimensional Gaussian filter, convolution with modeled haemodynamic response function and high-pass filtering, with a 128-s time-constant preceded analysis of the individual data in which t-contrasts were computed for the difference between action prediction and action observation (control) conditions. First-level t-contrast values were entered into second-level, random effects group analysis and one-way analysis of variances (ANOVAs). In order to correct for multiple comparisons, FDR (false discovery rate) or FWE (family-wise error) correction was applied to all reported activation clusters at a threshold value of $p < 0.05$. The WFU Pickatlas Talairach Daemon (Lancaster et al., 1997; Maldjian et al., 2003) was used at 5-mm range with MNI co-ordinate conversion to identify brain areas and probable Brodmann areas from the co-ordinates found.

RESULTS

Behavioral results

In order to establish the data requirements for ANOVA, deviations from a normal distribution were assessed using a one-sample Komolgorov–Smirnov test applied to data for each of 12 cells of the overall design; video condition (HL, HS, HC, BL, BS, BC) × group (hockey players, hockey non-players). Accuracy for the control conditions deviated significantly ($p < .05$) from a normal distribution, but all of the action prediction conditions were consistent with a normal distribution at $p > .05$. Further to this, for the eight action prediction conditions, one sample *t*-tests showed that data in each cell were significantly above chance (reference value 50%) and significantly below ceiling (reference value 100%) all at $p < .005$. Conversely, three out of the four cells indicating control conditions had median scores not significantly different from 100% (Wilcoxon test, at $p > .05$). Not surprisingly, performance on the control conditions (which hand is the racquet/stick in?) was at or near the ceiling thereby reducing variance and distorting the data. Because of this ceiling effect and because behavioral performance on the control task was not of significant interest these control data were excluded from the ANOVA. The data for the active conditions alone were therefore entered into a $2 \times 2 \times 2$ mixed ANOVA to compare hockey experts and novices across the four different direction prediction conditions (HL, HS, BL, BS). Thus, there were two within-participant variables: *video* type (hockey, badminton) and *occlusion* level (long, short), and one between-participant variable, hockey *expertise* (expert, novice). The ANOVA showed a significant main effect of video type, $F(1,28) = 249.8$, $p < .0005$; partial $\eta^2 = .90$; accuracy across all participants was higher on the hockey task ($M = 78.9\%$) than the badminton task ($M = 60.9\%$). The main effect of expertise did not reach significance ($p = .098$), neither did the main effect of occlusion level ($p = 0.33$) or the three-way interaction ($p = .82$). However, the expertise x video-type interaction was significant, $F(1,28) = 4.82$, $p < .05$; partial $\eta^2 = .19$. Analysis of the interaction (conducted with two one-way ANOVAs, one for the hockey videos and one for the badminton videos) revealed that the only significant difference lay in the hockey condition where experts significantly outperformed novices, $F(1,28) = 8.54$; $p < .01$; partial $\eta^2 = 0.16$; observed power = 0.517. Means and standard errors of accuracy in the four experimental conditions are shown in Fig. 1.

fMRI results

In a first-level analysis of the fMRI data individual t-contrasts were calculated for HL–HC, HS–HC, BL–BC, and BS–BC. These *t*-contrasts were entered into a full factorial second-level model, with the following factors: expertise (hockey expert, hockey novice), video type (hockey, badminton) and condition (long, short). Results were based on whole-brain, random-effects analysis and FWE correction at $p < .05$ and minimum cluster size = 5. *F*-Contrasts showed a significant main effect of expertise. There was, also, a significant main effect of video-type (Hockey vs. Badminton video) thus there are variations in the brain areas activated during direction prediction in different sports. This is evident in Fig. 2, which identifies voxels that were significantly more activated during action prediction than in the corresponding action observation control condition, for hockey and non-hockey players observing hockey and badminton stimuli.

As Fig. 2 shows, in aggregate, responses are found in an action-observation network and are closely comparable with previous published data (reviewed in the Introduction) for tennis and football. In detail however, there are differences in the distribution of activations within this network for the four sub-conditions. The corresponding data are shown in Tables 1a and 1b.

As is apparent from Fig. 2, expertise effects may differ in brain locations for hockey and badminton stimuli however the crucial comparison to test for domain-specific as opposed to domain-general expertise effects is the interaction between hockey expertise and video type, which proved to be non-significant. In this respect the fMRI results did not match the behavioral results.

Possible reasons considered for the non-significant interaction included firstly a possible confounding effect of the “control” condition, which, after all, differs from the action prediction task in both the stimulus content and in the associated task, and secondly differences in the difficulty of the hockey and badminton tasks, which may have a masking effect. To address these questions, a second ANOVA was conducted with a different design, in order to clearly differentiate differences in the effects of video type and expertise on the action observation condition from any possible such effects on the control condition. The first-level contrasts for this effect were activations relative to background, that is, HL-B, HS-B, HC-B, BL-B, BS-B and BC-B. The background in this case was explicitly modeled as the response during blank-screen intervals. In addition, the behavioral accuracy of responses was entered as a covariate for each action prediction condition and each participant. This was done in order to partial out possible effects due to differences in the difficulty of conditions. The F-contrasts for the main effects of expertise (expert–novice) video type (hockey–badminton) and condition (long, short, control) showed significant effects at $p < .05$ with a whole-brain FWE correction. However, no significant voxels were found for the two-way interaction between expertise and video type, the two-way interaction between expertise and condition, or the three-way interaction between expertise, video type and condition. These general findings were not altered by the presence or absence of the covariate. As there were no significant voxels responding to the expertise × video-type interaction, even at $p < .001$ uncorrected, a small-volume correction was not considered appropriate.

To further analyze the effect of expertise, t-contrasts were computed to identify voxels that differentially responded in hockey experts and novices during action prediction conditions alone. These results are shown as red blobs in Fig. 3. For comparison, voxels responding more strongly to hockey than badminton are shown in green, and voxels responding significantly to the covariate alone are shown in blue. Corresponding data showing the co-ordinates of active clusters are shown in Tables 2a and 2b.

The same ANOVA was re-run with and without accuracy as a covariate. As noted above, the presence or absence of the covariate did not affect the main effect of expertise. However it did affect the responses to video type. With the covariate, the activated region was restricted to occipital cortex. With no covariate, additional regions of parietal cortex showed significant activation.

To further analyze the expertise effects, planned comparisons were carried out. Although the ANOVA analyses suggested no interaction between expertise and video type, because some previous work has suggested sport specific effects of expertise (Calvo-Merino et al., 2005; Aglioti et al., 2008; Balser et al., 2014b) this more sensitive approach was used to probe expertise effects for each sport separately. Firstly, the

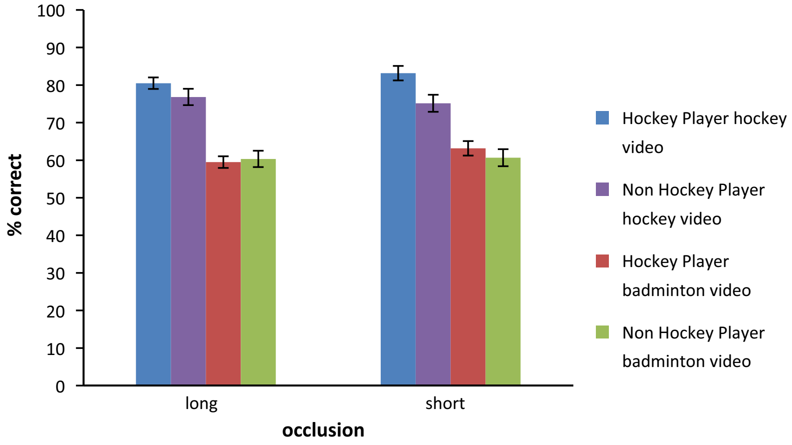

Fig. 1. Mean percentage accuracy of direction prediction on the two video types for hockey players and hockey non-players. Error bars are ±1 S.E.M.

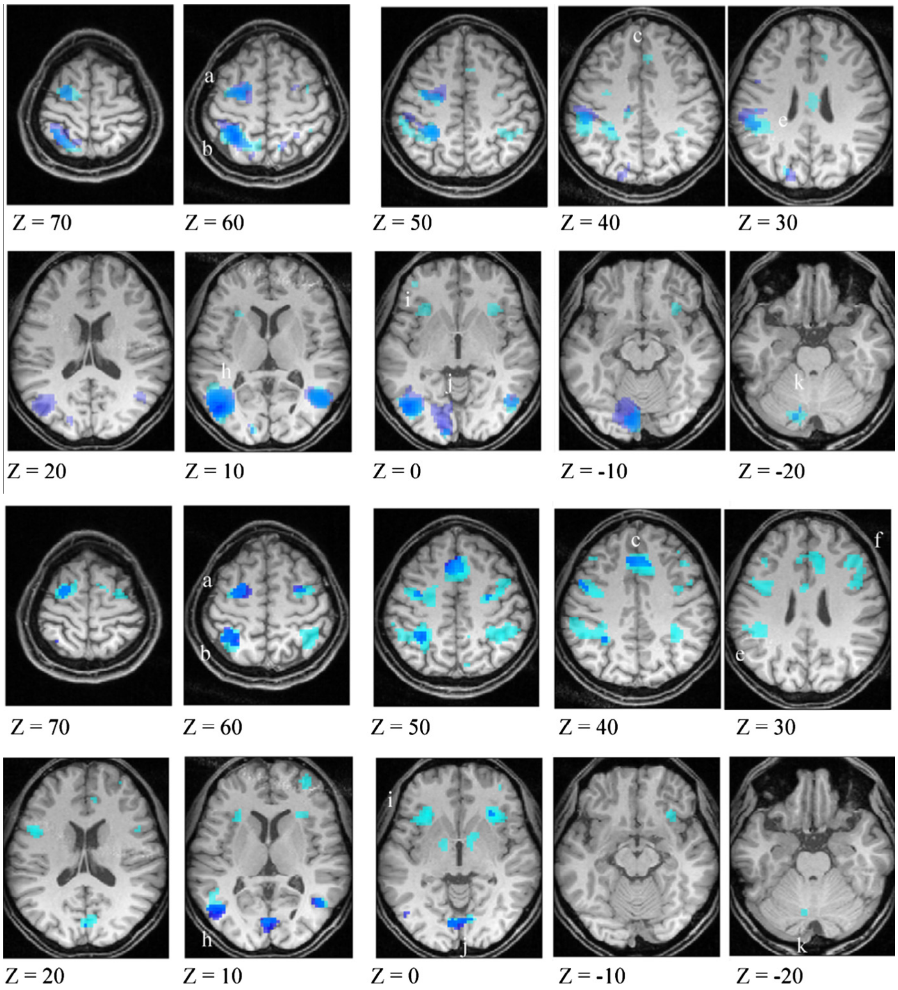

Fig. 2. Brain voxels responding significantly more strongly to action prediction than action observation control stimuli. The upper set of images show data from the badminton task, and the lower set show data from the hockey task. Light-toned blobs (cyan) represent observation data from hockey players, and the darker tones (blue) data from non-hockey players. Key: a = premotor cortex; b = superior parietal lobule; c = medial frontal cortex; d = anterior cingulate; e = inferior parietal sulcus; h = temporal–parietal junction; i = anterior insula; j = occipital cortex; k = cerebellum.

Table 1a. Location and extent of principal clusters responding more strongly to action prediction than action observation (control) stimuli for badminton tasks, and for expert and novice hockey players. For each cluster, the significance level (FDR-corrected $p < .05$) only of the largest peak is reported. The tabulated data correspond to Fig. 2 (upper)

AAL label	BA	MNI coordinates	Cluster size	Peak FDR-*p*-value
Experts: badminton				
Parietal sup L	7/40	−33 −46 55	577	6.89E−09
Supp motor area	8/32	3 17 49	466	2.88E−08
Insula ant R	13	−30 23 1	169	1.43E−07
Insula ant L	13	−36 17 −2	144	3.10E−07
Sup front sulcus L	6	−24 −7 55	551	9.77E−07
Precentral R	6	30 −20 52	436	6.68E−06
Calcarine R	18	3 −76 16	162	1.57E−05
Temporal mid L	39	−45 −67 13	69	6.85E−05
Inf parietal R	40	42 −43 49	317	0.00012
Temporal mid L	22	48 −61 13	29	0.000708
Frontal mid R	10	36 53 10	36	0.001259
Med globus pallidus		12 −1 −2	41	0.001628
Frontal mid L	9	−42 29 37	22	0.00624
Cerebellum crus 1 L		−6 −73 −26	23	0.013078
Cingulate ant L	24	−3 2 28	17	0.015654
Supp motor area R	6	12 −1 67	12	0.038533
Novices: badminton				
Temporal mid L	39	−48 −70 10	91	1.78E−11
Frontal sup L	6	−27 −7 58	139	9.01E−08
Calcarine R	18	3 −79 4	110	3.09E−05
Parietal sup L	40	−33 −49 55	150	8.74E−07
Supp motor area	8/32	−6 20 46	126	8.74E−05
Temporal mid R	39	45 −61 10	24	0.021185

Table 1b. Location and extent of principal clusters responding more strongly to action prediction than action observation (control) stimuli for hockey tasks, and for expert and novice hockey players. For each cluster, the significance level (FDR-corrected $p < .05$) only of the largest peak is reported. The tabulated data correspond to Fig. 2 (lower)

AAL label	BA	MNI coordinates	Cluster size	Peak FDR-*p*-value
Experts: hockey				
Temporal mid L	39	−45 −67 7	407	7.02E−11
Postcentral mid L	40	−30 −43 55	769	7.02E−11
Temporal mid R	39	51 −64 10	186	3.88E−09
Frontal mid L	6	−39 −7 52	283	3.99E−07
Calcarine L	18	−6 −85 −11	215	7.59E−05
Front inf orb R	47	33 23 −8	97	1.24E−05
Insula L	13	−33 20 −2	82	5.77E−06
Cingulum mid L	24	−15 −25 34	20	0.000554
Precuneus R	7	9 −55 55	16	0.000641
Cingulum mid R	24	6 −10 31	44	0.008651
Occipital sup R	19	−21 −82 34	25	0.003076
Parietal inf R	40	42 −46 49	93	0.004521
Cingulum ant R	32	12 35 28	23	0.011825
Frontal mid R	6	36 −7 52	27	0.002592
Novices: hockey				
Temporal mid L	39	−48 −70 10	480	2.97E−11
Parietal sup L	40	−30 −49 58	664	2.97E−11
Lingual L	18	−9 −79 −9	598	2.97E−11
Frontal sup L	6	−27 −7 −58	290	3.85E−11
Temporal mid R	19	51 −64 10	218	3.93E−11
Postcentral R	40	30 −49 61	11	0.029181
Precentral L	9	−51 5 34	10	0.035793
Parietal sup R	7	15 −58 61	11	0.039696

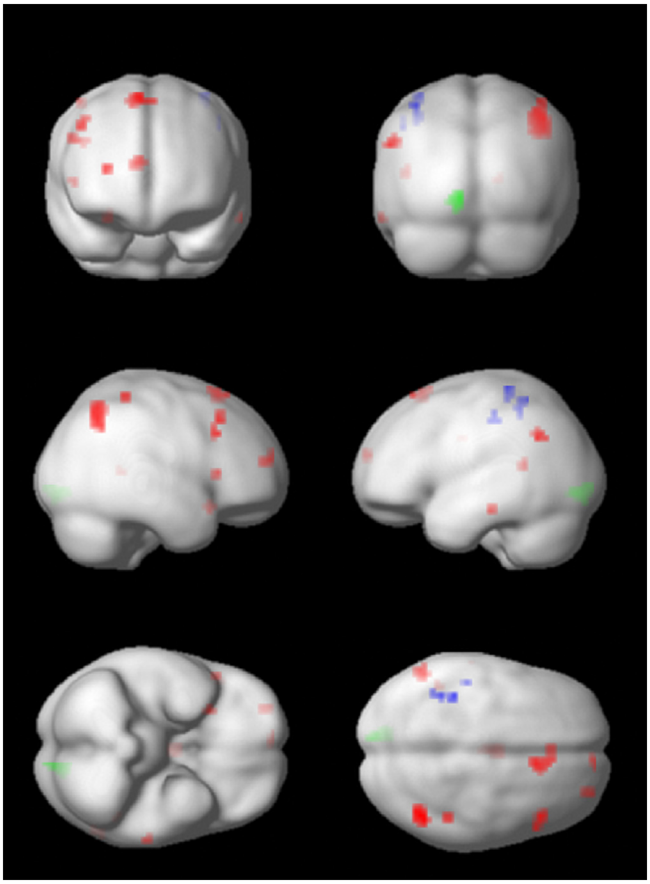

Fig. 3. Activations thresholded at $p < .05$ FWE with minimum cluster size = 5 on a whole-brain, second-level analysis. Red: hockey experts > hockey novices across all hockey and badminton action prediction conditions. Green: hockey videos > badminton videos. Blue: voxels responding to the covariate alone (mean response accuracy per participant per condition).

main expertise effect was tested using a t-contrast for the direction prediction conditions minus control conditions. T-contrasts, unlike F-contrasts, show the direction of an effect. First-level t-contrasts for (HL–HC) + (HS–HC) and (BL–BC) + (BS–BC) were calculated to separately estimate an overall level of activation for both hockey and badminton directional judgements relative to an action–observation control. A second-level, random effects, analysis was then conducted on these t-contrasts from the individual data. An initial analysis compared experts with novices on the contrast hockey action minus HC. Experts showed increased activation relative to novices of the right rostral inferior parietal lobule in Brodmann area 40 (see Table 3 and Fig. 4). This location was close to but not identical with the largest cluster in the ANOVA across both video types (Table 2a). This area has been shown to be activated in mirror neuron studies and is considered to be the human equivalent of area PF/PFG in monkeys (for reviews see Rizzolatti et al., 2001; Rizzolatti and Craighero, 2004; Rizzolatti, 2005; Iacoboni and Dapretto, 2006; Fabbri-Destro and Rizzolatti, 2008).

A second analysis explored expert–novice differences for the badminton action minus BC contrast. There were three areas of significantly greater activation in the experts' brains (see Table 4 and Fig. 5).

Brodmann areas 17 and 18 correspond to visual cortical areas V1 and V2 respectively. Brodmann area 9 has been linked to sustaining attention and working memory (Lloyd, 2007).

Thus, although overall, the interaction of expertise and video type was not significant when examined on a voxelwise basis; planned comparisons showed partitioning of the main effect of video type (hockey vs. badminton) in that there were significant effects of expertise, in separate voxel clusters, for hockey action and for badminton action.

The next analysis was to see if experts showed any differences in their activation depending on which sport they were watching. It was found that experts had two areas of their brain that were more active when watching hockey compared to badminton clips (see Table 5 and Fig. 6).

Brodmann area 5 is labeled as somatosensory association cortex and has been associated with sensory motor control of hand movements (Premji et al., 2011). The posterior cingulate was also more activated for hockey judgements and has been associated with episodic memory retrieval (e.g. Hirshhorn et al., 2012; Kuchinke et al., 2013).

Novices also showed a range of activation differences when comparing by sport. First, they showed greater

Table 2a. Clusters > 5 voxels showing main effects of expertise across both hockey and badminton action videos, all at $p < .05$ FWE corrected

AAL label	BA	MNI coordinates	Cluster size	Peak FWE-*p*-value
Action prediction: Hockey experts > hockey novices				
Angular R	40	45 −61 43	73	6.87E−05
Frontal sup med R	10	9 62 19	12	1.88E−05
Frontal mid R	8	48 23 46	10	.0001
Cingulum mid L	24	0 −7 31	21	.000107
Frontal sup med R	6	12 23 61	6	.000258
Frontal sup med R	6	0 32 61		.009997
Postcentral R	40	48 −40 61	8	.001126
Frontal sup R	10	30 56 13	11	.002358
Angular L	40	−57 −61 31	16	.004378
Frontal inf operc L	9	54 20 37	11	.007515
Frontal inf operc L	9	45 23 34		.018198
Temporal inf L	20	−63 −25 −20	5	.008735
Precuneus R	29	18 −43 7	5	.009326
Temporal mid L	22	−45 −49 13	7	.011109
Insula R	47	27 17 −20	7	.011798
Frontal inf tri R	47	51 20 4	5	.018119
Action prediction: hockey novices > hockey experts				
Temporal mid L	39	−48 −73 10	8	.000597
Postcentral L	5	−36 −37 70	8	.00381
Postcentral L	1	−45 −34 64		.010845

Table 2b. Other significant effects in ANOVA

AAL label	BA	MNI coordinates	Cluster size	Peak FWE-*p*-value
Action prediction: hockey > badminton videos				
Lingual L	18	−158 −85 −8	87	7.04228E−05
Calcarine L	17	−9 −94 −2		7.90127E−05
Calcarine L	17	−9 −91 −11		.000240372
Covariate only				
Postcentral L	1	−39 −37 67	21	.003222
Postcentral L	40	−48 −28 52	5	.008448
Precentral L	9	−48 5 37	5	.016621

Table 3. Expert vs. novice (hockey action minus hockey control)

Hemisphere	Lobe	Label	Brodmann area	MNI coordinates	Cluster size	FDR-*p*-value
Right cerebrum	Parietal	Inferior parietal lobule	40	39 −51 42	76	0.004

activation in the primary visual cortex for hockey judgements relative to badminton judgments (see Table 6 and Fig. 7).

In addition, novices showed reduced activation in Brodmann areas 30 and 8 for hockey judgements relative to badminton judgments (see Table 7 and Fig. 6).

Interestingly, the medial frontal gyrus (Brodmann area 8) has been shown to be associated with uncertainty (Volz et al., 2004). Higher levels of uncertainty correspond with higher levels of activation in this area and the behavioral data supports the notion that the novices were highly uncertain when making judgements about the badminton condition relative to the hockey condition (the badminton clips were significantly more difficult to predict than hockey clips (HL vs. BL; $t(29) = 11.94$, $p < 0.001$, $r = 0.83$. HS vs. BS; $t(29) = 9.70$, $p < 0.001$, $r = 0.76$)). A difference in activation was once more seen in Brodmann area 30 although this time in the right hemisphere of the occipital lobe in the cuneus area which is associated with visual processing including processing of real-world scenes (Henderson et al., 2011) and navigation and orientation (Maguire, 2001).

Finally, although there were no voxels showing significant interactions between expertise and the level of occlusion, and none showing the three-way interaction between expertise, occlusion level and video type, exploration was conducted to see whether the main effect of expertise could be partitioned further. In the light of the behavioral results, it was decided to test whether there were any significant differences in brain

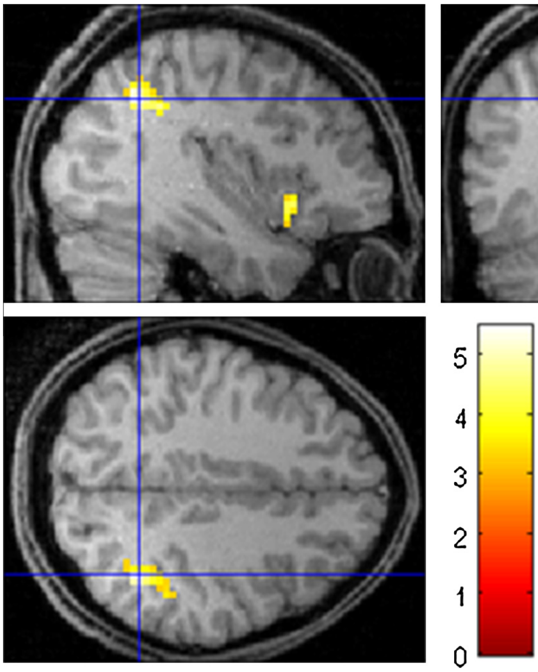

Fig. 4. The crosshairs indicate the location of the peak of activation shown in Table 3.

Table 4. Expert vs. novice (badminton action minus badminton control)

Hemisphere	Lobe	Label	Brodmann area	MNI coordinates	Cluster size	FDR-*p*-value
Left cerebrum	Occipital	Lingual gyrus	17	−21 −93 −6	89	0.002
Right cerebrum	Frontal	Middle frontal gyrus	9	27 30 36	55	0.008
Right cerebrum	Occipital	Cuneus	18	9 −96 15	62	0.007

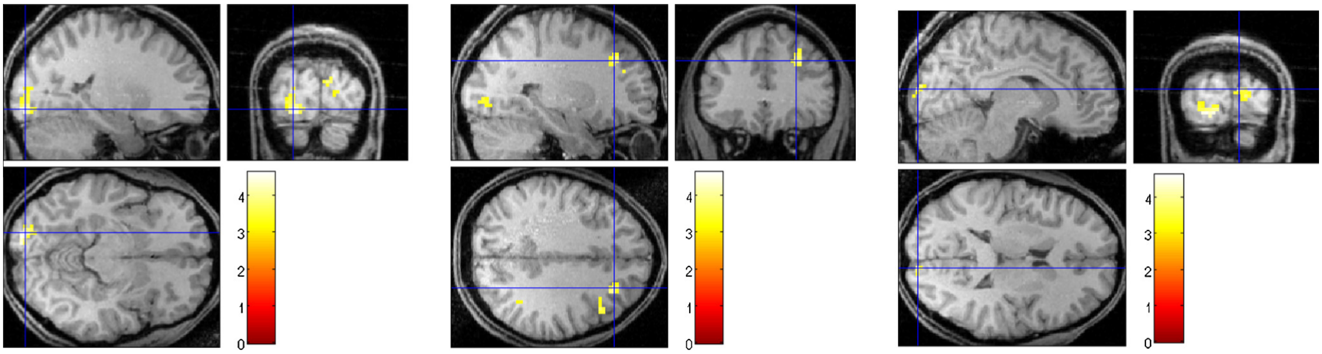

Fig. 5. The crosshairs indicate the three peaks of activation shown in Table 3.

Table 5. Experts (hockey action minus control vs. badminton action minus control)

Hemisphere	Lobe	Label	Brodmann area	MNI coordinates	Cluster size	FDR-*p*-value
Left cerebrum	Parietal	Postcentral gyrus	5	−6 −51 66	45	0.017
Left cerebrum	Limbic	Posterior cingulate	30	−6 −63 9	92	0.001

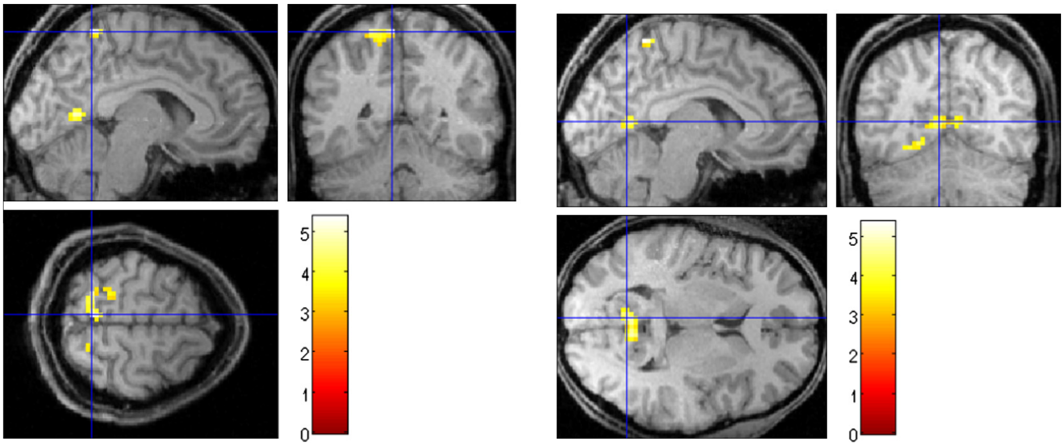

Fig. 6. The crosshairs indicate the significant peaks of activation shown in Table 4.

Table 6. Area showing greater activation for hockey judgements in novices

Hemisphere	Lobe	Label	Brodmann area	MNI coordinates	Cluster size	FDR-*p*-value
Left cerebrum	Occipital	Cuneus	17	−9 −93 3	469	< 0.0005

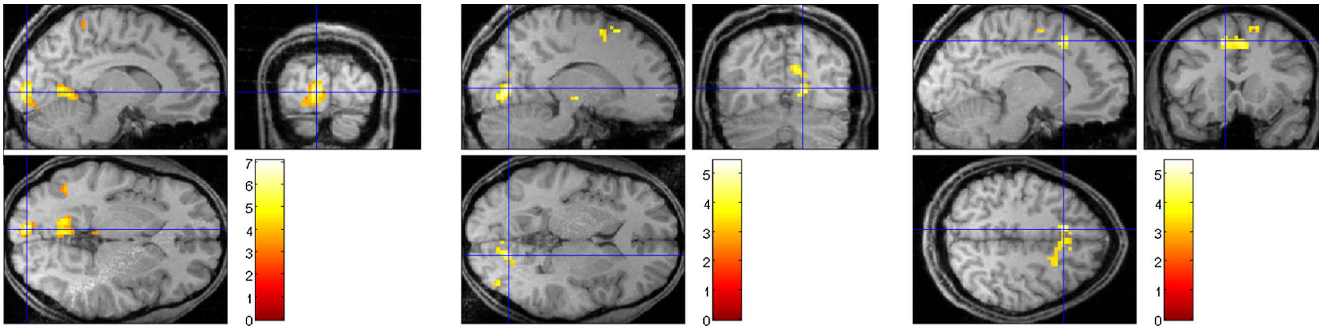

Fig. 7. The crosshairs show the peaks of significant activation differences from Table 6 (left) and Table 7 (middle and right).

Table 7. Areas showing reduced activation for hockey judgements in novices

Hemisphere	Lobe	Label	Brodmann area	MNI coordinates	Cluster size	FDR-*p*-value
Right cerebrum	Occipital	Cuneus	30	15 −72 6	133	< 0.0005
Left cerebrum	Frontal	Medial frontal gyrus	8	−9 15 51	112	< 0.0005

Table 8. Badminton early occlusion (expert minus novice)

Hemisphere	Lobe	Label	Brodmann area	MNI coordinates	Cluster size	FDR-*p*-value
Left cerebrum	Occipital	Lingual gyrus	17	−21 −93 −6	46	0.012

activation between experts and novices, in the early occlusion condition. As this condition should be considerably harder, and showed group differences in the behavioral data, it may provide information on whether different areas of the brain were called upon to solve the problem of predicting the shot direction in experts compared to novices. However, planned comparisons using ANOVA (using the (HS–HC) or (BS–BC) first-level contrasts) found that there were no activation differences between experts and novices for the HS trials. For the BS trials there was greater activation in the primary visual cortex of experts (see

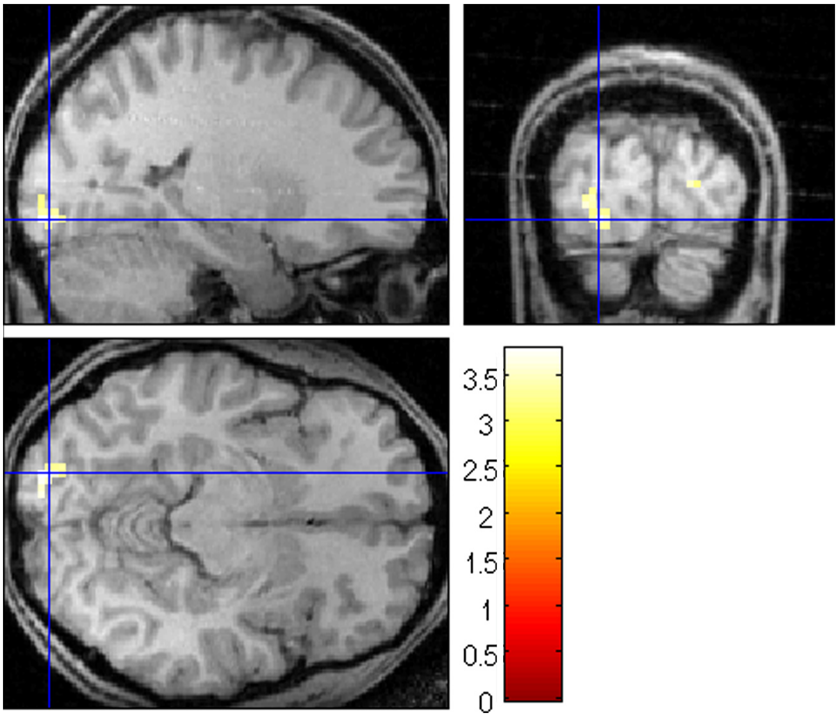

Fig. 8. The crosshairs show the peak of significant activation shown in Table 8.

Table 8 and Fig. 8) which is consistent with the view that the badminton task engaged processing of basic aspects of the visual stimulus more strongly in the experts.

DISCUSSION

The aim of this study was twofold. Firstly, the experiments were designed to explore differences in the brain function of participants when making a decision based on video clips of a sport in which one group were experts and one group were novices. Following this the aim was to discover if, when making a decision based on a sport in which neither group of participants were experts, the group who were experts in a different sport still used their brain in an ‘expert’ way.

Behavioral data

When looking at the behavioral data, a significant interaction was found between video type and hockey expertise, and this is consistent with the view that the perceptual skills used to predict direction of play in a temporal occlusion task are sport-specific. As the video clips for the two sports could not be precisely matched, overall differences in accuracy emerged for hockey and badminton clips as a main effect of video type in the ANOVA. However, since accuracy data for both video types was normally distributed and showed no ceiling or floor effect for either group of participants, there is no reason to doubt the validity of the significant interaction found in ANOVA. Further analysis of the interaction showed that the only significant difference between the two groups was found for the hockey clips, in particular when they were cut to the shortest time point. This supports much of the previous research in this area (e.g. Jones and Miles, 1978; Jackson, 1986; Houlston and Lowes, 1993) by showing that experts are superior to novices when the task is most difficult. Interestingly, there were no significant differences between the two groups on the badminton clips, which suggests that in this case there is no behavioral evidence of transfer of perceptual skill between sports. This finding contrasts with previous work on pattern recognition, which has found some transfer of recall for playing position patterns between expert and non-expert sports (e.g. Smeeton et al., 2004; Abernethy et al., 2005). Thus, it would seem that, unlike memory-based tasks, the skills tapped by advanced cue utilization tasks are sport specific.

Main findings

The fMRI analysis, unlike the accuracy data, showed significant main effects of expertise, and non-significant results for the interaction between expertise and video type. Two possible explanations for the discrepancy between fMRI and accuracy results were ruled out. The first possible explanation is that the control condition may somehow have confounded the fMRI results. The control condition was excluded from the behavioral ANOVA due to ceiling effects, however it was included in the first-level analysis of fMRI activations. However, when the fMRI ANOVA was repeated without the control condition, thus matching the ANOVA design for accuracy, it gave essentially the same result: a significant main effect of expertise and a non-significant interaction between expertise and video type. The second explanation is that differences in the difficulty of the task may somehow have confounded the results.

Therefore accuracy (for each condition and participant) was included as a covariate. This had essentially no effect on the expert–novice differences observed in fMRI. However, inclusion of the covariate did reduce the extent of the significant activation due to the main effect of video type (hockey vs. badminton video). The covariate alone produced significant activation in left parietal cortex and prefrontal cortex that are considered to be part of AON, but these areas did not overlap with those showing the effect of expertise. It must be recognized that although accuracy on the video task may be correlated with expertise, there are many aspects of expertise other than those captured in task accuracy which may affect how the expert brain reacts during an action prediction task. Some divergence of expertise effects in behavioral and fMRI measures was noted previously by Balser et al. (2014b), Bishop et al. (2013) and Wright et al. (2013).

Thus, in summary, the main ANOVA analyses appear to support previous work that has suggested there is a main effect of expertise on action anticipation in sport (Abreu et al., 2012; Bishop et al., 2013; Lyons et al., 2010; Wright et al., 2010, 2013; see also Press and Cook, 2015). In general, irrespective of the sport, experts appear to recruit a wider network of brain areas to make action anticipation judgements than novices.

However, although the main ANOVA analyses suggested no interaction between expertise and video type, because some past research shows sport-specific expertise effects (Calvo-Merino et al., 2005; Aglioti et al., 2008; Balser et al., 2014b), more sensitive planned comparison analyses were also carried out. This analysis showed that although both hockey and badminton tasks activated the action observation network, one area of the brain was significantly more strongly activated in experts than novices when viewing hockey clips. This area was the rostral inferior parietal lobule, a key component in the action observation or mirror neuron system (for reviews see Rizzolatti et al., 2001; Rizzolatti and Craighero, 2004; Rizzolatti, 2005; Iacoboni and Dapretto, 2006; Fabbri-Destro and Rizzolatti, 2008). Although the overall pattern of fMRI results does not favor domain specificity, this particular observation is consistent with the suggestion by Calvo-Merino et al. (2005) that the brain's response to seeing an action is influenced by the acquired motor skill of the observer in the action domain. This also fits with the work of Aglioti et al. (2008) on basketball and football players who only showed MEPs when watching clips from the specific sport they participated in, and with recent work by Balser et al. (2014b) who identified AON activation relating to sport-specific expertise in tennis and volleyball players.

The second aim of the present study was to see if expert hockey players used their brains differently compared to novices when watching a sport in which they had no expertise. Behavioral studies on talent transfer suggest that experts may be able to transfer their skills to a different sport (at least in pattern recognition tasks; Smeeton et al., 2004; Abernethy et al., 2005) and on this basis expert–novice differences in activation patterns, even on an unfamiliar sport for both groups, were expected. However, the behavioral data in the present study found no difference in success rate between the two groups at predicting the outcome of the badminton clips. Despite this absence of a behavioral difference there were expert–novice differences in activation patterns, suggesting that fMRI activations do not reflect performance accuracy in any simple way. One possibility is that experts and novices may use different strategies to predict shot direction for the badminton clips. When looking at brain function, the experts show AON activation, consistent with the importance of visual-motor experience, when making a decision about their own sport where novices do not. When making a decision about a neutral sport there were no differences in the behavioral data yet the expert group were seen to be engaging areas of their brain reported as being involved in visual processing (BA 17, 18; Boothe, 2002), and attention and working memory (BA 9; Lloyd, 2007) showing that they are perhaps employing a different strategy from novices when trying to solve the problem. This would be interesting when it comes to looking at talent transfer as, although the experts are apparently employing a different strategy from the novices, this strategy was no more successful. It may be that compared to a beginner they would need less motor experience in the new sport to apply their perceptual expertise correctly. An attempt to research this training element was made by Urgesi et al. (2012) when they found that both physical practice and observational training in novice volleyball players contributed in complimentary ways to enhancing perceptual expertise. However, greater research in this area is required.

Supplementary findings

It was found that there were no areas of the expert brain that were significantly more active when watching badminton than while they were watching hockey. However, there were two areas that showed significantly more activation when observing the hockey clips than when observing badminton. The left posterior cingulate was activated (Brodmann area 30) which has been associated with episodic memory retrieval (Maguire, 2001), and episodic memory has been proposed as the basis for the build-up of perceptual expertise through experience (Gobet, 1998). The other area activated more by hockey clips was the post-central gyrus (Brodmann area 5), which is the location of primary somatosensory cortex, the main sensory receptive area for the sense of touch. BA 5 is also implicated in motor imagery as well as in execution of motor responses (Solodkin et al., 2004) and could be activated in this scenario if the experts experience sensorimotor imagery when making a decision about the video clip presented to them.

Novices also showed significant differences in activation depending on the sport they were watching, even though they had similar experience levels (i.e. none) of each sport. They had more activation in Brodmann area 17, the primary visual cortex, than when they were observing badminton, which may reflect greater visual engagement with the easier hockey task. Conversely, there were two areas more active in the novice brain when watching the badminton clips than the hockey clips. These were the medial frontal gyrus in the frontal lobe (Brodmann area 8) and the cuneus in the occipital lobe (Brodmann area 30). Brodmann area 8 has been shown to be associated with subjective uncertainty (Volz et al., 2004). Higher levels of uncertainty show higher levels of activation in this area and the behavioral data of novices suggest that the greater difficulty of the badminton clips made them highly uncertain when making judgements about this condition when compared with the simpler, hockey condition. The activation in Brodmann area 30 was this time in the right hemisphere and this is more commonly associated with visual processing as opposed to episodic memory as discussed earlier. For example, Henderson et al. (2011) linked this area to viewing real-world scenes. It is possible that the difficulty of the task could mean that the participants were not focusing specifically on the actions present in the video. These differences are consistent with the view that experts and novices employ different perceptual strategies.

Conclusion

Looking at the results of this study as a whole, it can be seen that there are differences in how experts and novices use their brains to make a shot direction decision. As expected, when making a decision about the sport in which their expertise lies, the activation centers around areas associated with the action observation system, as well as memory and touch. Differences still remain when decisions are being made about a neutral sport but they are not the same differences as seen in previous work. It was found that the experience that the experts have had with hockey has had an impact on their visual processing. Interestingly, the greater difficulty of judgments for the badminton clips leads to the observation that this seems to have caused different strategies to be employed by the two groups. Whereas the experts seemed to persist with applying some visual processing strategy to try and make the correct decision even when the clips were very hard, the novices almost seemed to give up. This is an interesting finding yet it perhaps tells us more about the personalities of those people who are experts in their chosen sport than about whether their talent would transfer successfully to a different sport.

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