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Abbreviation:
CI = confidence interval

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What Is Different about a Radiologist's Brain?[1]

PURPOSE: To investigate neuronal activations during processing of radiologic and nonradiologic images by experienced radiologists and nonradiologist subjects by using event-related functional magnetic resonance (MR) imaging.

MATERIALS AND METHODS: Study was approved by local ethics committee, and informed consent was obtained. Radiologic and control images were presented to 12 experienced radiologists (mean age, 35.8 years ± 3.6 [standard deviation]) and 12 nonradiologist subjects (mean age, 33.0 years ± 6.9). Half of the images were artificially manipulated—that is, for example, a local shadow was introduced. Subjects had to indicate whether a visually presented image was original or manipulated, while neuronal activity was assessed by using event-related functional MR imaging. Analysis was performed on the basis of fixed-effects general linear models with correction for multiple comparisons (false discovery rate).

RESULTS: Radiologic images, when compared with control images, evoked stronger activations exclusively in the group of radiologists, notably in the bilateral middle and inferior temporal gyrus, bilateral medial and middle frontal gyrus, and left superior and inferior frontal gyrus ($P < .001$, corrected). Additionally, visual processing of control images (ie, nonradiologic images) differed significantly between experienced radiologists and nonradiologist subjects ($P < .001$, corrected). Radiologists showed strongest activation in the left-dominant more posterior superior and inferior parietal lobule, while nonradiologist subjects showed strongest activation in the right-dominant more anterior superior and inferior parietal lobule and postcentral gyrus.

CONCLUSION: With radiologic experience, there is selective enhancement of brain activation with radiologic images, and the visual system is modified in general.

Experienced radiologists have learned to analyze radiologic images systematically to interpret all findings and establish a medical diagnosis. This perception is different in novice radiologists or nonradiologist subjects who look at such images. The expertise of radiologists is believed to originate from continuous training by seeing many thousands of radiologic patterns and synthesizing them into a coherent, organized, and searchable mental matrix (1). Radiologic images are therefore of particular relevance to experienced radiologists, while nonradiologist subjects are hardly exposed to such specific images.

At the behavioral level, differences between novice and experienced radiologists have been documented (2). For example, the experienced radiologist quickly selects a diagnostic schema, which controls much of the subsequent interpretation of the images. The novice radiologist, however, often encounters problems in schema building and application. Novices seem to be less able to modify a schema in response to added or conflicting data, whereas experienced subjects remain flexible and innovative and modify schemata considerably (1). Moreover, studies of eye movement have indicated that experienced radiologists have high visual efficiency, since they fixate on important abnormalities within 0.5 second (3). It is unclear whether radiologic expertise also modifies the neuronal representation in terms of functional neuroplasticity.

Thus, the purpose of our study was to investigate neuronal activations during processing of radiologic and nonradiologic images by experienced radiologists and nonradiologist subjects by using event-related functional magnetic resonance (MR) imaging.

Author contributions:
Guarantors of integrity of entire study, S.H., E.W.R.; study concepts/study design or data acquisition or data analysis/interpretation, S.H., E.W.R.; manuscript drafting or manuscript revision for important intellectual content, S.H., E.W.R.; manuscript final version approval, S.H., E.W.R.; literature research, S.H., E.W.R.; statistical analysis, S.H.; manuscript editing, S.H., E.W.R.

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MATERIALS AND METHODS

Subjects

The study was approved by the local ethics committee. Twelve radiologists (mean age, 35.8 years ± 3.6 [standard deviation]; 10 men and two women; age range, 30–41 years) with 6.9 years ± 2.8 of experience in radiology and 12 nonradiologist subjects (mean age, 33.0 years ± 6.9; eight men and four women; age range, 25–49 years) with an academic background (studies in economy [n = 6], physics [n = 4], and law [n = 2]) gave their written informed consent prior to inclusion in the study. No significant difference between groups was present with regard to age or sex distribution (unpaired two-tailed t test and nonparametric Mann-Whitney test, respectively). Both radiologists and nonradiologist subjects reported that they had no experience with electron microscopic images, and the nonradiologist subjects additionally reported that they had no experience with radiologic images or other forms of systematic image analysis.

Dominance of right- or left-handedness was assessed by using an online version of the Edinburgh Handedness Inventory (4) (available at *airto.loni.ucla.edu/BMCweb/Consent/edinburgh.html*). Radiologists were strongly right-handed (n = 9), moderately right-handed (n = 1), weakly right-handed (n = 1), or weakly left-handed (n = 1). Nonradiologist subjects were strongly right-handed (n = 8), moderately right-handed (n = 3), or weakly left-handed (n = 1). Subjects had no history of medical, neurologic, or psychiatric disorders.

Stimuli and Task

Twenty radiologic images (radiographic, computed tomographic [CT], MR imaging, and ultrasonographic images) and 20 electron microscopic images (transmission and raster) were selected. Electron microscopic images were chosen as control images because these images are similar in important features, notably that they are also completely artificial images not occurring in everyday life. Since these images are uncommon for most people, emotions or memories are less likely to be elicited when compared with images of, for example, people or scenery. The task of the current investigation was explicitly not to arrive at a radiologic diagnosis, because the focus of this investigation was the processing of trained stimuli, not the process of assigning a medical diagnosis. Further, the comparison between radiologic images and control images, as well as the comparison between radiologists and nonradiologist subjects, would be confounded by the fact that a radiologic diagnosis could be established only for radiologic images and only by radiologists.

Each image was postprocessed by using a pixel-based paint program (Adobe Photoshop; Adobe, available at *www.adobe.com*). Artificial modifications were introduced in small varying parts of all images—for instance, motion filter, mosaic filter, and glass filter. All modifications were intentionally made to be subtle, because we wanted a challenging task that required subjects to actively scan the images for a few seconds. Evident manipulations that pop out in a few hundred milliseconds were not intended. Thus, each image existed in two variants—original and manipulated. Subjects were instructed to decide whether an image was original or manipulated and indicate their decision by using one of two response buttons. Figure 1 illustrates examples of radiologic and electron microscopic images, in original and manipulated forms.

Instructions

All subjects were familiarized with the task demands by using a training program outside the MR imager, with stimuli different from those involved in the experiment. All subjects understood the design of the experiment.

Experimental Setup and Procedure

A video projector was used to project the stimuli onto a translucent screen mounted to the table of the MR imager. Stimuli were seen via mirrors on the head coil. We used a PLUS video projector (PLUS Vision, Tokyo, Japan) with a resolution of 1024 × 768 pixels, which was placed in the control room. The visual angle was approximately 23° (horizontal) × 16° (vertical). The imaging room was darkened during the experiment. The subject's head was immobilized, and noise protection was provided. Two MR-compatible response buttons, operated with the left thumb, were used for the responses "original image" and "manipulated image."

Each run consisted of 10 radiologic images and 10 control images. Half of the images were originals, and the other half were manipulated. Except for these prerequisites, images were presented in randomized order. Each run began with presentation of a visual fixation cross for 10 seconds to compensate for saturation effects. Then, one pseudorandomly chosen image was presented for 8.5 seconds, followed by a fixation cross of 12.5 seconds, to compensate for blood oxygenation level–dependent signal delay and to scatter image acquisition onset relative to stimulus onset (repetition time, 2.5 seconds). One run lasted for 172 scans, or 7 minutes 10 seconds. Each subject underwent two experimental runs, equivalent to 20 images for the radiologic condition and 20 images for the control condition. To avoid putative systematic effects of uncontrolled variables, such as imaginableness, contrast, and plasticity, different experimental sets were created. If image A was presented in original form to subject 1, it was presented in manipulated form to subject 2. In the whole study, all images were presented with the same frequency in original and manipulated forms, and all were presented in the first and second runs. Therefore, any putative systematic differences between the different conditions should have been counter-balanced across all sets.

Since there might be systematic differences between the experienced group of radiologists and the nonradiologist group, such as a general modification of visual processing due to the massive load on the visual system as discussed later, it is not possible to compare directly the activations associated with radiologic images between experienced radiologists and the nonradiologist group. Therefore, the difference in activation between radiologic images and control images in the radiologist group was compared with the equivalent difference in the nonradiologist group. Putative systematic differences between the groups and systematic differences between radiologic images and control images should be cancelled out by using that approach.

Image Acquisition

MR imaging was performed with a 1.5-T imager (Sonata; Siemens Medical Systems, Erlangen, Germany), and transverse functional T2*-weighted MR images were obtained with an echo-planar single-shot pulse sequence. The matrix size was 64 × 64 (field of view, 192 × 192 mm). Twenty-five sections were acquired (4.5-mm section thickness, 1-mm gap), which covered the whole brain. The resulting resolution was 3 × 3 × 5.5-mm voxels. Repetition time was 2.5 seconds, flip angle was 90°, and echo time was 59 msec. The first three volumes were discarded from further analysis to avoid non–steady-state saturation effects. After

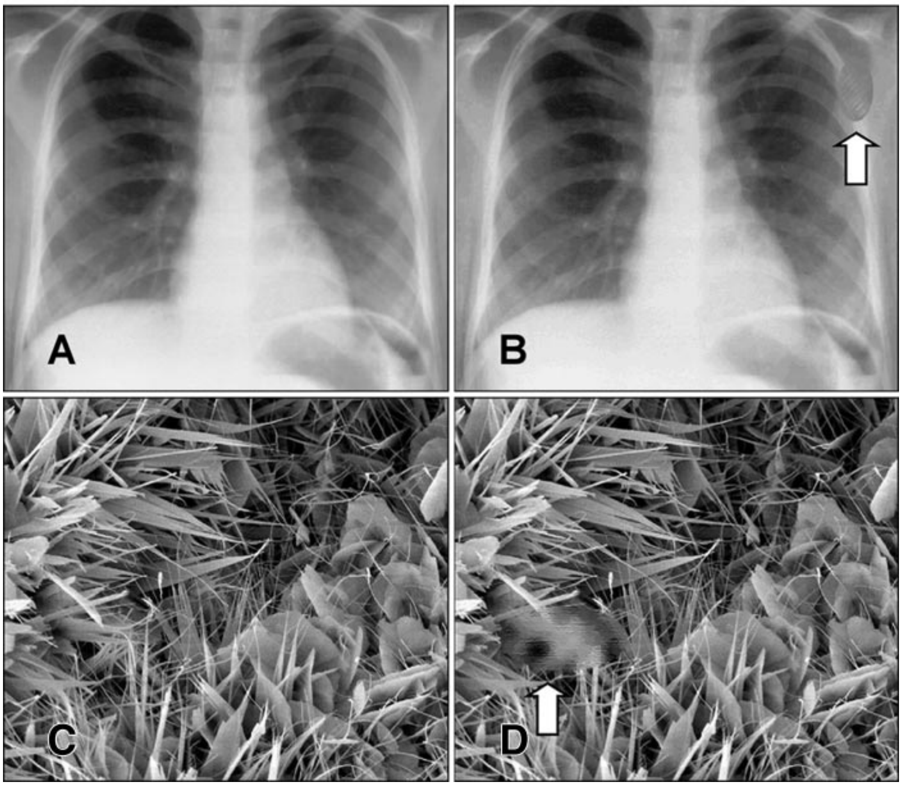


Figure 1. Sample images from our study. Subjects had to decide whether the images were original or manipulated, while neuronal activation was assessed with functional MR imaging. *A,* Radiograph without manipulation. *B,* Manipulated radiograph. *C,* Electron microscopic image without manipulation. *D,* Manipulated electron microscopic image. Arrows denote manipulated areas.

functional MR imaging, high-spatial-resolution data were acquired (1-mm isovoxel T1-weighted magnetization-prepared rapid gradient echo; matrix, 256 × 256; 176 sections; 1900/3.68 [repetition time msec/echo time msec]) for cortex normalization and cortex surface reconstruction.

Data and Statistical Analysis

Analysis of the functional MR imaging data was performed by using BrainVoyager 2000 and BrainVoyager QX (Brain Innovation, available at *www.brainvoyager.com*). Intrasession 1-mm T1-weighted magnetization-prepared rapid gradient-echo images were used as an anatomic reference for Talairach transformation of functional and anatomic images. Additionally, the cortex surface was reconstructed for surface-based statistical evaluation. Section imaging time of functional echo-planar images was corrected, and images were three-dimensional motion corrected by using sinc interpolation and smoothed by using a 3-mm Gaussian kernel. Echo-planar images were transformed into Talairach space (5). One predictor was created for each condition. All 48 functional measurement runs (24 subjects × two runs each) were combined into one general linear model by using separate subject predictors. All activations reported were calculated by using a fixed-effect general linear model and a significance threshold of $P < .001$, corrected for multiple comparisons (dynamic statistical thresholding with the false discovery rate approach) and with an extended threshold of 500 mm^3.

Since the direct comparison of radiologic images between radiologists and nonradiologists might be confounded by systematic differences between groups, this analysis was divided into two steps. In the first step, the differences for radiologists (radiologic images minus control images) and nonradiologists (radiologic images minus control images) were estimated separately. In the second step, these differences were compared between the two groups. Since no positive suprathreshold activation was present in the nonradiologist group, the comparison at the second step (between radiologists and nonradiologists) would be redundant and was therefore not illustrated additionally. Response latency and response accuracy were assessed by using an MR-compatible response box. Individual responses were analyzed by using software (Graphpad Prism, Graphpad; available at *www.graphpad.com*). Response accuracy and response latency for radiologic images and control images viewed by radiologists and nonradiologist subjects were analyzed by using analysis of variance. Additionally, the response latency of the individual events was compared pairwise between the radiologists and the nonradiologist subjects (separately for radiologic and control images) by using two-tailed nonpaired *t* tests (S.H.).

RESULTS

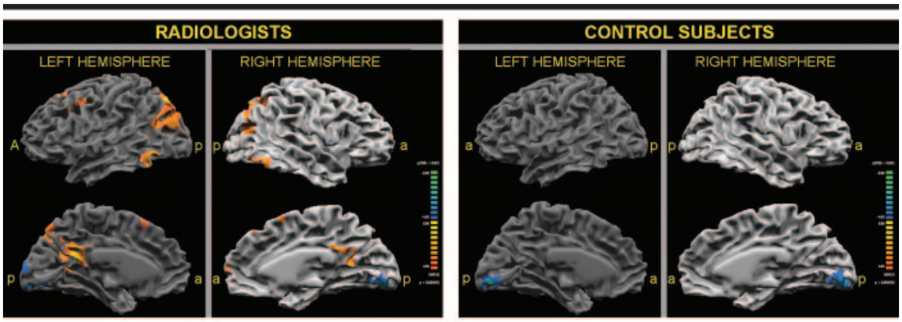
Correct Response and Response Latency

The mean accuracy of the correct response for the original or manipulated image in the group of radiologists was 58.3% ± 16.7 (95% confidence interval [CI]: 48.8%, 67.7%) and 55.3% ± 15.9 (95% CI: 46.3%, 64.2%) for radiologic and control images, respectively. Correspondingly, the accuracy in the nonradiologist subjects was 58.9% ± 8.5 (95% CI: 54.1%, 63.7%) and 52.8% ± 12.5 (95% CI: 45.8%, 59.9%) for radiologic and control images, respectively. The analysis of all individual events showed no significant difference (with analysis of variance) between the groups. The mean accuracy in the group of radiologists and the nonradiologist subjects was significantly above chance level ($P < .05$ and $P < .01$, respectively).

With regard to the response latency, radiologists responded after a mean of 4.96 seconds ± 0.96 (95% CI: 4.42, 5.50) and 4.99 seconds ± 0.85 (95% CI: 4.51, 5.46) to radiologic and control images, respectively. Nonradiologist subjects responded after a mean of 5.33 seconds ± 0.92 (95% CI: 4.81, 5.85) and 5.43 seconds ± 1.09 (95% CI: 4.81, 6.05) to radiologic and control images, respectively. Radiologists were significantly faster ($P <$ .05, two-tailed nonpaired *t* test) when analyzing both radiologic images and control images. On average, radiologists responded 0.404 seconds faster than the control subjects.

Comparison of Radiologic and Control Images

The neuronal activation associated with the visual processing of radiologic images and control images was compared in the group of experienced radiologists and the nonradiologist subjects (see Fig 2). Stronger activations for radiologic images compared with control images were present exclusively in the group of radiologists, notably in the bilateral middle and inferior temporal gyrus, bilateral medial and middle frontal gyrus, and left superior and inferior frontal gyrus ($P <$ .001, corrected for multiple comparisons, false discovery rate). Stronger activations for control images compared with radiologic images were found in both groups almost identically in the bilateral lingual gyrus and right fusiform gyrus ($P < .001$, corrected for multiple comparisons, false discovery rate). Since no positive suprathreshold activations were present in the nonradiologist group, the comparison between radiologists and nonradiologists is not illustrated, as the resulting areas are equivalent to the active areas in the radiologist group. All activations are listed in detail in Tables 1 and 2 and illustrated in Figure 2.



a. b.

Figure 2. Brain activation in the visualization of radiologic images versus electron microscopic images. **(a)** Brain activation in the group of experienced radiologists. **(b)** Brain activation in the group of nonradiologist subjects. Activations were based on a fixed-effects model with a threshold of $P < .001$, corrected for multiple comparisons (false discovery rate) and an extent threshold of 500 mm^3. Stronger activations for radiologic images are indicated yellow and red, and stronger activations for electron microscopic images are illustrated in blue and green. The right hemisphere is a little brighter to ease orientation. *a* = anterior, *p* = posterior.

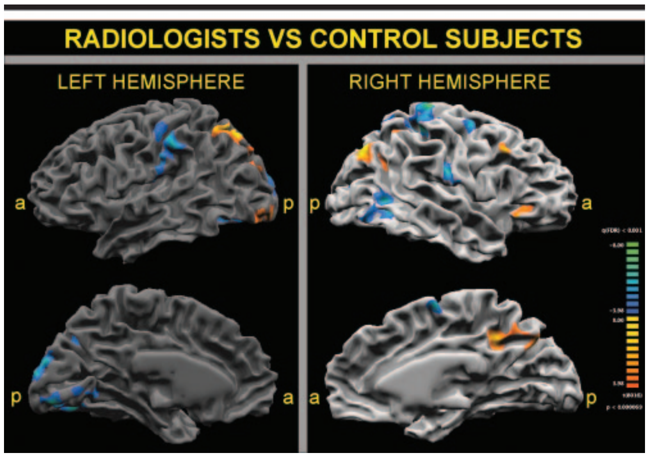


Figure 3. Images show difference in brain activation associated with processing of electron microscopic images by the radiologists versus the nonradiologist subjects (stronger activation in the radiologists compared with the nonradiologist subjects in yellow and red; stronger activation in the nonradiologist subjects compared with the radiologist group in blue and green). Equivalent to Figure 2, activations were based on a fixed-effects model with a statistical threshold of $P <$ .001, corrected for multiple comparisons (false discovery rate) and an extent threshold of 500 mm^3. *a* = anterior, *p* = posterior.

Comparison of Radiologists and Nonradiologist Subjects

The neuronal activation associated with the visual processing of control images (ie, nonradiologic images) was compared between experienced radiologists and nonradiologist subjects. Radiologists, when compared with nonradiologist subjects, showed strongest activations in the bilateral, left-dominant, and more posterior superior and inferior parietal lobule ($P < .001$, corrected for multiple comparisons, false discovery rate). Conversely, nonradiologist subjects, when compared with radiologists, showed the strongest activations in the bilateral, right-dominant, and more anterior superior and inferior parietal lobule ($P < .001$, corrected for multiple comparisons, false discovery rate). All significant activations are illustrated in Figure 3 and listed in detail in Table 3.

DISCUSSION

With regard to the neuronal correlate of expertise, we demonstrated that experienced radiologists differ from nonradiologist subjects in two aspects.

First, there is a specific enhancement in the neuronal activation associated with radiologic images selectively in the experienced radiologist group, which might reflect the particular behavioral relevance of radiologic images to experienced radiologists. Nonradiologist subjects without experience in the field of radiology did not show an equivalent neuronal response to radiologic images. In particular, radiologic experience was associated with enhanced neuronal activations in the bilateral middle and inferior temporal gyrus, bilateral medial and middle frontal gyrus, and left superior and inferior frontal gyrus. Activations in these areas have repeatedly been reported as a distributed cerebral network associated with visual attention and memory retrieval (6–11). Encoding and storing memories of visual objects and events have been linked to medial temporal regions (12). This might imply that radiologic images automatically attract visual attention, and the presented image might be compared with memorized radiologic reference images, although this is neither required nor necessary for the present task. Further, the radiologic reference images might continuously be updated, implementing new aspects of the current stimulus. No equivalent memory store is expected for the control images. Nonradiologist subjects should not have equivalent mental reference images, neither for radiologic images nor for control images—hence, the observed differences in neuronal activations.

Stronger activation for control images

TABLE 1
Significant Activations for the Comparison of Radiologic Images versus Electron Microscopic Images in Experienced Radiologists

Size of Activation Clusters (mm^3)	Maximum t Test Value	Side	Anatomic Structure	Brodman Area	x	y	z
24 317	8.4	Left	Precuneus	7, 19	−17	−63	25
		Left/right	Cingulate gyrus	23, 29, 30, 31			
		Left	Middle temporal gyrus	39			
9955	−7.2	Left/right	Lingual gyrus	18	2	−80	−9
		Right	Fusiform gyrus	19			
7046	6.7	Right	Precuneus	7, 19	28	−69	34
		Right	Middle temporal gyrus	39			
3289	7.3	Left	Inferior temporal gyrus	37	−48	−55	−11
2990	6.8	Right	Inferior temporal gyrus	37	48	−60	−10
		Right	Fusiform gyrus	37			
1926	5.8	Left	Precentral gyrus	6	−42	5	35
		Left	Middle frontal gyrus	9			
		Left	Inferior frontal gyrus	44			
1025	5.2	Left/right	Medial frontal gyrus	8	−1	36	46
968	5.9	Right	Medial frontal gyrus	10	5	53	5
927	5.6	Left	Superior frontal gyrus	6	−3	10	53
514	5.4	Right	Precentral gyrus	6	44	3	37
		Right	Middle frontal gyrus	9			

Note.—Significant activations are based on a cortex-based fixed-effects general linear model with a statistical threshold of $P < .001$ (corrected, false discovery rate) and an extent threshold of 500 mm^3. Columns represent size of activation clusters in cubic millimeters, maximum t test value, side, anatomic region, Brodman Area, and center of gravity of the cluster in Talairach space (5).

TABLE 2
Significant Activations for the Comparison of Radiologic Images versus Electron Microscopic Images in Nonradiologist Subjects

Size of Activation Clusters (mm^3)	Maximum t Test Value	Side	Anatomic Structure	Brodman Area	x	y	z
12 728	−9.5	Left/right	Lingual gyrus	18	2	−81	−7
521	−5.7	Right	Fusiform gyrus	19	15	−51	−8

Note.—Significant activations are based on a cortex-based fixed-effects general linear model with a statistical threshold of $P < .001$ (corrected, false discovery rate) and an extent threshold of 500 mm^3. Columns represent size of activation clusters in cubic millimeters, maximum t test value, side, anatomic region, Brodman Area, and center of gravity of the cluster in Talairach space (5).

compared with radiologic images (higher level of significance and larger size of activation clusters) was present almost identically in both groups in the bilateral lingual gyrus and fusiform gyrus, and most likely reflects physical differences between radiologic images and control images—for instance, radiologic images might be lower in spatial frequency content than the finely detailed electron microscopic images. Putative higher-level differences between radiologic images and control images—for example, differences in emotional content—were small enough such that these differences apparently did not influence significantly the results in areas other than primary visual areas.

Second, we could demonstrate that radiologic experience modifies the visual processing in general—that is, the visual processing of nonradiologic stimuli. This modification might result from the extraordinarily high load and repetitive usage of the visual system by experienced radiologists. Neuronal activations associated with the processing of nontrained images (control images, which a radiologist is not trained to read) between experienced radiologists and nonradiologist subjects revealed several differences between the two groups. Notably, radiologists show peak activation in the bilateral, left-dominant, more posterior superior and inferior parietal lobule, while nonradiologist subjects show peak activation in the right-dominant, more anterior superior and inferior parietal lobule and postcentral gyrus. Activations in the posterior superior and inferior parietal lobule, in particular the bilateral activation in the intraparietal sulcus known to separate the superior and inferior parietal lobule, has been reported for mental rotation of different objects in two- and three-dimensional space (13). This activation has been related to the generation of a mental representation of a visual object (13). The left hemisphere is more strongly involved in mental rotation of more complex stimuli (14). Additionally, the superior and inferior parietal lobule has been associated with attention and spatial working memory (15,16). In the context of the present investigation, one might speculate that experienced radiologists tend to create a mental representation of the presented image and readily activate spatial working memory and attention, allowing radiologists to mentally rotate the presented objects. This might be particularly helpful because radiologic images are often rotated, and the position of anatomic structures may vary. The ability to mentally rotate objects would probably be very helpful and efficient. Conversely, nonradiologist subjects, when compared with experienced radiologists, showed stronger activation in the bilateral right-dominant anterior superior and inferior parietal lobule and postcentral gyrus.

TABLE 3
Significant Activations for the Comparison Group of Radiologists versus Nonradiologist Subjects for Activations Associated with the Processing of Electron Microscopic Images

Size of Activation Clusters (mm^3)	Maximum *t* Test Value	Side	Anatomic Structure	Brodman Area	x	y	z
11 682	−9.6	Right	Postcentral gyrus	2, 3, 5	32	−37	55
		Right	Precentral gyrus	6			
		Right	Superior parietal lobule	7			
		Right	Inferior parietal lobule	40			
9504	12.7	Left	Superior parietal lobule	7	−17	−61	42
		Left/right	Precuneus	7			
		Left	Inferior parietal lobule	40			
7784	−10.6	Left	Cuneus	18, 19	−14	−79	0
		Left	Middle occipital gyrus	18			
		Left	Lingual gyrus	18			
		Left	Fusiform gyrus	19			
6030	9.9	Right	Superior parietal lobule	7	36	−63	36
		Right	Middle occipital gyrus	19			
		Right	Middle occipital gyrus	19			
		Right	Angular gyrus	39			
		Right	Middle temporal gyrus	39			
		Right	Inferior parietal lobule	40			
5745	−7.4	Left	Postcentral gyrus	2, 3, 5	−52	−28	38
		Left	Superior parietal lobule	7			
		Left	Insula	13			
		Left	Inferior parietal lobule	40			
3437	−8.3	Right	Inferior temporal gyrus	19, 37	46	−62	1
		Right	Middle occipital gyrus	19			
		Right	Middle temporal gyrus	39			
2677	10.5	Left	Cerebellum	NA	−32	−80	−17
2458	−6.9	Right	Cuneus	17, 18, 19	17	−83	16
1886	7.4	Left	Middle occipital gyrus	18	−29	−78	22
		Left	Cuneus	19			
		Left	Superior occipital gyrus	19			
1728	11.3	Right	Middle frontal gyrus	8, 9	50	13	37
		Right	Inferior frontal gyrus	44			
1652	−7.3	Left/right	Medial frontal gyrus	6	−3	−4	62
1580	−7.7	Right	Insula	13	50	−21	21
		Right	Inferior parietal lobule	40			
1013	6.4	Right	Inferior frontal gyrus	45, 47	39	23	0
964	5.5	Right	Superior frontal gyrus	9	29	51	26
			Middle frontal gyrus	10			
951	8.6	Left	Cerebellum	NA	−31	−62	−17
759	−8.1	Left	Precuneus	7, 19	−18	−72	37
604	−6.9	Left	Cerebellum	NA	−23	−45	−22

Note.—Significant activations are based on a cortex-based fixed-effects general linear model with a statistical threshold of $P < .001$ (corrected, false discovery rate) and an extent threshold of 500 mm^3. Columns represent size of activation clusters in cubic millimeters, maximum *t* test value, side, anatomic region, Brodman Area, and center of gravity of the cluster in Talairach space (5). NA = not applicable.

The anterior superior parietal lobule has been shown to be critical for the tactile discrimination of objects (17). In particular, the tactile discriminability of an object correlates with activation in the right anterior superior parietal lobule (17), while left hemispheric homologue activation in the anterior superior parietal lobule correlates with maintenance of activation in working memory (17). Nonradiologist subjects, when compared with radiologists, might therefore imagine how the presented stimulus feels. This tactile representation might be a part of the object recognition process.

These observations are consistent with the view that the adult brain has capacity for functional and structural neuroplasticity—that is, the modification of neuronal representation in response to training and experience. In line with the presented results, equivalent interaction of expertise and neuronal activation has been shown in professional musicians. Professional piano players, when compared with control subjects, show smaller motor activation clusters during an overtrained complex finger movement task (18), and professional violinists, when compared with amateur violinists, exhibited higher neuronal activity in the right primary auditory cortex during performance of a Mozart violin concerto (19). Furthermore, structural changes due to extensive experience have been documented. Licensed London taxi drivers, known for extensive navigation experience, show a significantly larger volume of the posterior hippocampi when compared with control subjects who did not drive taxis (20,21).

It is still under debate whether learning decreases neuronal activation—that is, it leads to a lower level of significance and/or smaller size of activation clusters because the brain is more efficient and needs to activate less ancillary areas (18,22). Conversely, training might increase neuronal activation because the brain is more perceptive and has developed the ability to activate ancillary areas, which might improve computation performance (23). Further, simultaneous decrease in neuronal activation in some areas and increase in other areas have recently been shown for acquisition of a new bimanual coordination task—that

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is, a training-related shift of neuronal activations (24). In light of the present investigation, we would argue that learning might enhance neuronal activations in specific regions, as present in the comparison between radiologic images and control images. Additionally, learning may shift neuronal activation, as present in the comparison of control images between radiologists and nonradiologist subjects.

One limitation of the present investigation is that it was designed to address the question as to whether or not learning and experience modify neuronal representations and, if found, to generate hypotheses about the origin of these modifications based on the location of activations and our knowledge from other studies, as discussed earlier. However, future studies are necessary to specifically confirm or reject these hypotheses. For example, a cross-sectional survey of radiologists at various levels of training and experience or a longitudinal study might be able to demonstrate training-related neuroplasticity over time, helping to better understand the mechanisms and evolution of neuroplasticity related to training.

A further concern is the low level of accuracy for the detection of image manipulations, which was only slightly yet significantly above chance level. It is important to realize, however, that as long as the subject tries to solve a task, the neuronal networks necessary for computation of that task will be active, given that the task is not extraordinarily difficult, which might cause frustration and possibly lead to the subject ceasing to perform the task. It is particularly not the case that low accuracy implies low neuronal activations. We considered it more important to use a difficult task, which requires the subject to visually scan the presented images for a few seconds, as confirmed by the reaction times in the range of 5 seconds. We can therefore expect stronger neuronal activations than in an easier task with putatively higher accuracy yet less processing time required by the subjects to detect the abnormalities. Although radiologists responded significantly faster than nonradiologist subjects in the order of 400 msec at the same level of accuracy, this difference should be interpreted with caution, given the low level of accuracy.

In conclusion, with radiologic experience, there is selective enhancement of brain activation for radiologic images and a general modification in the visual system.

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