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Hemispheric activation differences in novice and expert clinicians during clinical decision making

Pam Hruska[1] · Kent G. Hecker[1,2] · Sylvain Coderre[3] · Kevin McLaughlin[3] · Filomeno Cortese[4] · Christopher Doig[5] · Tanya Beran[1] · Bruce Wright[6] · Olav Krigolson[7]

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Abstract Clinical decision making requires knowledge, experience and analytical/non-analytical types of decision processes. As clinicians progress from novice to expert, research indicates decision-making becomes less reliant on foundational biomedical knowledge and more on previous experience. In this study, we investigated how knowledge and experience were reflected in terms of differences in neural areas of activation. Novice and expert clinicians diagnosed simple or complex (easy, hard) cases while functional magnetic resonance imaging (fMRI) data were collected. Our results highlight key differences in the neural areas activated in novices and experts during the clinical decision-making process. fMRI data were collected from ten second year medical students (novices) and ten practicing gastroenterologists (experts) while they diagnosed sixteen (eight easy and eight hard) clinical cases via multiple-choice questions. Behavioral data were collected for diagnostic accuracy (correct/incorrect diagnosis) and time taken to assign a clinical diagnosis. Two analyses were performed with the fMRI data. First, data from easy and hard cases were compared within respective groups (easy > hard, hard > easy). Second, neural differences between novices and experts (novice > expert, expert > novice) were assessed. Experts correctly diagnosed more cases than novices and made their diagnoses faster than novices

✉ Kent G. Hecker
kghecker@ucalgary.ca

[1] Department of Community Health Sciences, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada

[2] Department of Veterinary Clinical and Diagnostic Sciences, Faculty of Veterinary Medicine, University of Calgary, Calgary, AB, Canada

[3] Undergraduate Medical Education, Cumming School of Medicine, Calgary, AB, Canada

[4] Seaman Family MR Research Centre, Hotchkiss Brain Institute, University of Calgary, Calgary, AB, Canada

[5] Department of Critical Care Medicine, Cumming School of Medicine, Calgary, AB, Canada

[6] Division of Medical Sciences, University of Victoria, Victoria, BC, Canada

[7] Neuroscience Program, Centre for Biomedical Research, School of Exercise Science, Physical, and Health Education, University of Victoria, Victoria, BC, Canada

on both easy and hard cases (all p's < 0.05). Time taken to diagnose hard cases took significantly longer for both novices and experts. While similar neural areas were activated in both novices and experts during the decision making process, we identified significant hemispheric activation differences between novice and expert clinicians when diagnosing hard clinical cases. Specifically, novice clinicians had greater activations in the left anterior temporal cortex and left ventral lateral prefrontal cortex whereas expert clinicians had greater activations in the right dorsal lateral, right ventral lateral, and right parietal cortex. Hemispheric differences in activation were not observed between novices and experts while diagnosing easy clinical cases. While clinical decision-making engaged the prefrontal cortex (PFC) in both novices and experts, interestingly we observed expertise related differences in the regions and hemispheres of PFC activation between these groups for hard clinical cases. Specifically, in novices we observed activations in left hemisphere neural regions associated with factual rule-based knowledge, whereas in experts we observed right hemisphere activation in neural regions associated with experiential knowledge. Importantly, at the neural level, our data highlight differences in so called type 2 clinical decision-making processes related to prior knowledge and experience.

Keywords Dual process theories · Clinical decision making · Functional magnetic resonance imaging · Novice expert studies

Introduction

Dual processing theories (DPT), prevalent in medical education and decision making literature, attempt to explain what, how and when analytical and non-analytical types of decision processes are utilized and exist within one's mind (Eva 2005; Evans 2003; Evans and Stanovich 2013). Non-analytical processes, referred to as type 1 decision-making, are characterized as being autonomous, fast, intuitive, automatic, and non-declarative, whereas analytical, or type 2 processing is regarded as being slow, deliberative, logical, and declarative (Evans 2008; Evans and Stanovich 2013). Having been presented in diverse ways, DPT literature is moving away from previous held beliefs that decision-making is dependent on two distinct systems, each with their own underlying and dedicated neural areas (Evans 2003), to the idea that there is oscillation between neural areas dependent on modifiers which have yet to be fully defined (Croskerry 2009a, b; Evans and Stanovich 2013).

Cognitive process involved in clinical decision making are likely interactive and iterative which, depending upon the clinical problem, could use one or a combination of approaches in order to arrive at clinical diagnosis (Eva 2005). When initially approaching a clinical problem, it is felt that an automatic or intuitive response would be unconsciously activated (pattern recognition), and that the analytical system would be engaged to confirm or validate the initial hypothesis (hypothetico-deductive), especially in atypical, high-stake or complex situations (Pelaccia et al. 2011). Croskerry (2009a, b) proposed a schematic model to explain characteristics associated with type 1 and 2 processing for a more visual representation for how one might approach presenting clinical problems. This model suggests that if an illness presentation is not recognized through type 1 processing or pattern recognition, an override of type 2 processing may be used. While this attempts to make the cognitive process of clinical decision making more overt, the dynamics and interactions of when and how analytical and non-analytical processes utilized and the neural areas sub serving these types of cognitive processes still remain unclear.

The way knowledge is structured and subsequently retrieved by use of decision-making strategies such as dual processing has been shown to differ based on content familiarity, level of experience, and demand of the task. The most common approach for studying relevant underlying knowledge structures is by examining differences between novices and experts (Ericsson et al. 2006). In general, experts when compared to novices, generate faster and more accurate problem solving solutions, are better at pattern detection, analyze problems more qualitatively, are better able to self-monitor for mistakes, and take advantage of any and all sources of information available all while seeming to expend less cognitive effort (Ericsson et al. 2006). It is felt the development of expertise is due to multiple exposures to clinical problems that allows clinicians to incorporate knowledge and clinical information into pre-existing categories (Norman 2005). Dispersed learning and repeated testing also appear critical in refinement of knowledge structures and for developing accurate retrieval of relevant information from long term memory (Larsen et al. 2013; Raman et al. 2010).

Summarized, experts and novices differ in clinical reasoning in a couple of notable ways: (1) experts are able to differentiate clinically relevant information when a clinical case is presented and generate earlier more accurate hypotheses (Coderre et al. 2010; Elstein et al. 1978), and (2) experts have developed more abstract knowledge representations which allows them to encapsulate knowledge in broad ways using more general concepts (Gruppen and Frohna 2002). These points are further reinforced by findings which demonstrate novices use basic science and declarative knowledge in reasoning and decision making (Norman 2005), whereas experts offer more coherent explanations and show greater accuracy in reasoning and decision making while using less basic science (Patel et al. 1989).

As noted earlier, the predominant neural region of interest in clinical decision-making is the prefrontal cortex (PFC) (Lee et al. 2007). Different subdivisions of the PFC noted to be engaged in decision making in humans in general include the dorsolateral prefrontal cortex (DLPFC) and the frontopolar cortex (Krawczyk 2002). The DLPFC is involved in maintaining and manipulating information in working memory, and the frontal polar cortex is implicated in rule-based decisions (Krawczyk 2002). Research exploring specialization of hemispheres suggests the left hemisphere is dominant for analytical and semantic processing, dependent on concrete material, whereas the right is activated with episodic memory retrieval, when associating stimuli and responses, and with abstract or holistic processing (Gazzaniga 2000; Bever and Chiarello 1974; Fangmeier et al. 2006; McElroy and Seta 2004). Applied within the context of clinical decision making, it could be anticipated that while both groups will activate the PFC during clinical decision making, underlying neural areas supporting novices and experts lateralize to different hemispheres.

Based on previous findings we made three predictions: (1) Among novice and expert clinicians, there would be evidence of shared neural processing in some basic form, resulting in PFC activations across groups and tasks, (2) hemispheric differences in neural activation would be observed related to differences in decision-making strategies/processes employed by novice and expert clinicians that could be attributed to differential use of type 1 and/or type 2 decision processes, and (3) observed differences in neural activity could be impacted by case difficulty.

Methods

This research is an extension of Hruska et al. (2015). For a full description of the study methodology, including the fMRI research methodology, the clinical cases and the data acquisition, please refer to this paper. For a brief overview of fMRI research, please see "Appendix".

Participants

This study was conducted in accordance with the ethical standards prescribed in the Declaration of Helsinki, the Calgary Health Ethics Research Board (CHREB), and the Seaman Family MR Research Center. Twenty healthy right-handed volunteers with normal or corrected-to-normal vision and no history of brain injury or cerebrovascular abnormality participated. Handedness was a criteria because language processing of right handed participants has been shown to predominantly be lateralized to the left cerebral cortex (Savoy 2006).

Participants were ten second year medical students from the University of Calgary [novices; 8 male, mean (range) age 26.5 (22–38) years, SD = 5.3] and ten practicing gastroenterologists [experts; 5 male, mean (range) age 39.5 (32–50) years, SD = 4.5]. All expert participants had formal academic teaching responsibilities at University of Calgary Alberta, Canada.

Stimuli and procedures

During scanning, participants read sixteen written clinical cases during a single 1-h fMRI session. Eight cases were deliberately made to be "easy", in which the patient's contextual data was concordant with the presented analytical data, and eight were made to be "hard" with patient contextual data being discordant with the analytical data presented. For each case, participants were given 80 s to read a clinical scenario and then were asked to indicate the single most likely diagnosis in the form of a multiple-choice question with four answer choices. Answers were captured using handheld MR-compatible response boxes (Cedrus, San Pedro, CA, USA) with which participants had 20 s to make their selection. Use of fixation periods in-between reading and answering tasks for a length of 10 s was used to establish cognitive baseline for contrast during data analysis.

Data acquisition and analysis

Behavioural data and analysis

For each case, participants' accuracy (correct, incorrect) and response time (s) were recorded. Two-way analysis of variance (ANOVA) was used to assess overall accuracy (%) and mean response time (s) between experience (novice, expert) and case difficulty (easy, hard). An alpha level of 0.05 was assumed for these analyses.

Functional and structural magnetic resonance imaging (fMRI) data acquisition, processing and analysis

The data acquisition and processing were the same as outlined by Hruska et al. (2015). Three levels of analyses were performed using fMRI data. For the first-level analysis, neural fMRI data captured from each multiple-choice question for each participant were separately analyzed contrasting decision making [the multiple-choice questions (MCQ) phase; neural task] with the fixation phase (10 s; MCQ > fixation; neural baseline activity). The second-level fixed-effects analysis combined the functional data for each participant (16) into easy (8) and hard (8) average images. During this level of analyses we contrasted easy relative to hard cases (easy > hard) and hard relative to easy cases (hard > easy).

The third-level mixed-effects analysis combined the second-level contrasts of the two groups of participants separately to model group level differences and to contrast the group

effects. Here we had contrasts reflecting the group effects separately (novice vs. expert) and contrasts examining group difference (novice > expert, expert > novice).

Statistically significant clusters of activation were identified on the entire group statistical map by using a voxel-wise threshold to $z > 2.3$ ($p < 0.05$) and the FSL cluster analysis. Given our outlined hypotheses, we included decision making versus fixation contrasts for both easy and hard clinical cases for both groups to show whole brain activation, and also conducted specific region of interest analyses (ROI) (Poldrack 2007). ROIs were defined within the prefrontal cortex (DLPFC, VLPFC) and similar statistical criteria were used to evaluate activation: a voxel-wise threshold to $z > 2.3$ ($p < 0.05$) and a criteria of at least 30 contiguous voxels (Worsley et al. 1992, 1996). The Montreal Neurological Institute (MNI) coordinates were used to determine the most probable anatomical label from the Harvard-Oxford Cortical Structural Atlas package in FSL.

Results

Behavioral results

The two-way ANOVAs examining the impact of expertise (novice, expert) and case difficulty (easy, hard) on accuracy and response time demonstrated two key results. One, experts (78 ± 12 %) correctly diagnosed more cases than novices [(58 ± 25 %), $F(1,36) = 11.2$, $p < 0.005$]. Two, experts (6.0 ± 1.8 s) made their diagnoses faster than novices [(8.7 ± 2.8 s), $F(1,36) = 17.4$, $p < 0.005$]. Additionally, participants were more accurate on easy (76 ± 16 %) than on hard cases [(60 ± 24 %), $F(1,36) = 7.3$, $p < 0.05$]. Participants also answered harder cases more slowly (8.4 ± 2.1 s) than easy cases [(6.2 ± 2.7 s), $F(1,36) = 11.2$, $p < 0.005$]. In both analyses there were no interaction effect between expertise and case difficulty.

fMRI results

Initially we focused on separate analyses to generate group activation maps for the novice and expert clinicians while they answered the easy and hard multiple-choice scenarios. In line with accepted practice (Poldrack 2007) we did this to identify regions of interest (i.e., regions with differential activation between easy and hard cases and/or novices and experts) that were activated during clinical decision making for subsequent contrast analyses. Not surprisingly, processing and answering the multiple choice questions (both easy and hard) evoked significant changes in hemodynamic activity in multiple brain regions for both novice and expert clinicians—see Fig. 1 and Tables 1 and 2 for full details. Tables 1 and 2 provide the anatomical structure names, cluster size and MNI coordinates for the visual representation presented in Fig. 1. In general, we saw increased activations in the occipital, parietal, temporal, and prefrontal cortices during the answering of the MCQ. In easy cases for both novices and experts, common neural areas were activated in the left lateral occipital cortex, left paracingulate gyrus, and right middle frontal gyrus. In hard cases for both novices and experts, common areas of activation were found in the left inferior frontal gyrus, left lateral occipital cortex, right inferior frontal gyrus and left frontal pole.

In line with our predictions and supported by our observation of the group activation maps we conducted follow up analyses where we examined novice–expert differences (i.e., novice > expert, expert > novice) during clinical decision making for easy and hard cases. We found no significant differences in brain activity between groups during clinical

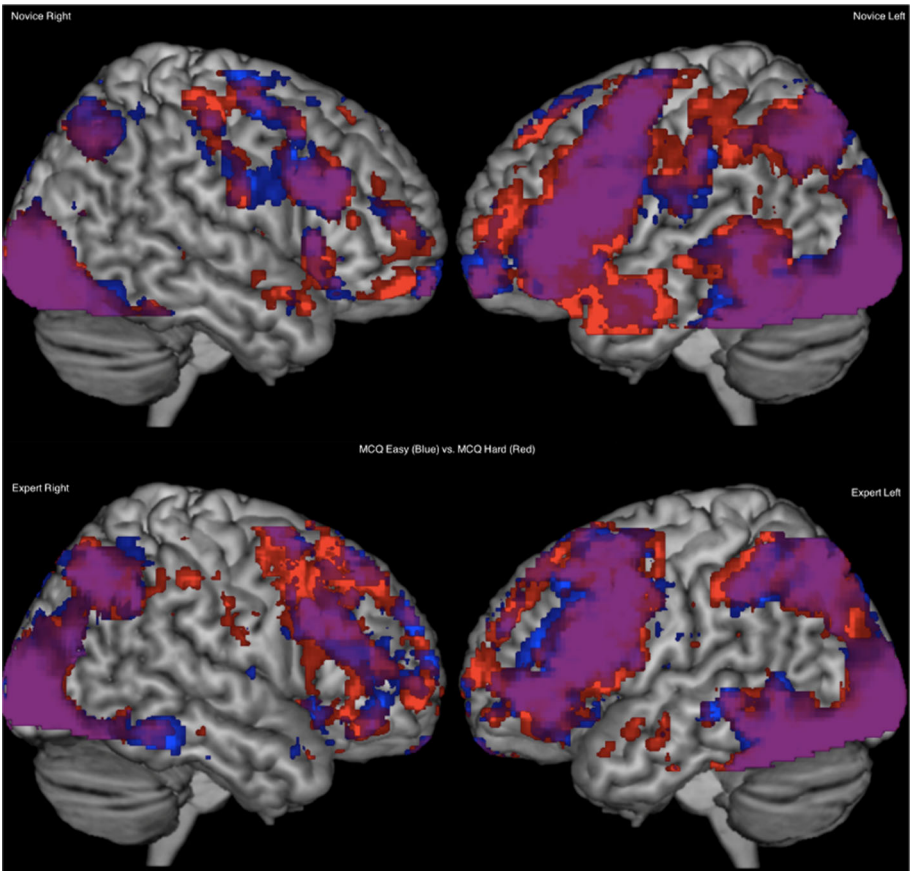

Fig. 1 Combined neural areas of activation in clinical decision making for novices (*top row*) and experts (*bottom row*). *Top row* (right hemisphere and left hemisphere): novice brain. *Bottom row* (*right hemisphere* and *left hemisphere*): expert brain. Decision making easy cases (*blue*) versus decision making hard cases (*red*). Common areas of activation (*purple*). (Color figure online)

decision making for the easy cases. There were however important neural distinctions for hard MCQ. In tasks with increased difficulty, we found that novice clinicians had greater activations than expert clinicians in the left anterior temporal cortex and left ventral lateral prefrontal cortex. Conversely, expert clinicians had greater activations than novice clinicians in the right dorsal lateral, the right ventral lateral, and the right parietal cortex (see Fig. 2; Table 3). While both novices and experts demand use of the PFC, there are hemispheric activation differences as well as differences in recruitment of other supportive brain regions between the levels of clinicians.

Discussion

The combination of behavioural and fMRI results suggest that even though there are shared neural areas used by novice and expert clinicians' during easy clinical cases, increased task difficulty produces distinct neural and hemispheric differences between the two groups

Table 1 Common areas of neural activation (clusters) for novices diagnosing easy and hard clinical cases

Hemisphere	Region	Cluster Size	Max Z	MNI coordinates		
				X	Y	Z
Easy MCQ (corresponds to blue colour in the top row of Fig. 1)						
Left[a]	Occipital pole	11,554	5.16	53	16	30
Left[a]	Frontal pole	3879	4.68	66	85	38
Left[a]	Lateral occipital cortex	1209	5	52	29	67
Left	Paracingulate gyrus	474	4.13	47	82	51
Right	Inferior frontal gyrus	402	4.85	17	74	50
Left	Frontal pole	333	4.26	51	97	31
Right	Frontal orbital cortex	184	3.61	28	77	33
Right	Hippocampus	146	3.49	32	48	33
Right	Frontal pole	87	3.77	36	96	31
Right	Lateral occipital cortex, superior division	73	3.58	26	34	58
Right	Lateral occipital cortex, superior division	68	3.69	30	30	60
Right	Middle frontal gyrus	57	3.73	26	63	65
Hard MCQ (corresponds to red colour in the top row of Fig. 1)						
Right[a]	Lateral occipital cortex	14,060	5.68	57	17	29
Left[a]	Inferior frontal gyrus	6264	4.98	70	73	47
Left[a]	Lateral occipital cortex	2134	4.72	50	26	65
Right[a]	Cingulate gyrus, anterior division	1310	4.99	41	78	49
Right	Frontal orbital cortex	341	4.34	30	79	35
Right	Inferior frontal gyrus, pars opercularis	331	5.83	20	72	49
Left	Frontal pole	224	4.29	51	97	29
Right	Lateral occipital cortex, superior division	196	4.38	31	32	59
Left	Frontal pole	122	4.31	62	92	40
Left	Postcentral gyrus	120	3.42	76	52	55
Right	Postcentral gyrus	79	3.41	21	50	66
Right	Frontal pole	62	4.69	27	92	40
Right	Frontal pole	55	3.83	28	89	28

[a] Cluster list of activations

during complex clinical tasks. The neural activation of left ventral lateral prefrontal cortex (VLPFC) we observed in novices is concordant with previous literature suggesting this area is important for retrieving semantic representations from memory (Cabeza and Kingstone 2006). More specifically, it has been proposed that the VLPFC supports semantic selection in the generation of basic causal explanations and inferences (Barbey and Patterson 2011). Also, we observed greater activation for novices in the left anterior temporal cortex. This area has been identified as being crucial in semantic ability, which is an aspect of long-term declarative memory composed of knowledge acquired about the world such as facts, concepts and beliefs (Cabeza and Kingstone 2006; Rogers et al. 2006). From these data, we can imply novices solve complex clinical tasks with the support of the VLPFC to generate basic explanations and inferences retrieved from semantic memory.

In experts we observed greater activations in the right VLPFC and right DLPFC while diagnosing hard clinical cases. As with the left biased activation seen in novices, the right

Table 2 MCQ: Common areas of neural activation (clusters) for experts diagnosing easy and hard MCQ

Hemisphere	Region	Cluster size	Max Z	MNI coordinates		
				X	Y	Z
Easy MCQ (corresponds to blue colour in the bottom row of Fig. 1)						
Left[a]	Inferior frontal gyrus	12,820	5.4	68	71	47
Left[a]	Lateral occipital cortex	1708	4.5	58	27	63
Right[a]	Lateral occipital cortex	1011	4.43	31	34	60
Right[a]	Middle frontal gyrus	535	4.41	19	76	52
Right[a]	Parahippocampal gyrus, posterior division	411	3.92	34	48	32
Right	Inferior temporal gyrus, temporooccipital part	127	3.67	14	42	28
Left	Paracingulate gyrus	108	4.26	46	80	56
Right	Middle frontal gyrus	93	3.43	28	68	67
Right	Frontal pole	81	3.55	41	92	52
Right	Frontal pole	48	3.42	30	83	59
Hard MCQ (corresponds to red colour in the bottom row of Fig. 1)						
Left[a]	Inferoir temporal gyrus, temporooccipital part	11,407	5.04	70	34	23
Left[a]	Inferior frontal gyrus, pars opercularis	3947	4.51	70	73	48
Left[a]	Lateral occipital gyrus, superior division	2047	4.59	58	28	63
Right[a]	Superior frontal gyrus	1957	4.57	44	83	57
Right[a]	Superior parietal gyrus	1141	4.13	32	37	60
Right	Inferior frontal gyrus, pars opercularis	295	3.76	30	72	47
Right	Middle frontal gyrus	224	4.39	28	66	66
Left	Frontal pole	124	3.91	54	87	53
Right	Middle frontal gyrus	77	3.36	29	62	62
Right	Frontal pole	68	4.41	20	85	30
Right	Frontal pole	61	3.69	28	94	34
Left	Cingulate gyrus	56	3.38	45	64	47
Left	Frontal pole	50	3.42	48	96	41

The same anatomical label appears more than once. The anatomical labels refer to fairly large areas of the brain and our results demonstrate small clusters of significant activations within these larger anatomical areas

[a] Cluster list of activations

VLPFC and DLPFC have also been associated with accessing stored knowledge. However, the pattern of brain activity we observed is in line with theories that suggest that in addition to generating basic explanations, the DLPFC supports evaluation of the options in light of some held normative standard and test for attributions of correctness (Barbey and Patterson 2011). Interestingly, we also observed greater activation for experts in the right parietal cortex—a finding associated with increased attentional demand (Bahrami et al. 2014).

Earlier we outlined that decision theories have postulated that the right hemisphere supports abstract or holistic processing whereas the left hemisphere is more associated with concrete, knowledge based processing (Fangmeier et al. 2006; McElroy and Seta 2004). Applied within the context of our study, where novices activated the left hemisphere and experts the right, it can be suggested that novices make clinical decisions based on concrete representations and experts with more abstract representations. Stated differently, it is

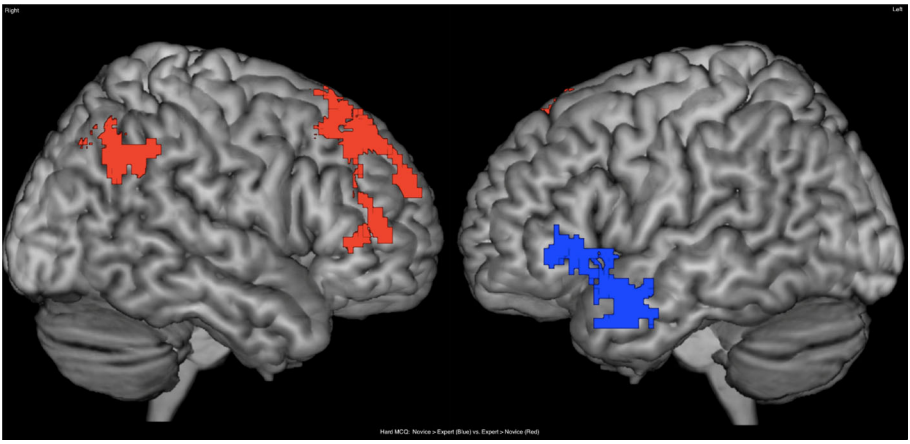

Fig. 2 Novice expert hemispheric differences in decision making. Hard MCQ novice > expert (*blue*); expert > novice (*red*). (Color figure online)

Table 3 Hemispheric differences in decision making

Hemisphere	Region	Cluster size	Max Z	MNI coordinates		
				X	Y	Z
Novice > expert: hard questions (blue colour in Fig. 2)						
Left	Frontal pole	778	4.24	−52	36	−2
Expert > novice: hard questions (red colour in Fig. 2)						
Right	Frontal pole	907	4.69	36	36	48
Right	Angular gyrus	453	4.17	44	−56	38

Novice > expert: hard questions

likely that novices use more concrete representations of semantic knowledge (facts) during decision-making (Cabeza and Kingstone 2006). The left hemisphere, significantly recruited by novices during hard tasks, has been demonstrated as being used when analyzing responses to environmental stimuli presented, in high similarity decision making, for rule based processes, and when using explicit cues for guiding decision making (Krawczyk 2002). Right hemispheric activations on the other hand, significantly recruited by experts on hard questions, have been noted to require prior knowledge and activated in decision-making amongst multiple options (induction); in comparison between exemplars; when decisions are guided internally by choices or based on memory and personal experiences; during ambiguity resolution independent of explicit rules; and during option assessment and categorization or framing of information (Krawczyk 2002; McElroy and Seta 2004).

How do our findings relate back to the medical decision making literature and dual process theories? We suggest the nature of our research design, which explicitly prepared participants to know they would be in a test-like scenario, positioned them to be more cognizant of their decisions. As a result, and in light of speculations that high stake situations or more complex situations force people into type 2 decision making, we propose our findings relate to analytical or type 2 processing. This form of decision-making strategy has been tied to the PFC (Krawczyk 2002), suggesting that more complex problems require

a search of knowledge and experiences and are associated with greater PFC neural activation. As discussed, we found greater PFC hemispheric activation differences during hard questions between novice and experts suggesting there are potentially different analytical decision making processes within type 2 processing; one based on factual knowledge (novices) and the other based on experience (experts). We determined that there were no significant differences in activation between novice and experts for the easy questions; however, this does not mean that the PFC was dormant during these tasks (they were active, as shown in Fig. 1); rather, the activation was equal in both groups. While we provide baseline information for differences in novice/expert neural correlates of decision making most likely attributed to type 2 processing, future studies which continue to vary the cognitive tasks used to more specifically target type 1 and type 2 processes will allow for more breadth and depth of fMRI data to further refine our understanding.

Limitations

Establishing 'baseline' in fMRI research is complicated and is very much dependent on experimental design. Our use of fixation crosses as a contrast as well as Durning's (2012) use of reading as a contrast offer two variations in methodology, making comparison of studies a challenge as these nuances in design affect data interpretation and subsequent results. Future research could include the use of simple opposing tasks as baseline (Goel 2007). Doing so could provide increased awareness of the effects baseline tasks have on data analysis, and could also helpful as a method to determine if analytical or non-analytical processes can be more clearly targeted.

Despite standardized scenarios and MCQs being persistently used in medical education, moving away from this artificially imposed context may be important for determining how clinicians truly make decision in clinical environments (Croskerry 2005). With participants being aware of test like scenarios, increased use of analytical thought by cognitive override could be a confounding concern for truly eliciting type 1 cognitive processes (Croskerry 2009a, b).

Conclusion

The PFC is a fundamental neural area recruited by novice and expert clinicians' in clinical decision making during complex tasks. More importantly we are the first to identify that hemispheric activation differences occur in different clinician levels of expertise with increased task difficulty. We suggest our data could imply there are different analytical (type 2) decision making processes utilized on the novice-expert continuum, where novices use semantic, factual knowledge that is rule-based guided by basic causal explanations, to processes used by experts that are guided by more experiential knowledge allowing for comparison between exemplars by dedicating more attention for evaluative assessment.

Appendix: fMRI basics

Functional magnetic resonance imaging (fMRI) images are made possible by tracking hemodynamic response to neural activity over time (Huettel et al. 2009; Logothetis 2003). When neurons become active in response to a task or demand, hemodynamic changes of

increased blood volume, increased blood flow and alterations in oxygenation occur (Attwell and Iadecola 2002; Heeger and Ress 2002). These changes produce the blood oxygen level dependent (BOLD) signal, which can be simplistically described as a ratio of oxygenated to deoxygenated hemoglobin (Ashby 2011). The underlying assumption in fMRI is that increased oxyhemoglobin concentration indicates nearby neural activity (Savoy 2001).

A block design was chosen for this research, where tasks were presented in a sequential manner with alternating periods of stimulation and rest (Amaro and Barker 2006). Specifically, experimental blocks of clinical decision-making tasks (multiple choice questions), alternated with rest blocks called fixation periods. Fixation periods served as baseline, and can be thought of as a control condition during which no task is being performed (Raichle and Mintun 2006). In fixation periods, no text was presented and no response was expected from participants; it involved simply looking at a plus sign (fixation cross) on the screen for 10 s intervals.

To determine neural areas of activation in clinical decision making, averaged neural activity across fixation trials were contrasted to averaged neural activity in defined clinical decision making experimental blocks (answering MCQ). When differences in level of activation were found to be greater during the experimental phase of the task (i.e. during decision making) than activation during fixation (baseline/rest), neural activity is interpreted as being attributed to the cognitive process of clinical decision making (Amaro and Barker 2006).

Subject data obtained in this fMRI research are representative of each participant's brain. These pieces of data are called voxels, analogous to 3D pixels, and are volumetric in nature (Ashby 2011). Each voxel is represented by 3D coordinates (x, y, z), which are used to identify associated structural areas using brain atlas tools.

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