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Working with Brain Scans : Digital Images and Gestural Interaction in fMRI Laboratory

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ABSTRACT A significant part of functional magnetic resonance imaging (fMRI) practice in neuroscience is spent in front of computer screens. To investigate the brain neuroscientists work with digital images. This paper recovers practical dealings with brain scans in fMRI laboratories to focus on the achievement of seeing in the digital realm. While looking at brain images, neuroscientists gesture and manipulate digital displays to manage and make sense of their experimental data. Their gestural engagements are seen as dynamical phenomenal objects enacted at the junction between the digital world of technology and the world of embodied action.

Keywords digital images, fMRI, gesture, laboratory studies, multimodal semiotic interaction

Working with Brain Scans:

Digital Images and Gestural Interaction in fMRI Laboratory

Morana Alac

Magnetic resonance imaging (MRI) technology is a key modern digital imaging system used for scientific and medical purposes. The goal of MRI is to provide detailed images of the anatomical structure of internal body parts, such as the brain. This technique uses radiofrequency, magnetic fields, and computers to create images based on the varying local environments of water molecules in the body. During an MRI scanning session, hydrogen protons in brain tissues are induced to emit a signal that is detected by the computer, where the signals, represented as numerical data, are converted into visual representations of the brain. A new dimension in the acquisition of physiological and biochemical information with MRI is mapping human brain function, or functional MRI (fMRI). fMRI detects the local changes in magnetic field properties occurring in the brain as a result of changes in blood oxygenation. The measures of the change are translated into visual representations of the activity in the specific brain areas activated during the scanning session.

These 'visual representations of what is not visual' are the concern of the present paper. But rather than discussing their numeric versus visual character, the focus is on the specific ways in which such 'pictures of numbers' (Tufte, 1983) feature in work and collaboration. By recalling Michael

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Lynch's (1991) discussion of optical and digital 'topical contextures', this paper describes how brain scans, despite their visual power, become 'visible' (Goodwin, 1994) for fMRI practitioners, not only through visual perception, but also through the involvement of hands.

Important recent projects in Science and Technology Studies have focused on social and cultural aspects of brain mapping (for example, Beaulieu, 2002, 2004; Alac, 2004; Dumit, 2004; Joyce, 2005; Prasad, 2005a, b). This research has pointed out that a comprehensive understanding of MRI and positron emission tomography (PET) images requires an account of the environment of production and reception of such images. While successfully engaging with questions about objectivity, standardization and generalization, the research remains somewhat remote from the details of individual actions in fMRI practice, and thus leaves questions of 'digitality' (Lynch, 1991), materiality and embodiment unexplored. We do not learn much about the material status that 'digital brains' may conserve or acquire during specific instances of laboratory work and interaction. To address these questions, while staying attentive to discursive constructions, the present paper examines the intersection between scientists and fMRI technology.

By focusing on the ordinary methods that scientists use in daily situations of research, the paper aims to take forward work initiated by 'laboratory studies' more than two decades ago (Latour & Woolgar, 1979; Knorr-Cetina, 1981; Lynch, 1985, 1993; Traweek, 1988). The goal is an 'examination of the methodical way in which observations are experienced and organized so that sense can be made of them' (Latour & Woolgar, 1979: 37). Moreover, in addition to the study of talk and graphical representations (for example, Lynch & Woolgar, 1990), the present paper is concerned with gestural acts (for example, Goodwin 2000b). I look at how the gesture participates in the dynamic, embodied, and often non-representational enactments that feature in the details of *situated action* (Suchman, 1987, 2000) and characterize the work with digital images.

Where the Interaction is

This paper is based on an ethnographic study of two research laboratories that investigate human cognitive processes through the employment of fMRI. Initially, the focus of the study was on documenting activities at the fMRI center where scientists conduct their scanning sessions. The attention was on the ways in which fMRI technology features in collaboration among scientists from multiple laboratories. As the project progressed, my focus gradually moved from the fMRI center to the individual laboratories – work environments where fMRI data are analyzed. The actions in the laboratories highlighted the intersection between scientists and digital screens.

During the study, I observed and recorded working sessions, carried out semi-structured interviews, and gathered documents that ranged from scientific reports to email correspondences and architectural plans. To attend to the interface between the body and technology (Ihde, 2002), my long-term participant observation was combined with an interest in specific occurrences of multimodal semiotic modalities, such as talk, gesture, gaze, and body orientation (for example, Goodwin, 2000a) recorded on digital video, and subsequently discussed with the scientists. While conducting the study, I was a doctoral student in the Department of Cognitive Science and hence a member of the research field. Because of this position, the everyday activities of a doctoral student – attending talks, taking classes, presenting and discussing research results – were not easily discernable from my ethnographic work.

I shall examine two excerpts from the interactional and practical activity in one of the laboratories. The excerpts are drawn from a corpus of 18 hours of video recordings collected during approximately 2 years of fieldwork. Both instances feature interactions between two neuroscientists involved in the identification of an fMRI image artifact.

My attention to ongoing, local practices brings the complex character of 'brain scans' to the forefront. I argue that brain scans feature in everyday laboratory work as sites of interaction.

fMRI Laboratories

The laboratories in which my fieldwork took place – 'Laboratory I' and 'Laboratory II' – study human visual perception, mainly through fMRI techniques. Their primary interest is to localize visual processes in specific brain regions, and to determine ways in which visual stimuli are processed there. Dissatisfaction with commercial 'off-the-shelf' data analysis tools led each laboratory to design its own software. Although the two software suites are different, they both generate 'inflated' and 'flattened' cortical maps, and thus allow for more precise identification and location of brain activation. While the use of such software programs requires specific competencies, the members of the two laboratories emphasize the higher degree of creativity and control over experimental data that such software allows.

During my ethnographic study the number of active members in both laboratories fluctuated from five to ten, with a PhD student (PH) from Laboratory I collaborating with Laboratory II on a project regarding her doctoral dissertation. As she initiated the collaboration, the two laboratories had a long-awaited opportunity to closely compare the two software programs. The design of this kind of software and the related methodological improvements are the way for laboratories to become obligatory points of passage in the research field (Latour, 1988). The comparison between the two software programs, while allowing for some competition between the laboratories, strengthened the possibility of the laboratories' impact on the field, largely dominated by the commercial software. To accomplish the comparison, the PH and the postdoctoral student (PD), who introduced the PH to the software designed in Laboratory II, acted as 'linkages' between the two laboratories. While the contact between the laboratory members remains usually confined to scientific conferences and other professional meetings (members may meet each other when collecting their experimental data at the fMRI center or when serving on various university committees), the PH and the PD – two young female researchers – crossed the laboratory boundaries to encounter the members of the other laboratory in their work environment.

This paper focuses on two short videotaped excerpts from those encounters. Both excerpts come from an early stage of fMRI data analysis in Laboratory I where 'functional' images – low-resolution images that represent cognitive processes – and 'structural' images – high-resolution images that reveal the anatomy of the brain – have to be aligned with each other.[1] This instance of collaborative work and interaction took place between the PD visiting from Laboratory II and the principal investigator (PI) of Laboratory I.[2] In order to carry out the software comparison, the two practitioners used software from Laboratory I to process experimental data previously analyzed with software used in Laboratory II.

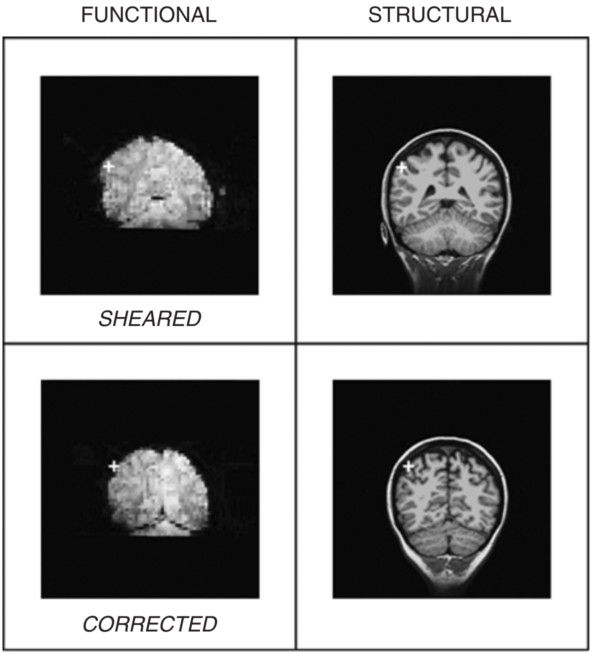
The processing of the same data set with the two software programs was of interest to the practitioners inasmuch as it promised to highlight the differences and potential advantages of one software program over the other. The process was of interest to me inasmuch as it promised to recover the ways in which the collaborative seeing of digital images may be achieved.

Seeing the Brain Image Artifact

During the moments of collaborative work reported here, the PD and PI are seated in front of a computer in Laboratory I. A small functional image is displayed at the center of the screen (Figure 1, upper left-hand side). The use of mouse commands allows the PI to alternate the display of functional and structural images (Figure 1, upper left- and right-hand sides). While rapidly switching between the images, the PI notices a 'shearing' artifact. The artifact is considered to be an intrusion that needs to be removed from the data. In brain-mappers' jargon the image showing the characteristic distortion is said to be 'sheared' (from what is called 'shear strain' in classical mechanics), while the activities dedicated to its reduction are called 'shearing correction'.[3] The elimination and purification of data from artifacts is one of the central aspects of laboratory practice (see, for example, Latour & Woolgar, 1979; Lynch, 1985).

The artifact detected by the PI regards the functional scan. To picture the distortion, two functional images in Figure 1 – upper and lower left-hand side – should be compared. The upper-left portion of the figure features a brain image with an artifact, while the representation in the lower left-hand side shows how a corrected image that represents another layer of the brain may look. As the figure illustrates, the cross sign in the upper-left field is not located on the edge of the brain representation, as is the case for the rest of the images. The discrepancy between the images indicates the characteristic type of distortion. Importantly, the distortion in the single functional image displayed on the computer screen indicates that the functional scan representing the entire volume of the brain is characterized by it. The practitioners believe that this type of distortion, rather than pertaining to the experimental subject's brain or to her/his actions during the scanning

FIGURE 1
Functional and structural images as they appear on the computer screen



session, is relative to the workings of the scanning technology. To deal with the artifact, practitioners direct a group of computational processes to align the functional scan to the structural scan of the same experimental subject (which is not considered to be distorted).

The defining mark of the fMRI culture is its interest in the anatomical specialization of brain regions for processing of different types of information. To create 'brain maps' fMRI researchers project measures of cognitive behavior on the spatial representations of the human brain. Laboratory I and Laboratory II study the visual cortex mapped into complex regions whose different parts are considered to be dedicated to processing of specific visual information. Despite being one of the best-studied parts of the human brain, there are still controversies and disagreements about the existence, general layout, and the extent of some of the areas of the visual cortex. Thus, the proper alignment of functional data with the corresponding anatomical scans is imperative.[4]

Importantly, the shearing artifact that the PI notices was not detected when the data were analyzed in the other laboratory. Thus, the PI demonstrates to the PD how to identify an image that can be classified as 'sheared', and shows how its correction is achieved by using the software designed in his laboratory.[5] As the excerpts from the interaction suggest, the two aspects of the activity are intertwined: the correction itself functions as a part of the classification process, and the classification – oriented towards the practical actions – depends on such processes for its own articulation. An important issue, then, is to decipher what those practical actions entail when the 'stuff' that the scientists are dealing with is digital. As Lynch (1991: 62) proposes in a study of digital image processing in astronomy, in this context I also will 'emphasize implications of digitality that do not turn on the correctness of the visual psychology or epistemology developed in its terms … [and] will argue that digitality is an embodied relation with its own forms of practical efficacy'.

Certainly, the practitioners' actions concern the web of relations that go beyond the digital screen. The fact that the shearing artifact was noticed in the PI's laboratory, while it had been overlooked in the PD's laboratory, has to do with a chain of historical events and disciplinary-specific practices. Those practices, heavily invested in enhanced ways of looking at the human body (for example, Cartwright, 1995), shape and are shaped by the design, development, and use of instruments and technology. For example, it is significant that Laboratory II's 'predecessor' laboratory had conducted research in human psychology rather than physiology and that the software developed there was originally designed for function localization rather than brain mapping. Software designed for function localization enables the user to compute parts of the process automatically, rather than allowing her/him to engage with some of the components of the data manipulation process. Frequently, the user looks only at what neuroscientists call 'regions of interest' rather than inspecting images of the whole brain. It is to be expected that this type of software and the associated techniques for viewing and analyzing fMRI data can lead researchers to overlook certain kinds of image artifacts.

However, local practices with digital images are not simply 'shaped by' and do not merely 'reflect' the dynamics of the encompassing socio-technical network. Rather, they are directly involved in the articulation of scientific evidence. The PI proudly reported that the described sessions of collaborative data analysis led Laboratory II to modify its software so that the inadequacies in the brain images can be 'more easily spotted'. In other words, the moments of local interaction between the two scientists produced consequences for the configurations of technology and migration of techniques from one laboratory to the other, thus generating potential effects on the future appearance of fMRI representations.

Techniques for Seeing

The first excerpt opens with the PI using mouse commands to manipulate the computer screen so that serially organized images can be compared. When he notices that the data were not corrected for shearing in Laboratory II, he sets out to display the distortion for others to see. While doing so he ratifies the rational character of the procedures developed and used in his laboratory. In addition to reporting the practitioners' talk, the transcript details aspects of the bodily conduct as well as the effects of the computer screen manipulation. The way in which the acts of seeing are managed through the temporal and spatial coordination of gesture, talk, and the manipulation of the digital screen is intriguing.

EXCERPT 1

The practitioners' utterances are transcribed following transcription conventions from Jefferson (2004):

=	Equal signs indicate no interval between the end of a prior and start of a next piece of talk.
(0.0)	Numbers in brackets indicate elapsed time in tenths of seconds.
(.)	A dot in parentheses indicates a brief interval within or between utterances.
:::	Colons indicate that the prior syllable is prolonged. The longer the colon row, the longer the prolongation.
–	A dash indicates the sharp cut-off of the prior word or sound.
(guess)	Parentheses indicate that transcriber is not sure about the words contained therein.
(( ))	Double parentheses contain transcriber's descriptions.
.,?	Punctuation markers are used to indicate 'the usual' intonation.

The action line, charter above the talk, follows transcription convention from Schegloff (1984):

o	indicates onset movement that ends up as gesture.
a	indicates acme of gesture, or point of maximum extension.
h	indicates previously noted occurrence held.
t	indicates thrust or peak of energy animating gesture.
r	indicates beginning or retraction of limb involved in gesture.
hm	indicates that the limb involved in gesture reaches 'home position' or position from which it departed for gesture.
p	indicates point.
....	Dots indicate extension in time of previously marked action.
	The transcript below the talk line indicates the temporal change of the digital display:
/ / /	Oblique signs indicate the display of functional images.

Gray square shapes indicate the display of structural images.

1 PI So (you) usually (0.1) at this point (0.5)
/ /
2 I usually do a little bit of shearing (0.1)
/ / / / / / / / / / / / / / / / / / / /
3 to help get the::(.)
/ / / / / / / / /

((The following gesture is a movement of both hands placed as if holding a round object. As the left hand moves up, the right hand moves down. Lexical affiliate is 'sheared'.))

4 o..............
you can see
/ / / / / / / / / /

5 ....a...h....................................
it's sort of (0.5)((the PI looks toward the PD)
/////////////////////////////////////

FIGURE 2

FIGURE 3

6 ....
PD (Interesting)
//////////

7 ....
PI ((the PI turns back toward the screen)) it's sort of =
//

FIGURE 4

8 ....
PD =Yeah
/

9 ....
PI it's actually sh– it's actually sheared
/// ////// //////

((The following gesture is a movement of the left hand placed onto the screen with the thumb and index finger an inch or so apart moving along the border of the brain image. Lexical affiliate is 'going up this way'.))

10 o....p....a...............h..
So – it's going up this way
/ / /

Figure 5

11 ...r.hm
PD Right ((the PD moves her upper body back, and then returns to the initial position))
/ / / /

The PI offsets up the instruction for seeing by saying: 'So (you) usually (0.1) at this point (0.5)=I usually do a little bit of shearing (0.1)'. By saying 'a little bit of shearing' he refers to the procedure of 'shearing correction'. His usage of 'usually' and 'at this point' evokes and manages the sequential order of the laboratory procedures, while the deictic expression 'at this point' also relies upon co-present recipients to 'follow' the unfolding sequence in the midst of its scenic details. Notice the interchangeable use of 'I' and 'you' in 'so (you) usually (0.1) at this point (0.5)' (line 1), and 'I usually do a little bit of shearing (0.1)' (line 2), suggesting a reflexive coupling between 'what is usually done', 'what should be done' and 'what is being done in the current moment of practice'. Similarly, the PI's usage of 'you' in line 3 – 'you can see' – does more than represent the PI's belief that the PD can already see the distortion in the image; it prepares the terrain for a collaborative management of the visual scene. The PD is invited to participate with the PI in an enactment of 'professional vision' (Goodwin, 1994). In and through the techniques used in his laboratory, she will progressively be subsumed under the generic 'you' that can see what he says.

One of the significant aspects of the PI's activity is the rapid alternation of the images on the computer screen. Over the course of the experiment, series of brain images are recorded in which each image represents a brain slice. The PI uses mouse commands to rapidly alternate the images in a series comparing functional with corresponding structural images. The transcript indicates the display of functional images with series of obliques, while the presence of structural images is represented with gray rectangular shapes. When the PI detects a particular non-alignment among images, he refers to the shearing artifact. The artifact is thus relative to the image series. Likewise, identifying the artifact – ostensively governed by methodological prescriptions – requires a skill that involves a fine coordination of eyes and hands.

The opening of the excerpt is characterized by an active search through the image series (lines 1–3). When an appropriate functional image is identified (line 3), the PI utters 'you can see it's sort of' (line 4–5). The PI then places both of his hands in the space located between the two practitioners and the computer screen. He uses his hands to enclose a portion of the void space as if holding a round object (Figure 2). He then moves his left hand up while his right hand moves down (Figure 3). Throughout the activity his two hands conserve the shape in which they were placed at the beginning of the gestural enactment.

In line 5 the PI turns towards his addressee, and in line 6 the PD signals her understanding and the co-participation in the activity. But while turning toward the PD, the PI's hand remains in the position assumed during the previous gesture (Figure 4). The steady hand position is significant, as it links the enactment carried out in line 5 with its lexical affiliate – 'sheared' – which is pronounced only in line 9. As described by Emanuel Schegloff (1984: 275), ' … the gesture – both its onset and its acme or thrust – precedes the lexical component it depicts'. Thus, by 'projecting' aspects of possible later productions, the gesture makes them available to analysis by a recipient before their actual occurrence (Schegloff, 1984: 267).

To understand the organization of the discursive action, however, one needs to take into account the tight temporal coordination between the PI's talk and gesture with his alteration of the images on the computer screen. In line 7, while keeping his left hand in the 'frozen' gesture, the PI reinitiates to search through the image series. He utters the lexical affiliate of the 'shearing gesture' only when an appropriate functional image is displayed on the screen (line 9). At this point, the PI remobilizes his gesturing hand to enact another shearing (line 10). The second gesture is located in an immediate vicinity of the computer screen. Therefore, holding the gesture through lines 5–9 also links the gestural enactment in line 5 with its subsequent elaboration in line 10.

The linkage between the already executed and the future enactment starts with an indexical component (line 10). When the PI directs his left hand toward the computer screen, he briefly points with his index finger to the upper-left portion of the image (Figure 5). After pointing to the image, the PI performs the second 'shearing gesture'. He places his thumb onto the screen, and, while holding his thumb and index finger an inch or so apart, he carefully moves his hand across the screen (Figure 6). During the execution of the gesture, he keeps his right hand on the computer mouse to alter the images on the screen and orchestrate the entire performance (see, for example, Whalen et al., 2002). The PI's talk, gestures, and his engagement with the computer are tightly organized through their mutual reference. The organization not only concerns the coordination between gesture and talk, but it also coordinates the practical activity at hand.

Gesture, talk and the manipulation of the digital screen function together as techniques for managing perception.

Coordination of Digital Screens with Bodies in Action

Particularly salient elements of the interaction are the two gestures executed in lines 5 and 10. The gestures, together with practitioners' talk, gaze, and body orientation turn the physical space occupied by the practitioners into a field of meaning production. In the context of laboratory practice, the multiple 'semiotic fields' (Goodwin, 2000b), such as the field of the digital screen and the one inhabited by material bodies, are superimposed and intertwined. The way in which the images are aligned with the gestures, body orientation, gaze, and talk suggests an action-oriented, publicly available, and intersubjective character or seeing.

The first gesture – the gesture enacted in line 5 – is performed at a relative distance, but in front of the brain image. Whereas the digital image provides a rich substrate for the action and allows for the potentially numerous interpretive paths, the gesture functions as an 'eidetic' mark that 'brings into relief the essential, synthetic, constant, veridical, and universally present aspects of the thing "itself"' (Lynch, 1990: 163). At the same time the practitioners' orientations toward the screen, their talk, the alignment with the digital images, and the general context of the practice constrain the interpretation of the gesture. Even though the gestural enactment does not take place in synchrony with its lexical affiliate, the PI's orientation toward the screen displaying a functional image, and his talk (his saying 'you can see' in line 4, for example) – embedded in the context of the practical problem solving – indicate that the gesture is about the feature in the images.

The same is true for the gesture performed in line 10 (Figure 5): the gesture's meaning is relative to the ongoing activity and the laboratory setting in which it is lodged. Here, however, the visibility of the shearing is generated through a physical coupling between the gestural enactment and the digital images. The gesture marks the salient feature in the images by touching and moving across the computer screen. However, its enactment does more than reveal features of the images to the PD. The gesture is also implicated by the PI's coordination and comparison of the images.

The gesture first touches the screen just as the functional image is replaced by the structural one. During the gestural movement across the screen, the display is alternated again, and the functional image appears. Through the activity, the gesturing hand links the appearance of the cross (a sign that marks the corresponding spot in the series of brain representations – see Figure 1) in the structural image with the corresponding sign in the functional image. This allows the PI to 'enact a memory trace' across multiple images and single out the exact location of the misalignment. The articulation of visibility through the coordination of hands, eyes, keyboard device, and the digital screen is part of the local act of problem-solving. The PD 'learns to see the shearing' not only by looking at the images, but also by participating in the articulation of the space that surrounds the two practitioners. The process of learning and understanding is one of participation: it situates the practitioners within the visual field, not outside it.

Seeing Dynamic Phenomenal Objects

The digitality of images reflects their dynamic character – not only in the nature of the images, but also in the ways that they are dealt with. The observed coordination of the bodies and technology has a salient temporal dimension. PI's rapid alteration of the digital images generates the appearance of motion so that discrepancies among the images can be understood in terms of a unified whole. The apparent motion is coupled with the PI's utterance: 'it's going up this way' (line 10). The utterance is an expression of what proponents of Cognitive Semantics call 'fictive motion' (for example, Talmy, 2000): it organizes perception in terms of motion and change, even though the described entity – the fMRI image – is static.

Importantly, the PI also enacts motion in the space of material bodies in action. His gesturing hands in line 5 do not directly 'represent' a distorted round object. Instead, they enact a process of transformation of a round object. Likewise, in line 10 they do more than index a feature in the image: the gestures participate in the interpretive act as an embodied enactment of the process of change. The dynamic quality of the act provides an account of how the distortion came about: the gestures generate explanations of the distortion in terms of a three-dimensional (3D) object that is vertically sheared.

The practitioners I studied know that the 'shearing' of the image is a consequence of an abstract computational transformation. Even so, their semiotic enactments indicate concrete, physical transformations. In other words, their practical accounts of the experimental data are given in terms of objects that can be seen, experienced and dealt with, rather than in terms of causal and abstract explanations.

It should be noticed also that the dynamic embodied account of how the distortion came about implies that the process may be reversed by applying vertical shearing in the opposite direction. The enactment not only performs what happened in the past, it also evokes future practical actions. The next section will illustrate in detail the action of applying shearing in the opposite direction. In fact, this is a process through which the practitioners understand the work that needs to be done to correct the distortion.

Inasmuch as they are about future practical actions, the enactments bring to mind some aspects of Heidegger's distinction between things 'present-at-hand' (*Vorhandene*) and things 'ready-to-hand' (*Zuhandene*). The two practitioners do not represent sheared features as objective properties that can be passively contemplated. Rather, they enact those features as manipulable things that 'subordinate themselves to the manifold assignments of the "in-order-to"' (Heidegger, 1962 [1927]: 98). As lines 5 and 10 indicate, the relevant feature of the fMRI scans is first made manifest through the activity that mimics a direct engagement. The sheared feature becomes visible as a thing encountered through 'circumspection' – a purposeful way of acting without the necessity of having a purpose in mind (see Dreyfus, 1991: 73). However, rather than allowing the images to fade away through such an interaction,[6] the enactment of the sheared object generates visibility of the images.

Making the Work Visible

After making the artifact publicly available through enactment of the 'in-order-to' structures that show themselves only in practices, the purification of the experimental data needs to be explicated in a step-by-step fashion. The practitioners deal with fMRI images – the digital structures that generate the effects of manipulability – to access the data by making the work visible. In other words, the features of fMRI images become perceivable in terms of the work, structured by the disciplinary expectations and the routine practices that have developed for the accomplishment of the task, and made publically available through the interaction between the digital images and gestures.

EXCERPT 2

((The following gesture consists of two short clockwise motions articulated around wrist. The hand, positioned next to the computer screen, is formed as if holding a round object)).

12 o...................t....t.....
PI You rotate (into the into)

FIGURE 7

13 h....................
so that you know (.)

((The following gesture first indexes a left portion of the brain image and then indicates up.))

14 o...................p...........................p
(so that) the expanded part is sort of=

((The following gesture is performed as if drawing two axes. Lexical affiliate is 'axes'.))

15 o..a…………a……
in one of the axes

((The following gesture is a grasping motion. Lexical Affiliate is 'squish'.))

16 o………..t…….
(.) and you squish

FIGURE 8

((The following gesture is a counterclockwise motion articulated around wrist. Lexical affiliate is 'rotate back'.))

17 o………………t…………..
and then (you) rotate back

FIGURE 9

((The following gesture is an abrupt opening of the hand. Lexical affiliate is 'un-squish'.))

18 o.t…………r….hm
(.)and un-squish ((turns toward the PD))

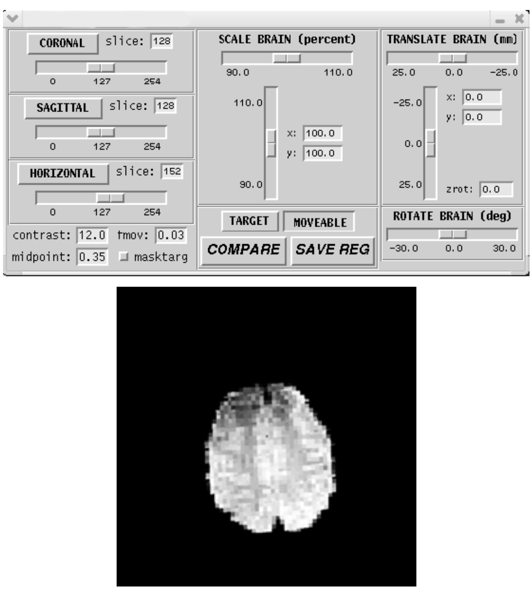
FIGURE 10

19 so: rotate 30 degrees, shrink vertically, rotate back, stretch vertically ((turns towards the PD and smiles.))
20 PD: Uh-huh.

The organization of the activity described here is shaped by the way in which the software program designed in Laboratory I works. Because of the program's limitations, the fMRI image series cannot be automatically corrected. Instead, a sequence of transformations is required to achieve the correction announced by the gestures in lines 5 and 10 (Excerpt 1).

Figure 11 shows a detail of the computer screen when the shearing artifact was being corrected. The correction requires the user to interact with

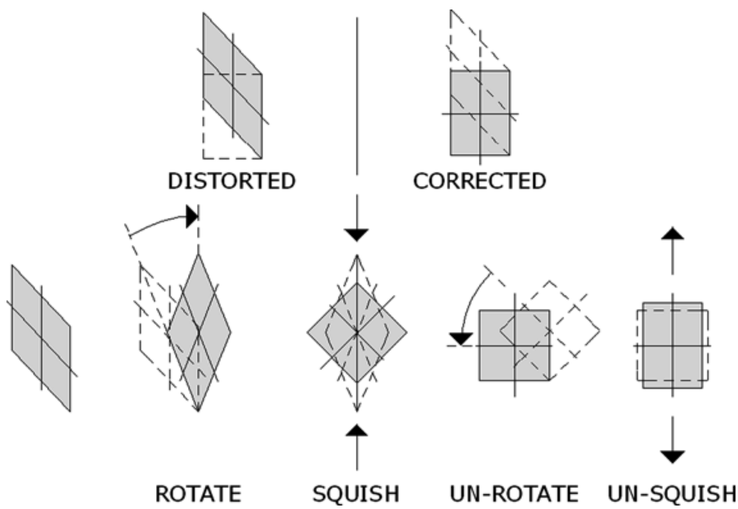
FIGURE 11
Detail of the computer screen during the shearing correction (proportions have been modified to enhance the visibility of the menu)



the scroll bars via mouse commands to direct mathematical transformations on the digital data. The transformations of the digital data are indicated in the visual format: in response to the manipulations of the command menu, the brain images appear modified.

Once the shearing artifact is detected in the images, four consecutive commands need to be selected. First, the scroll bar labeled 'ROTATE BRAIN (deg)' needs to be 'moved' towards the right. When this is done, the vertical scroll bar labeled 'SCALE BRAIN (percent)' has to be moved down. The third command is the movement of the scroll bar 'ROTATE BRAIN (deg)' towards the left. And finally the horizontal scroll bar 'SCALE BRAIN (percent)' has to be moved towards the right. The commands' function is illustrated in Figure 12. To make the distortion more easily perceivable, the Figure represents the brain image in a schematized rectangular rather than a round form.

Figure 12
Schematized representation of the four stages of shearing correction



However, like the brain images on the screen, the figure is a partial, two-dimensional (2D) representation of the experimental data.

Despite the appearance of the 2D representations on the computer screen, the practitioners need to work with 3D data. They need to perform the changes on something that is more akin to a series of 2D images than to a single 2D representation. The procedure requires significant expertise. The practitioners need to infer the shape of the 3D object before and after it is digitally modified while looking at a 2D fMRI image. The design of the computer interface allows them to do so with the scroll bars and labels, which evoke a sense of physically manipulating 3D objects – for example, with the command 'rotate brain'. Note that these features only evoke objects and actions; the environment in which the interaction between the user and the experimental data takes place is a 2D digital space.

Similar to the computer commands and labels are PI's linguistic expressions – 'rotate' (line 12), 'squish' (line 16), 'rotate back' (line 17), 'un-squish' (line 18), 'shrink vertically' and 'stretch vertically' (line 19) –

which evoke a sense of physically manipulating objects. But to engage 3D data in an immediate manner the practitioners have another resource at hand: the space of gestures and embodied semiotic interaction.

In line 12, the PI places his right hand on the computer screen and rotates it clockwise (Figure 7). Next, in lines 14–15, he explains that the rotation has to position the brain image so that its expanded part is located in a vertical position ('on one of the axes'). He points briefly toward the brain representation and then upward (line 14). The enactment is followed by a gesture of an ephemeral representation of the two Cartesian axes (line 15). This position is crucial for the next step of the transformation ('squishing'), in which a vertical force is enacted. The gestures in lines 16–18 mime the acts of 'squishing' (Figure 8), 'rotating back' (Figure 9), and 'unsquishing' (Figure 10). After performing the four-step transformation, the PI turns towards the PD to check that she has been following of the action. The PI's bodily movement and the PD's affirmation ('Uh-huh', line 20) mark the completion of the meaning-making unit.

An analogous activity was recorded in the laboratory 2 months earlier, during another instance of data analysis. The PI and two graduate students were seated in front of the computer screen when the PI noticed a distortion in the fMRI image. While orienting toward the computer screen, the PI described how the distortion should be corrected:

EXCERPT 3

((The following gesture is a counterclockwise motion of the right hand articulated around wrist. The hand, positioned in the immediate vicinity of the screen, is formed as if holding a round object. Lexical affiliate is 'rotate 30 degrees this way'.))

21 o……….t……………………………
PI (.)If you rotate 30 degrees this way

((The following gesture is a motion articulate with two hands as if holding an object and slightly pushing it from both sides. Lexical affiliate is 'squash'.))

22 o ………..t……...
and then squash

FIGURE 13

((The following gesture is a clockwise motion articulated with both hands as if holding a round object. Lexical affiliate is 'un-rotate'.))

23 o............t...........
and then un-rotate

FIGURE 14

((The following gesture is an abrupt opening of the right hand. Lexical affiliate is 'un-squash'.))

24 o.....t............
and un-squash.

The semiotic action performed here is quite similar to the one in the previous excerpt, except for the fact that the PI in that instance persistently gestures with one rather than both hands, and starts the enactment with a clockwise rotation. The rituality of the performance reveals the tight connection between semiotic enactments and the world of instruments and other technologies. The semiotic enactment is contingent on the design of the computer screen and the 'usual' laboratory activities.

At the same time the ritual performance highlights the pervasiveness of the gestural enactment in the management of perception. The PI reaches toward the computer screen and acts as if he were holding an object and moving it towards the left/right (lines 21 and 23). Similarly, he enacts the action of 'squashing' the image as if he were squeezing a 3D object (line 22). By enacting the physical manipulation on the fMRI data, the gesture participates in the production of visibility by making the encounter with the phenomenal object possible. Whereas in lines 5 and 10 (Excerpt 1) the two shearing gestures participate in the enactment of phenomenal objects, so that the future work on such objects can be grasped, here the gestures participate in the performance of the exact steps in such work. Thus, the interaction renders the future work not only graspable, but directly perceivable and publicly shared.

Blurring the Boundary Between the Digital World and the World of Practice

Despite the PI and PD's orientation toward the computer screen, not everything is available there. As mentioned earlier, the PI's command selection has consequences not only for the brain slice displayed on the screen, but also for the data representing the whole brain. How do the practitioners deal with what is invisible on the screen? The interaction between the practitioners and the digital screen recovers complex acts of coordination, delegation, and selection. These acts are involved in an enactment of hybrid phenomenal objects.

One could speculate that the problem of invisibility would be solved by designing a visual display that would reveal at once all the richness of the data – 'it is only a matter of time and technology'. Regarding this point, the PI remarked that if in fact all the layers of the 3D data were displayed (while discussing this point he evoked an image of a 'translucent cabbage') their richness would overwhelm the viewer, who would then be unable to deal with the scene. Instead, including the gestural action in the process presents the viewer with a form that evokes the 3D character of the data, while leaving the potentially overwhelming detail concealed.[7]

When talking about 'gestural action' one should, however, not assume that the single semiotic modality carries the meaning on its own. The gesture is rather poor when considered in isolation. The gesturing hand is shaped as if holding a 3D object, but without its interaction with the other semiotic resources, the enacted object remains generic: there is nothing intrinsic to the gesture that defines the object as a brain. Similarly, the images are completely static: they simply exhibit assumed positions before and after their computational manipulation. The linguistic labels displayed on the screen and referenced in the PI's utterances describe motion, but nothing is moving on the screen. The richness of the process, instead, comes from the interaction.

In this regard, the specific location and dynamic qualities of the gesture are significant. Their unfolding takes place in close proximity to the computer screen. The gesturing hand, accurately positioned around the visual contours in the brain-slice representation, touches the digital screen while it enacts 'rotation', 'squishing', and 'squeezing' of a round object. Moreover, the sense of time and movement is generated through the gesturing hand and the manipulation of the screen. The process is accompanied by the PI's verbal labels of the movements as 'rotation', 'squishing', and 'squeezing'.

Bringing together gesture, talk, and the structure in the environment (what Goodwin [1995, 2000b] calls 'environmentally coupled gestures') is not simply a cumulative process. The interaction entails acts of selection and delegation. Although the practitioners know that the shearing correction needs to be accomplished through the mathematical manipulation, the abstract computational processes, which are not accessible through direct inspection but actually performed on the digital data, are largely delegated to the machine. While they consider the numerical data and the mathematical processes to be the central and omnipresent in their practice (see Beaulieu, 2002), the practitioners do not access them directly while working with 'digital brains'. Rather, those invisible layers are indexed by the PI's gestural enactments, tightly coordinated with the digital images and conceived as performances of practical actions. The enactments – which depend on the digital images – generate a sense of physical engagement, even though the digital images cannot be physically manipulated – nothing like the ordinary sense of the words 'rotation', 'squishing', and 'squashing' is performed on the data.

This type of activity suggests that the practitioners deal with hybrid structures. Instead of referring to numerical data, digital images, or physical objects, they engage with multifaceted phenomena that change through time.[8] In other words, the experience allows the practitioners to grasp the nature of the distortion and its correction by encountering something that is simultaneously material and digital, concrete and abstract, human and machine, 3D and 2D, action and object, present and future.[9]

Hybridization of Digital and Physical as Practical Engagement with Experimental Data

It has often been pointed out that the involvement with the digital screens transposes the user into an alternative realm – a realm of fiction. To engage with the digital data in an immediate manner, the user needs to 'project her/himself on the other side of the screen or pass through the screen to enter the virtual world of fiction' (for example, Morse, 1998; Lister et al., 2003; see also Turkle, 1995).[10] By analogy, it could be claimed that the fMRI practitioners' semiotic accounts of enacted hybrid objects are imaginary, fictive, or metaphoric renderings instantiated in the public space of action.

Several recent studies have dealt with the problem of imagination as a public process accomplished through the coordination of participants' conduct and the material world of their practice (Nishizaka, 2000, 2003; Suchman, 2000; Murphy, 2004, 2005). In the examples they provide, the participants treat what is imagined and enacted in the interaction space – a loading dock (Murphy, 2004, 2005), submarines' routes in a computer game (Nishizaka, 2003), or a highway (Suchman, 2000) – as something that has potential for future existence: the loading dock could be constructed, the submarines could be visualized as taking an alternative route on the computer screen, the highway could be lowered and the earth could be removed.

In the shearing example, however, the public performance is not conceived as imaginary, nor is it seen as something that could exist outside its local enactment. In fact, we may not even be able to imagine or 'see in front of our mind's eye'[11] something that is simultaneously 2D and 3D, abstract and concrete, digital and material.

At the same time, and despite the hybrid character of their publicly enacted objects, the practitioners treat them as real and ordinary. While tacitly 'asking' practitioners to partially delegate their work to the machine, the production and understanding of multifaceted phenomenal objects provide practitioners with a sense of direct engagement with their experimental data. The negotiation and hybridization between the digital and the physical is a practical way to understand and deal with the world.

Discussion

There is a substantial body of literature that deals with vision as a situated and interactionally organized phenomenon (for example, Goodwin, 1994, 2000c, 2003; Heath & Hindmarsh, 2000; Hindmarsh & Heath, 2000; Nishizaka, 2000; Suchman, 2000; Ueno, 2000). Following this line of research, the present work discusses 'seeing' as a process situated at the intersection between instruments and technology, practices, settings, and the practitioners' embodied accounts. It describes how the local management of seeing invokes previous dealings and cumulative practical know-how, and how it receives its rhetorical force by reference to the 'usual' procedures of laboratory members. These procedures are nested in larger, historically evolving, socio-technical networks whose specifications are bound to the locally instantiated assemblages of instruments, embodied techniques, and everyday discourses in the laboratory (see, for example, Lynch, 1993).

The specific focus of the paper, however, is on the achievement of seeing in the digital realm. The excerpts we examined recover the complexities in the practical dealings with brain scans. 'Seeing' of brain images is about engagement that requires coordination of scientists and digital technology in the context of fMRI practice. The PI's embodied accounts of shearing not only function as indexical signs or transient inscriptions imposed on the computer screen to categorize and make the features of images visible. They also instruct the PD on how to spot the image artifact by enacting what should be done, can be done, and usually is done in the PI's laboratory.

These 'acts of seeing' explore a border between the virtual and the physical, 2D and 3D, abstract and concrete, past, present and future: they generate emergent properties and distributions of agency. The enacted phenomenal objects provide practitioners with a sensation of rotating, squishing, or squashing something, even though nothing is being rotated, squished or squashed. The PI and PD talk about, see and experience a round object that changes and is being changed through time while they interact with menus on a computer screen – to display 2D brain scans and to direct invisible mathematical transformations on them.

Understanding the artifact and its correction by enacting a hybrid object that moved and needs to be rotated, squished, and squashed is a part of practical problem-solving in the PI's laboratory as well as a component of his 'powerful seeing'. Not only does the PI's reading of the images prevail through moments of local interaction: it also participates in propagation of the embodied techniques and the methods of organizing the tools and instruments practiced by his research group. As pointed out by the PI, the interaction with the PD left traces in practices for managing scientific facts beyond the walls of his laboratory. But would this have been possible without the PD's willingness to cross the laboratory boundaries and participate in the act of collaborative seeing?

Concluding Remarks

Jonathan Crary (1990), among others, has pointed out that the introduction of computer-generated imagery leads to something he calls 'abstraction of the visual'. He proposes that digital images, unlike traditional analog media such as film, photography, and television, are not relative any longer to a point of view 'located in the real space':

> Computer-aided design, synthetic holography, flight simulators, computer animation, robotic image recognition, ray tracing, texture mapping, motion control, virtual environment helmets, magnetic resonance imaging, and multispectral sensors are only a few of the techniques that are relocating vision to a plane severed from a human observer. … Most of the historically important functions of the human eye are being supplanted by practices in which visual images no longer have any reference to the position of an observer in a 'real', optically perceived world. (Crary, 1990: 1–2)

While one might think that this 'abstraction of the visual' and the difference between new digital and traditional analog media necessarily entail a disembodiment of the digital image user, interactions in the MRI laboratory reveal a somewhat different state of affairs. During the moments of work and interaction, digital brain images are coupled with practitioners' bodily orientations, gestures, and talk. Practitioners' read the experimental data in terms of embodied actions that take place at a level comparable to physical, real-world engagement. Rather than estranging them from a direct engagement with objects, reading digital images enables them to re-enter a world of culturally meaningful embodied actions.

In this sense, 'seeing' of fMRI images is an embodied process achieved through a coordination of 'visual' information with the world of meaningful actions and practical problem-solving. In other words, the visibility is not only relative to what goess on inside the practitioner's head or to what is present on the screen. Seeing is tied to actions that arise out of experiences with the manipulation of objects and everyday practical dealings.

Research in human–computer interaction (HCI) has pointed out that because of their aptness for understanding, the products of scientific visualization – including fMRI images – provide the human user with a significant power in handling abstract data.[12] Rather than dealing with an enormous amount of numbers, digital images allow scientists to solve the abstract task in the visual realm. Just as important, fMRI images are 'visual' and 'visible' versions of what previously was not visual, inasmuch as they allow the practitioners to deal with the invisible in a practical manner. The excerpts I have presented indicate how the laboratory setting and the human encounters within it provide practitioners not only with an abstract sense of vision, but also with a way of seeing digital images that involves the hands as well as the eyes. Such acts of seeing concern the enactments of the dynamic and multimodal objects in the practice of fMRI.

Notes

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1. The fMRI images that we usually encounter in research journals, popular media, or the Internet frequently feature brain representations in black and white with colorful spots on them – usually in blue, green, yellow, and red. These images are a result of a merging process between structural and functional images.
2. The PI was also one of the main designers of the software used in his laboratory.
3. To picture the distortion one can consult its schematized rendering in the upper portion of Figure 12.
4. During the early stage of data analysis described here, the two practitioners analyze scans pertaining to one experimental subject. Even though the members of the two laboratories publish fMRI images that represent the brain of a single individual, a more frequent practice is to collect data from a series of subjects and publish images showing averaged data. When fMRI data are averaged across subjects, the practitioners align the data to a 'common space'. Usually they align the structural scans to a standard template (one example is the 'Talairach's coordinate system of the human brain where the representations of the single brain are projected, via the registration procedure, to 'Talairach brain'; see Talairach & Tournoux, 1988) and then copy the parameters to the functional scan to translate it in the new space (with commercial software it is also possible to directly co-register the functional scans to the common space). Thus, the reduction of the shearing artifact in the early stages of data analysis, even though not directly related, is in fact implicated in fMRI images even when those images represent 'averaged brains'.
5. Kelly Joyce pointed out that in order to see artifacts in MRI images radiologists need to ' … train their sight over time' through ' … interaction with other physicians, texts, and machines' (Joyce, 2005: 449).
6. The concept of 'ready-to-hand' is frequently referred to in the literature on interaction with technology. See, for example, Dourish (2001: 109) and Suchman (1987: 53).
7. This certainly does not deny that an expert has no need to resort to such public resources. But it does point out the public grounding of expertise.
8. The importance of hybrid semantic structures in human understanding has been pointed out by Conceptual Integration Theory (Coulson, 2000; Fauconnier & Turner, 2003). Rather than accounting for stable knowledge structures represented in long-term memory, the theory identifies systematic projections of language, imagery, and inferential form to model the dynamic evolution of speakers' on-line representations (Coulson & Oakley, 2000). The semiotic enactments of shearing artifact share some features with the process of conceptual integration. The hybrid semiotic construct is at the same time about the brain image that indexes the experimental data, and the embodied multimodal performances that make such data and their manipulations publicly available. Mutual reference and integration provides access to the problem solution in terms of ordinary actions. The practitioners deal with the experimental data and their correction by performing round objects that share some visual features with the digital image and are being rotated, squished, and squashed, even though neither the digital data nor the fMRI images can be subjected to those operation. The process of hybridization is largely generated in the social space of action. Rather than being exclusively mental phenomena internal to single individuals, as it is largely the case in the usual applications of the conceptual integration theory, important elements

of the production of visibility involve integrations between multiple semiotic fields generated through the use of gesture, digital images, and body orientation as features of the practical problem solving. For a related account, in which only one of the semantic spaces is a material phenomenon, see Hutchins (2005).

9. Ochs et al. (1996) describe somewhat similar phenomenon – a blending between the scientists and the objects of their study – as 'referentially ambiguous entities'.
10. For an example of the popular rendering of the idea, see the 1982 Walt Disney Productions science fiction film *Tron* directed by Steven Lisberger.
11. Nishizaka (2003) contains a comprehensive discussion and critique of the idea of mental image.
12. Neuroscientists themselves often point out that the largest part of the human visual cortex is dedicated to processing visual information.

References

Alac, Morana (2004) 'Negotiating Pictures of Numbers', *Social Epistemology* 18(2): 199–214.

Beaulieu, Anne (2002) 'Images are Not the (Only) Truth: Brain Mapping, Visual Knowledge, and Iconoclasm', *Science, Technology, & Human Values* 27: 53–86.

Beaulieu, Anne (2004) 'From Brain Bank to Database: The Informational Turn in the Study of the Brain', *Studies in History and Philosophy of Biological and Biomedical Sciences* 35: 367–90.

Cartwright, Lisa (1995) *Screening the Body: Tracing Medicine's Visual Culture* (Minneapolis, MN: University of Minnesota Press).

Coulson, Seana (2000) *Semantic Leaps: Frame-shifting and Conceptual Blending in Meaning Construction* (New York: Cambridge University Press).

Coulson, Seana & Todd Oakley (2000) 'Blending Basics', *Cognitive Linguistics* 11(3–4): 175–96.

Crary, Jonathan (1990) *Techniques of the Observer* (Cambridge, MA: MIT Press).

Dourish, Paul (2001) *Where the Action is: The Foundations of Embodied Interaction* (Cambridge, MA: MIT Press).

Dreyfus, Hubert L. (1991) *Being-in-the-world: A Commentary on Heidegger's Being and Time, Division I* (Cambridge, MA: MIT Press).

Dumit, Joseph (2004) *Picturing Personhood: Brain Scans and Biomedical Identity* (Princeton, NJ: Princeton University Press).

Fauconnier, Gilles & Mark Turner (2002) *The Way We Think: Conceptual Blending and the Mind's Hidden Complexities* (New York: Basic Books).

Goodwin, Charles (1994) 'Professional Vision', *American Anthropologist* 96(3): 606–33.

Goodwin, Charles (1995) 'Seeing in Depth', *Social Studies of Science* 25: 237–74.

Goodwin, Charles (2000a) 'Practices of Seeing, Visual Analysis: An Ethnomethodological Approach', in T. van Leeuwen & C. Jewitt (eds), *Handbook of Visual Analysis* (London: Sage Publications): 157–82.

Goodwin, Charles (2000b) 'Action and Embodiment within Situated Human Interaction', *Journal of Pragmatics* 32: 1489–1522.

Goodwin, Charles (2000c) 'Practices of Color Classification', *Mind, Culture and Activity* 7(1–2): 19–36.

Goodwin, Charles (2003) 'The Semiotic Body in its Environment', in J. Coupland & R. Gwyn (eds), *Discourses of the Body* (New York: Palgrave/Macmillan).

Heath, Christian & Jon Hindmarsh (2000) 'Configuring Action in Objects: From Mutual Space to Media Space', *Mind, Culture and Activity* 7(1–2): 81–104.

Heidegger, Martin (1962 [1927]) *Being and Time* (New York: Harper).

Hindmarsh, Jon & Christian Heath (2000) 'Embodied Reference: A Study of Deixis in Workplace Interaction', *Journal of Pragmatics* 32: 1855–78.

Hutchins, Edwin (2005) 'Material Anchors for Conceptual Blends', *Journal of Pragmatics* 37(10): 1555–77.

Ihde, Don (2002) *Bodies in Technology* (Minneapolis, MN: University of Minnesota Press).

Jefferson, Gail (1984) 'Glossary of Transcript Symbols with an Introduction', in G.H. Lerner (ed.), *Conversation Analysis: Studies from the First Generation* (New York: John Benjamins Publishing Company): 13–31.

Joyce, Kelly (2005) 'Appealing Images: Magnetic Resonance Imaging and the Production of Authoritative Knowledge', *Social Studies of Science* 35(3): 437–62.

Knorr-Cetina, Karin (1981) *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science* (Oxford: Pergamon Press).

Latour, Bruno (1988) *The Pasteurization of France* (Cambridge, MA: Harvard University Press).

Latour, Bruno & Steve Woolgar (1979) *Laboratory Life: The Social Construction of Scientific Facts* (London & Beverly Hills, CA: Sage Publications).

Lister, Martin, Jon Dovey, Seth Giddings, Iain Grant & Kieran Kelly (2003) *New Media: A Critical Introduction* (New York and London: Routledge).

Lynch, Michael (1985) *Art and Artifact in Laboratory Science: A Study of Shop Work and Shop Talk in a Research Laboratory* (London: Routledge & Kegan Paul).

Lynch, Michael (1990) 'The Externalized Retina: Selection and Mathematization in the Visual Documentation of Objects in the Life Sciences', in M. Lynch & S. Woolgar (eds), *Representation in Scientific Practice* (Cambridge, MA: MIT Press): 153–86.

Lynch, Michael (1991) 'Laboratory Space and the Technological Complex: An Investigation of Topical Contextures', *Science in Context* 4(1): 81–109.

Lynch, Michael (1993) *Scientific Practice and Ordinary Action: Ethnomethodology and Social Studies of Science* (New York: Cambridge University Press).

Lynch, Michael & Steve Woolgar (eds) (1990) *Representation in Scientific Practice* (Cambridge, MA: MIT Press).

Murphy, Keith M. (2004) 'Imagination as Joint Activity: The Case of Architectural Interaction', *Mind, Culture, and Activity* 11(4): 267–78.

Murphy, Keith M. (2005) 'Collaborative Imagining: The Interactive Use of Gestures, Talk, and Graphic Representation in Architectural Practice', *Semiotica* 156 (1–4): 113–45.

Nishizaka, Aug (2000) 'Seeing what one Sees: Perception, Emotion, and Activity', *Mind, Culture and Activity* 7(1–2): 105–23.

Nishizaka, Aug (2003) 'Imagination in Action', *Theory & Psychology* 13(2): 177–207.

Ochs, Elinor, Patrick Gonzales & Sally Jacoby (1996) '"When I Come Down I'm in a Domain State": Talk, Gesture, and Graphic Representation in the Interpretative Activity of Physicists', in E. Ochs, E. Schegloff & S. Thomson (eds), *Interaction and Grammar* (Cambridge: Cambridge University Press): 328–69.

Prasad, Amit (2005a) 'Scientific Culture in the "Other" Theatre of "Modern Science": An Analysis of the Culture of Magnetic Resonance Imaging Research in India', *Social Studies of Science* 35(6): 463–89.

Prasad, Amit (2005b) 'Making Images/Making Bodies: Visibilizing and Disciplining through Magnetic Resonance Imaging', *Science, Technology, & Human Values,* 30(2): 291–316.

Schegloff, Emanuel A. (1984) 'On Some Gestures Relation to Talk', in J.M. Atkinson & J.C. Heritage (eds.), *Structures of Social Action: Studies in Conversation Analysis* (Cambridge: Cambridge University Press): 266–96.

Suchman, Lucy (1987) *Plans and Situated Actions: The Problem of Human–Machine Communication* (New York: Cambridge University Press).

Suchman, Lucy (2000) 'Embodied Practices of Engineering Work', *Mind, Culture and Activity* 7(1–2): 4–18.

Talairach, Jean & Pierre Tournoux (1988) *Co-planar Stereotaxic Atlas of the Human Brain* (New York: Thieme Medical Publishers).

Talmy, Leonard (2000) *Toward a Cognitive Semantics* (Cambridge, MA.: MIT Press).

Traweek, Sharon (1988) *Beamtimes and Lifetimes: The World of High Energy Physics* (Cambridge, MA: Harvard University Press).

Tufte, Edward R. (1983) *The Visual Display of Quantitative Information* (Cheshire, CT: Graphics Press).

Turkle, Sherry (1995) *Life on the Screen: Identity in the Age of the Internet* (New York: Simon and Schuster).

Ueno, Naoki (2000) 'Ecologies of Inscriptions: Technologies of Making the Social Organization of Work and the Mass Production of Machine Parts Visible in Collaborative Activity', *Mind, Culture and Activity* 7(1–2): 59–80.
Whalen, Jack, Marilyn Whalen & Kathryn Henderson (2002) 'Improvisational Choreography in Teleservice Work', *British Journal of Sociology* 53(2): 239–58.

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