

CEREBELLAR ACTIVITY EVOKED BY COMMON TOOL-USE EXECUTION AND IMAGERY TASKS: AN fMRI STUDY

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ABSTRACT

The purpose of this study is to identify the functional brain networks activated in relation to actual tool-use in humans. Although previous studies have identified brain activity related to tool-use gestures (Moll et al., 2000), they did not investigate the brain activity involved in such tool-use. We investigated brain activity using functional magnetic resonance imaging (fMRI) while human subjects mentally imagined using sixteen common tools and while they actually used them. Brain activity for both actual and imagined tool-use was found in the posterior part of the parietal cortex, in the supplementary motor area, and in the cerebellum. Under imagined tool-use conditions, we found brain activity in the premotor and right pars opercularis. Under actual tool-use conditions, we found it in the primary motor area, in the thalamus, and in the left pars opercularis. Our precise analysis in the cerebellum indicated that activity evoked by imagery was located significantly more lateral to that evoked by actual use. We found a relationship between activity in the tool imagery and execution conditions by comparing their t-value-weighted centroid of activation coordinates. Moreover, for half of the subjects the spatial distribution pattern for each tool was similar, suggesting that neural mechanisms contributing to skillful tool-use are modularly organized in the cerebellum.

Key words: tool-use, imagery, fMRI, cerebellum

INTRODUCTION

Such intelligent animals as humans and chimpanzees can use tools. To acquire the ability to use particular tools, for example, scissors or chopsticks, humans and chimpanzees require much practice; however, once such ability is acquired, it cannot be forgotten. According to computational neuroscience, such abilities are carried out by inverse models that calculate the motor command to achieve task goals and forward internal models that predict the sensory feed back from the efference copy of the motor command. Based on these models humans predict or simulate the input-output properties of tool-use (Kawato et al., 1987). By internally representing the relationship between tool manipulation and the outcome of tool-use behavior, the predictive control of tools becomes possible, enabling us to use them quickly and smoothly.

Computational neuroscience fields have proposed that internal models exist in the cerebellum (Kawato, 1999). Recent functional neuroimaging studies (Imamizu et al., 2000) have found cerebellar activity that reflects an internal model of a novel tool, indicating that internal models of novel tools are modularly organized (Imamizu et al., 2003). We investigated whether the internal models of such common tools as chopsticks and scissors are also modularly organized in the cerebellum.

On the other hand, in neurological fields numerous works have suggested that the parietal

cortex is one location candidate that stores internal models (Blakemore et al., 2003; Sirigu et al., 2004). Furthermore, many studies have indicated that the parietal cortex is the most important part of a tool-use network. A neuropsychological investigation demonstrated that apraxic patients with a left parietal lesion without paralysis or aphasia make spatial and temporal errors in tool-use as well as when pantomiming such gestures (Heilman et al., 1986). Pantomime has been considered an effective test for apraxia since some reports have shown a strong correlation between pantomime and actual tool-use (Goldenberg et al., 1998; De Renzi and Lucchelli, 1988). In functional magnetic resonance imaging (fMRI) experiments on healthy subjects, Moll et al. (2000) and Choi et al. (2001) compared activity evoked by tool-use pantomimes to that evoked by a hand movement task devoid of any tool-use connotation by matching the intrinsic properties of the movements employed in the tool-use pantomime task. The involvement of the intraparietal sulcus (IPS) was shown in tool-use skill as well as cognitive knowledge of tool-use. In positron emission tomography (PET) experiments on healthy subjects, Rumiaty et al. (2004) compared activity evoked by imitating observed pantomimed action and pantomiming the use of an observed object, finding activity in the dorso-lateral prefrontal cortex and the dorsal and ventral parietal lobules. We know that pantomime is a useful test for apraxia. However an apraxic patient with Alzheimer's disease had more difficulties in a pantomime task

than in an actual tool-use task (Kato et al., 2001). Some patients showed the opposite case; they could pantomime but had difficulty in actual tool-use (Watson et al., 1986; Motomura et al., 1994).

As an example of a non-common tool-use experiment using PET, Inoue et al. (2001) asked subjects to manipulate a small graspable object with a pair of tongs and found activity in the posterior parietal cortex ipsilateral to the hand used. Their study excluded the cerebellum from analysis because it was outside of the transaxial field of view. An activation study using PET in monkeys (Obayashi et al., 2001) with an actual tool-use task revealed IPS, the supplementary motor area (SMA), the ventral part of the premotor, the cerebellum, and some other areas of the brain. However, no actual and common tool-use studies with human subjects have been conducted.

Therefore, to understand the mechanisms of actual tool-use we must determine the brain activity involved when subjects actually use tools. The aim of the present study is to investigate brain activity related to the actual use of various common tools and to infer the underlying neuronal mechanisms. The task for actual tool-use not only evokes brain activity related to the cognitive knowledge of tool-use and skills for tool-use but also to muscle activity. Therefore, we investigated and compared brain activity related to actual tool-use tasks with activity related to tool-use motor imagery to isolate the cognitive components of common tool-use.

MATERIALS AND METHODS

Subjects

Eight neurologically normal subjects (23-39 years old; three females and five males) participated in the experiment. Each subject received explanation of the experiment and signed an agreement. The protocol was approved by the Ethics Committee of ATR. All participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971) and had normal or corrected-to-normal vision.

Tasks

There were three conditions in this experiment. In the execution condition, subjects were asked to use one of sixteen common tools along with an appropriate object with visual feedback (e.g., using scissors to cut a sheet of paper). All tools and target objects for the tools are given in Table I. Subjects were instructed to use all tools with the right hand and taught the operation of each tool; then they practiced with each tool a few times before fMRI scanning. In the imagery condition, subjects were asked to imagine using a tool the

TABLE I
Tool and manipulation for tools

Tool	Manipulation
Brush	Brushing something hair-like
Chopsticks	Picking up a bead using chopsticks
Paper clip	Clipping papers together with a clip
Comb	Combing out something hair-like
Screwdriver	Turning a screw
Fork	Threading beads using a fork like rolling up spaghetti
Hammer	Hammering a nail
Knife	Cutting clay with a knife
Monkey wrench	Adjusting a nut and turning it
Pencil	Drawing something on a piece of paper
Pliers	Turning a nut with pliers
Saw	Mimicking the sawing of a board by making a little cut
Scissors	Cutting a sheet of paper
Spoon	Catching beads using a spoon
Toothbrush	Cleaning a small hole
Wrench	Turning a nut with a wrench

same way it was used in the tool-use execution condition. In this condition, the subjects did not actually manipulate the tools but held them and looked at the target (e.g., paper) in the same manner as in the execution condition. In the third condition, a control condition, subjects were asked to hold the tool without imagining its use while keeping their eyes open and maintaining the same hand and arm posture.

Figure 1 shows an instance of tool-use in an execution task. Subjects lied on the bed of the fMRI scanner and looked at their own hand and the tool through two mirrors that were combined to remove all reversal or inversion of the visual image.

Each condition lasted 30 seconds. The transitions and type of conditions were indicated by a sound stimulus of different frequency presented using Presentation Version 0.42 from Neurobehavioral System Execution and imagery conditions were always followed by the control condition. Each condition was repeated nine times per session (eighteen minutes). The order of the execution and imagery conditions was randomized. At the beginning of the session the subject was

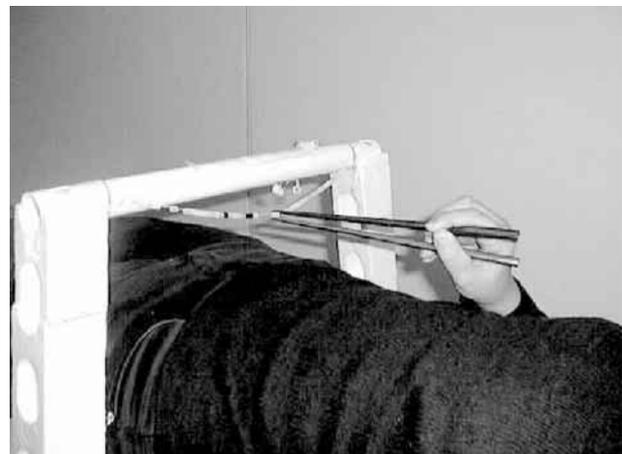


Fig. 1 – Example of a task situation (chopsticks).

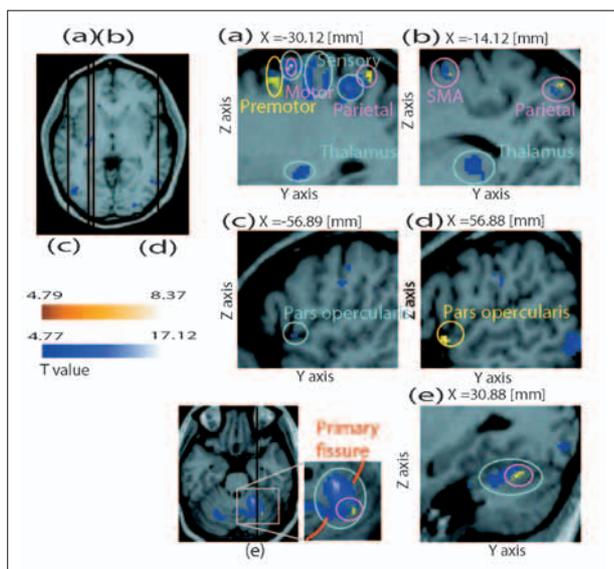


Fig. 2 – Comparison of brain activity between tool-use motor imagery (yellow) and actual use (blue). Images a, b, c, and d show sagittal sections at the black lines in left panels; x, y, and z in the figure indicate MNI coordinates. The typical structural image of one of the eight subjects was used.

handed a tool that did not change during the session. Thus, the subjects underwent 16 sessions for the 16 tools. The sessions were conducted over a few days, and the order of tools was randomized.

MRI Acquisition

The 1.5T MRI scanner (Shimadzu-Marconi Magnex ECLIPSE 1.5T) of the ATR brain imaging center was used to obtain blood oxygen level dependent (BOLD) contrast functional images. Images weighted with the apparent transverse relaxation time (T_2^*) were obtained with an echo-planar imaging sequence (repetition time = 6 sec, echo time = 50 msec, flip angle = 90°). We acquired 182 sequential whole-brain volumes ($64 \times 64 \times 64$ voxels at 3×3 mm isotropic resolution) in each session. High-resolution anatomical images of all subjects were also acquired with a T_1 -weighted sequence.

MRI Analysis

We used Statistical Parametric Mapping 99 (SPM99) software for image processing and statistical analysis. The first two volumes of images were discarded to allow for T_1 equilibration, while the remaining 180 image volumes were realigned to the first volume. T_2 and T_1 structural images were coregistered to the average realigned echo-planar imaging (EPI) image and then spatially normalized to the Montreal Neurological Institute (MNI; Montreal, Canada) reference brain. The typical structural image of one of the eight subjects was used in Figure 2. The structural images used in Figure 3 were constructed from the normalized T_1

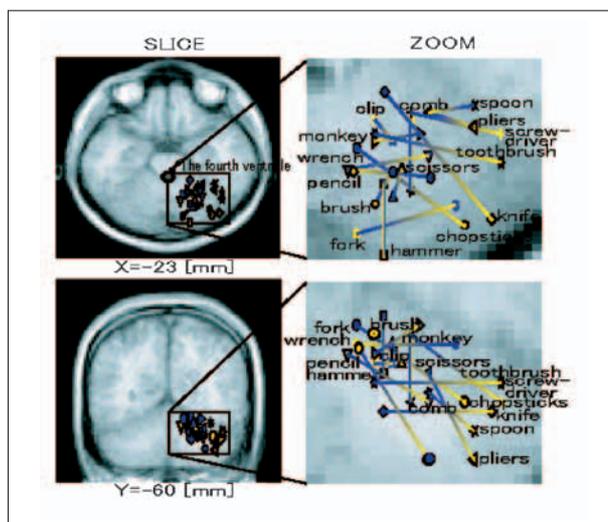


Fig. 3 – Distribution of t-value-weighted centroid of activation coordinates in tool-use (blue) and imagery (yellow) conditions. Right figure shows expansion of square area in left figure and coordinates.

averaged over all subjects. The normalized EPI images were spatially smoothed with a Gaussian kernel with a 6 mm full width at half maximum (FWHM). To remove the drift component of the signal change carried with time, high-pass filtering was applied. The voxel time series was temporally smoothed with a Gaussian filter (FWHM of 4 seconds). Parameter estimates for the imaging and execution trials were determined by fixed effect analysis for each subject using a boxcar function convolved with the hemodynamic response function (HRF). The model was designed to estimate the main effects of each condition (16 tools of execution and imagery).

ANALYSIS

Analysis of Execution and Imagery Conditions

Using fixed effect analysis, we investigated activity related to the execution and imagery conditions for each subject across the sixteen tools. Then the main effect of the imagery and execution condition data were independently used for a random effect analysis to investigate activities common to all subjects (random effect analysis $p < .001$ uncorrected).

Analysis of Activity Position in Right Upper Cerebellum

To investigate activity specific to each tool, we conducted subtraction analysis (imagery minus control and execution minus control) across the subjects separately for each tool (fixed effect model $p < .05$ corrected). Because we did not detect any significant activity, we excluded the SAW tool from this analysis. We limited the region

TABLE II
Coordinates and *t*-values of activation peaks for imagery and execution condition as revealed by random effect analysis ($p < .001$ uncorrected). Regions of ten highest *t*-value peaks are listed

	Anatomical description	Laterality	<i>x</i>	<i>y</i>	<i>z</i>	<i>t</i> -value
Imagery						
Central region	Precentral	L	-38	0	50	8.37
	Precentral	R	48	10	48	6.18
Frontal lobe	Postcentral	L	-46	-28	52	7.17
	Supplementary motor area (SMA)	L	-12	4	66	7.55
	Supplementary motor area (SMA)	L	-8	-6	74	5.99
	Pars opercularis	R	56	12	-6	7.6
Parietal lobe	Posterior part of intraparietal sulcus (IPS)	L	-26	-72	54	8.37
	Posterior part of intraparietal sulcus (IPS)	L	-26	-58	52	6.07
	Angular gyrus	L	-50	-64	42	7.96
Cerebellum	Lobule VI	R	32	-62	-28	6.18
Execution						
Central region	Precentral	L	-30	-12	66	17.12
Parietal lobe	Posterior part of IPS	R	26	-66	52	8.63
	Inferior parietal	R	40	-48	54	12.74
	Supramarginal	R	58	-22	26	9
Occipital lobe	Middle occipital	L	-46	-76	-2	9.7
	Inferior occipital	R	36	-92	-10	8.36
Temporal lobe	Inferior temporal	R	52	-64	-4	14.12
Subcortical area	Putamen	L	-30	-20	0	9.03
Cerebellum	Lobule IV, V	R	18	-48	-24	14.87
	Lobule VI	L	-20	-60	-32	10.3

of interest to the right cerebellum superior to the horizontal fissure, since we consistently found activities in this area over all tool conditions. Based on these results, we calculated a *t*-value-weighted centroid of activation for each tool and investigated the centroid distributions.

RESULTS

Activation Differences between Imagery and Execution Conditions

Figure 2 shows significant activation ($t > 4.79$, $p < .001$) related to the execution condition (blue regions) and the imagery condition (yellow regions). Pink circles indicate a blue and yellow mosaic, i.e., overlap between the imagery and execution conditions.

Regions activated only in the imagery condition were found in the left premotor area and right pars opercularis, while regions activated only in the execution condition were found in the primary motor area, the left sensory area, the thalamus, the pars opercularis, and bilaterally in the cerebellum. Overlap between the imagery and execution conditions was found in regions of the left motor area, the SMA, the parietal area, prominently in the posterior IPS, and in the right cerebellum (Figure 2e).

In the left panel of Figure 2e, the red line indicates the primary fissure in the cerebellum. Activation related to the execution condition was only located anteriorly to the primary fissure, whereas the overlap was located posteriorly to the fissure. All coordinates are listed in Table II.

Positional Relationship between Imagery and Execution Conditions

For all tools and subjects, control condition activation was subtracted from the activation of the tool-use imagery and execution conditions to assess the brain activity of imagery and execution, respectively ($p < .001$ uncorrected). Figure 3 shows the *t*-value-weighted centroid of activation for each tool projected to horizontal and coronal planes.

Yellow and blue markers indicate the centers for the imagery and execution conditions, respectively. Corresponding markers are connected by a gradation line that is colored yellow and blue on the imagery and execution sides, respectively. As shown in Figure 3, imagery activation is located more laterally and posterior relative to the execution activation, which is located more medially and anterior.

Coordinate Distribution of the Upper Right Part of Cerebellar Activity

First, we calculated the coordinates of the *t*-value-weighted centroid of activation. Then, we calculated the distance between these coordinates and the fourth ventricle, located in the middle of the cerebellum, and averaged these distances over all tools separately for each subject. Finally, we used a signed rank test to examine for significant difference in the distances averaged across subjects between the imagery and the execution conditions.

Figure 4 shows the distance of the imagery condition (left) and the execution condition (right) from the fourth ventricle located in the center of the cerebellum. According to the signed rank test, the distance in the imagery condition was significantly

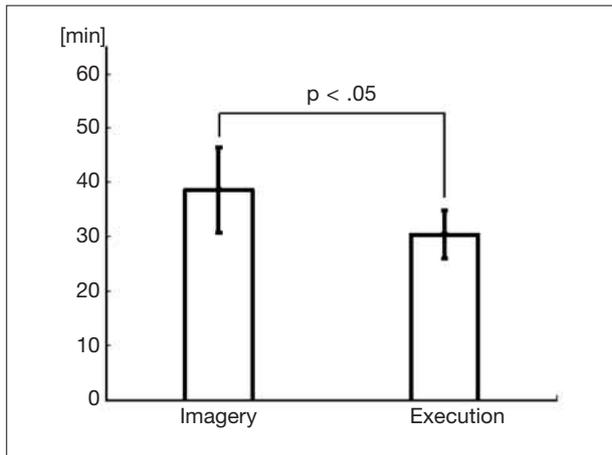


Fig. 4 – Distance from fourth ventricle to coordinates of *t*-value-weighted centroid of activation coordinates in tool-use execution and imagery tasks.

larger than in the execution condition ($p < .05$), which is consistent with observations that, on average, imagery activation is located more laterally and posteriorly.

Analysis of Relation between Imagery and Execution Conditions

Activation for each tool across subjects was investigated in the right upper part of the cerebellum using the same method as in section “Analysis of activity position in the right upper cerebellum”. In this limited area, the first principal component of all coordinates from both tasks for each tool was calculated. Then all coordinates were projected to the first principal component, and the distances between a given point and projected coordinates were calculated. These distance data were categorized into the execution and the imagery conditions. The coordinates in the execution condition group and in the imagery condition are plotted on the *x* and *y* axes of Figure 5, respectively. If each pair of tool coordinates is located along the primary fissure boundary line, the first principle component for these coordinates will be located near the primary fissure. If execution and imagery condition coordinates are located at a similar location, they will be projected to a closer position and plotted on a 45° sloped line.

Figure 5 shows the plots of the projected coordinates of the *t*-value-weighted centroid of activation in the tool-use imagery task as a value of the *x* axis and those in the tool-use execution task as the value of the *y* axis. The dotted line in the figure indicates a 45° slope, and the solid line indicates the principal component vector. The correlation coefficient was .5497, which is significantly larger than zero ($p < .05$). The coordinates of the *t*-weighed centroid of activation in the imagery and execution conditions were thus located spatially close to each other.

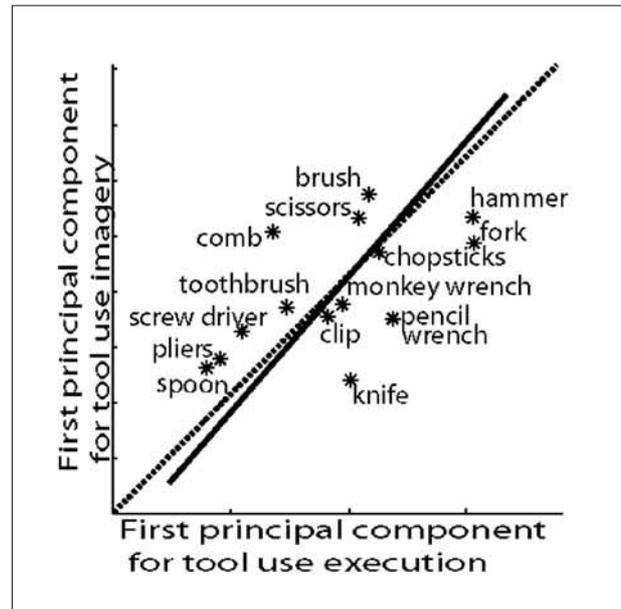


Fig. 5 – Relationship between *t*-values-weighted centroid of activation coordinates in tool-use execution and imagery conditions.

Positional Relationship of Tools in the Right Upper Cerebellum

In this section, we show the analysis results of the distribution of activities by tool in the right upper cerebellum when subjects imagined tool-use. First, we examined brain activity separately for all tools and subjects (fixed effect model $p < .001$ uncorrected). The distances of *t*-value-weighted centroid of activation were calculated from the fourth ventricle to these coordinates. Second, we investigated the order of distance in each subject and compared it to the order obtained from the group-analysis activation map, as shown in Figure 4. In this case, since there was no significant activation evoked by the SAW tool, it was excluded from the analysis. Correlation between individual and group order was examined by Spearman rank correlation coefficient. Four of the eight subjects showed marginally significant correlation between the order of the distance from the fourth ventricle for each tool ($p < .10$), suggesting similarity in the spatial distribution of the tools.

DISCUSSION

Comparison with Previous Tool-Use Studies

Action or grasping related brain circuits have been studied in macaque monkeys. The connectivity between the parietal cortex and inferior frontal areas has been well-studied (Matelli and Luppino, 2001). We also found activity in the parietal cortex especially in the posterior IPS and in the inferior frontal region in the case of tool-use.

Activity in the inferior frontal region was found in the left hemisphere only during execution condition and in the right hemisphere only during imagery condition (Figures 1c and 1d). However, with a lower threshold ($p < .005$ uncorrected), bilateral activities can be found in both imagery and execution conditions. While (Johnson-Frey et al., 2003) have shown the importance of this region for grasping, our experiments showed that this region was more activated during test conditions than the control condition of grasping. Therefore, we believe this region is involved in tool-use functions and not just grasping. Tamada et al. (1999) investigated the learning of a new tool (a rotated computer mouse) and found activity in the inferior frontal region when a rotated computer mouse condition was contrasted with a normal computer mouse condition. In Tamada et al.'s (1999) and our experiments, both the test and control conditions had a grasping component, so that inferior frontal region activity needs to be interpreted as a cognitive function, such as knowledge of how the tool works. This cognitive function cooperates with tool-use in the absence of motor components; simply imaging the use of a tool is sufficient to activate the inferior frontal region. Moreover, cortical activity in the left inferior frontal region found during the execution condition in the present study was localized laterally in comparison to the activities reported by Tamada et al. (1999), suggesting that spatial localization may be different for novel and common tools.

As shown in Figures 2a and 2b, activation near the left IPS of the parietal lobule is consistent with fMRI studies that showed left IPS activation in a pantomiming task (Moll et al., 2000). Similarly in another study, the left IPS was activated both in left-hand and right-hand tool-use pantomime (Choi et al., 2001). As in a PET study, the dorsal lateral parietal cortex was activated during the pantomiming of object use (Rumiati et al., 2004). The present result is consistent with studies conducted on nonhuman primates (macaque monkeys) using complex tools (Obayashi et al., 2002) and intermanual transfer of tool-use (Obayashi et al., 2003), which reported significant activities in the left IPS and cerebellum. As shown in Figure 2e, we found activity in the cerebellum. The cerebellum has not been studied as much as the cerebral cortex because of such technical problems as the limited transaxial field of view of PET. In addition, it is difficult to control muscle activity and sensory input. To differentiate activity from muscle and sensory input and activity from tool-use, our imagery condition had no changes of muscle movement during the task. Recent studies have shown that the cerebellum is also important for tool-use (Obayashi et al., 2001; Imamizu et al., 2000, 2003), and other experimental data and the clinical studies have shown that the lateral part of the cerebellum has various cognitive functions

(Grafman et al., 1992; Parsons et al., 1995). The one of reports related to cerebellar activity, Parsons et al. (1995) showed parietal, premotor and cerebellar activities in their paradigm which involves deciding whether a hand is left or right. This decision is accomplished by the subject only by "thinking" of that hand as it was his/her own hand. It is by all means a simulated motor act, and could be done without actually employing tools in the scanner. The activity shown by Parsons et al. (1995) may relate to the internal model of the mental rotation of the hand which calculates input and output of the hand movement. On the other hand, our experiment showed that the cerebellum is also activated by imagery of tool-use. The activity in the cerebellum could be related with tool-use as other previous studies (Obayashi et al., 2001; Imamizu et al., 2000, 2003) or imagery of the hand movement as shown in Parsons et al. (1995). Thus not only parietal, premotor, primary motor areas but also cerebellum may be involved in both "imagery of object usage" and "object usage".

Activity reported from a PET experiment on using new tools was found in the right IPS area (Inoue et al., 2001), which is inconsistent with other pantomime and novel tool-use experiments as well as this experiment. We believe that the left IPS is an important region for tool-use, and their finding of right IPS activity might be caused by different experimental conditions, such as a non-common tool-use experiment.

In our tasks, the control condition was tool-holding, which might have implicitly activated the same brain regions as tool-use imagery. We cannot reject this possibility. But even if the intended and implicit imagery of the control condition share the same brain functions, as Grezes et al. (2003) have shown, we found significantly larger activity in tool-use imagery tasks compared with tool-holding tasks. Furthermore, the subjects were asked to simply hold the object and no imagery was required during the tool-holding condition, so tool-holding was a suitable control for tool-use imagery. Therefore, most of the difference between the imagery and control conditions was imagined or not imagined tool-use.

Pantomime is a traditional test for Ideomotor Apraxia. The left posterior parietal lesions, including the intra parietal sulcus, often lead Ideomotor Apraxia (Heilman et al., 1986, 1997; Goldenberg, 2003). However, left parietal stroke patients showed improvements in actual tool performances compared to pantomiming use (Wada et al., 1999). In apraxia patients, the dissociation of automatic and voluntary tool-use is known as automatic voluntary dissociation. The result that a subject who has damage to the left parietal cortex can still use the actual tool indicates that the left parietal cortex is not always involved in the actual tool-use process. Pantomime and actual tool-use appear to involve different mechanisms.

Pantomime requires a more intentional process while actual tool-use can also be carried out at least partly by an automatic process.

Consciously accessing knowledge about tool-use might be distinct from the automatic skills related to tool-use, as suggested by a hypothesis of the automatic-voluntary dissociation first described as Baillarger-Jackson principle (Jackson, 1884). He showed a patient who could not make the sign of the cross at the clinic but did so automatically when entering a church. In this case, the patient had an internal model for signing the cross, but could not voluntarily retrieve it in an arbitrary situation and could only automatically retrieve it. Sirigu et al. (2004) proposed that internal models for voluntary (self-initiated) actions exist in the parietal cortex. Signing the cross at the clinic is an intentional and voluntary action, and thus this function might be located in the parietal cortex. Hanakawa et al. (2003) reported the relationship between the accuracy of motor imagery and activity in the left IPS and superior precentral regions. Since such accuracy may relate to how much the subject intentionally concentrates on doing so, it could be strongly related to intensity of intentional efforts. Accordingly, Sirigu et al.'s (2004) internal model could be closely related to conscious actions, which at least partially necessitates intentional processes. In general, this intentional process might also increase the intentional visual (imagery) process more than the automatic processes. Recent vision research revealed IPS activity when a voluntary saccades task was contrasted with a reflexive (automatic) saccades task using fMRI (Mort et al., 2003). When contrasting reflexive with voluntary tasks, IPS was not activated. So, we speculate that the parietal cortex could be more related to internal models of intentional processing than to those of automatic processing.

Distribution of t-Value-Weighted Centroid of Activation Coordinates

Figure 3 suggests that tool-use execution activation is processed in the superior part of the cerebellum and that tool-use imagery tends to be located in the more inferior and lateral parts. The distance from the fourth ventricle in the imagery condition was larger than the execution condition (Figure 4). Furthermore, we found significant correlation in the distances of the projected point on the principle vector of the t-value weighed centroid coordinates between imagery and execution conditions (Figure 5). These results support the hypothesis that the cerebellum is involved in non-motor functions. Relative to the cerebellar study, the brain activity in both movement and imagery processing were located in the posterolateral part of the cerebellum (Naito et al., 2002). This study also suggests that a positional

correlation exists between the imagery and execution activation sites. Regarding the distance from the fourth ventricle for each tool, similarity was found in the order of tools among the subjects, as revealed by Spearman rank correlation coefficient. This similarity of distances was prominent in near and far coordinates for half of the subjects. These results suggest that tool-use skills and/or cognitive knowledge of tool-use are acquired in similar distribution, even though there is a large difference between subjects who have different familiarity of tool-use or different skill acquisition.

We used an extended tied mixture model to represent the spatial distribution of the brain activity that showed that cerebellar activity can be explained with six clusters (Furukawa et al., 2002). In Grodd et al. (2001), most of the clusters showed similar somatotopic topography of hand and wrist muscle control while two other clusters were located in the bilateral region near the posterior superior fissure, which are not included in Grodd et al.'s (2001) topography map. Therefore, these two clusters were considered to be related to the internal model of tool-use rather than simple muscle control. One cluster related to the internal model in the right cerebellum was located more posterior and more lateral to the cluster for the hand muscle control area. In Figure 5, "chopsticks" and "scissors", which require complex finger controls, were projected in a closer region. At the same time, "screwdriver" and "pliers", which require wrist controls, were projected in a closer region. In the horizontal section shown in Figure 3, "screwdriver" and "pliers" were located more anterior than "chopsticks" and "scissors". These position relationships are compatible with Grodd et al.'s (2001) topography map that showed that the wrist is located more anterior than the finger control center. So we speculate that internal models are engaged for the related muscle control areas of the hand, the fingers, and the wrist, and they will be shifted near the location of the hand muscle control center in the cerebellum. This could be one reason why activity related to the internal model was similar among subjects: the muscles used should be identical between subjects for each tool.

On the other hand, the organization of internal models in the cerebellum seems also related to familiarity because cerebellar activity was associated with novel tool-use manipulation (rotated computer mouse manipulation) by hand (Imamizu et al., 2000). This novel tool internal model activates more lateral area than activity associated with common tool-use in the present experiment. Therefore, a newer internal model might be acquired in more lateral parts of the cerebellum and then gradually move to the more medial and anterior area where the action- or movement-related muscle control centers exist.

As mentioned above, some studies exist which examine cerebellar function related to tool-use, but generally the cerebellum has not been considered an important site for tool-use especially in clinical studies. Clinical studies of tool-use have often examined apraxic patients, where apraxia is defined by tool-use difficulty without paralysis. However, most apraxic patients have damage to the left parietal cortex, while cerebellar-associated apraxia is rare or non-existent. Because the internal models for tool-use are located close to the muscle control center in the cerebellum, it would be highly unlikely to have selective damage to the tool-use internal models in the cerebellum without also damage to the general motor control areas. This would result in more severe motor deficits and no longer considered apraxia. Thus, it is really difficult to find an apraxia patient with cerebellum damage. Another reason for the lack of clinical studies relating the cerebellum to tool-use, is that if the cerebellum has a particular role in automatic tool-use (see discussion section), then patients may still be able to use tools intentionally via the parietal pathway. Therefore, because the behavior at the clinic is mostly intentional action for patients, previous patient studies may have ignored any deficit in automatic tool-use.

Network Related to Tool-Use in Brains

Tamada et al. (1999) reported functional connectivity between the cerebellum and pars opercularis or pars triangularis in tasks that require the acquisition of internal models. We also found activity in the pars opercularis or pars triangularis and the cerebellum, so these activities may also be functionally connected, as in Tamada et al.'s (1999) study.

It seems that both parietal and cerebellum networks exist for tool-use. Parietal activity confirms the neuropsychological findings from apraxia, and cerebellum activity confirms other experiments related to tool-use. Perhaps the existence of parallel networks could explain automatic-voluntary dissociation in apraxia (i.e., parietal automatic and cerebellar intentional networks). During tool-use, even when a subject automatically controls the tool, at some point he/she begins to control that tool intentionally, making slight adaptations to the surrounding environment. We don't know if the parietal and cerebellum regions actually work cooperatively or simply in parallel but at least it seem there are two ways for tool-use. Interestingly, the existence of a brain network connection between the cerebellum and parietal regions was reported in neurophysiological and anatomical studies (Clower et al., 2001, 2005). These input-output relationships between parietal and cerebellum regions could be used in tool-use mechanisms.

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