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TECHNICAL REPORT

Action and Object Processing across Three Tasks: an fMRI Study of Picture-Naming, Word Reading and Repetition in Italian

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ACTION AND OBJECT PROCESSING ACROSS THREE TASKS: AN FMRI STUDY OF PICTURE-NAMING, WORD READING AND REPETITION IN ITALIAN

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Abstract

Numerous studies have investigated the neural processing of actions versus objects. Some have reported distinct areas subserving each item type, while others have found highly overlapping networks. These inconclusive results could be due to the use of different methodologies and tasks, as well as to the different ways these items are defined -- i.e., as semantic concepts (actions vs. objects) or as lexical/grammatical entities (nouns vs. verbs). The aim of this fMRI study was to evaluate whether the semantic processing of actions and objects can be linked to distinct brain regions, and whether different tasks result in different patterns of activation in the same set of participants. Healthy native speakers of Italian saw and heard action and object stimuli presented in three different ways: black and white line drawings (picture-naming), single printed words (reading), and aurally-presented words (repetition). Overall, across two of the three tasks, actions produced more activation than objects in left precentral gyrus, bilateral middle and superior temporal gyrus, right fusiform gyrus, and right cerebellum. At no time did objects result in greater activation than actions. These findings suggest that the brain networks supporting action and object processing overlap. Furthermore, the fact that the type of task can influence the relative degree of action versus object activation differences most likely reflects the effect of presentation modality (i.e., pictures vs. written/spoken words) on the processing of one conceptual category versus the other.

Keywords: *actions; objects; fMRI; Italian; picture-naming; reading; repetition.*

Introduction

Over the years, several researchers have tried to gain a greater understanding of how we process actions and objects (typically presented in the form of verbs and nouns). Studies have been conducted across different languages (e.g., Chinese: Arévalo et al., 2011; Bates et al., 1991; Chen & Bates, 1998; Li et al., 2004; Lu et al., 2001; English: Buckner et al., 2000; Caramazza & Hillis, 1991; Tranel et al., 2005; Tyler et al., 2008, 2004, 2003, 2001; Warburton et al., 1996; German: De Bleser & Kauschke, 2003; Greek: Kambanaros, 2008; Italian: Berlingeri et al., 2008; Laiacona & Caramazza, 2004; Miceli et al., 1984; Siri et al., 2008), with healthy and brain-injured populations (e.g., patients with Alzheimer's Disease: Cappa et al., 1998; frontotemporal and cortico-basal dementia: Cotelli et al., 2006; Rhee et al., 2001; aphasia: Arévalo et al., 2007, 2005; Daniele et al., 1994) as well as using different tasks (e.g., input vs. output, see Caramazza & Hillis, 1991; Székely et al, 2005).

In clinical research, injury to the left frontal lobe has mostly been associated with verb-processing impairments, while left temporal injuries have been associated with noun-processing deficits (e.g., Chen & Bates, 1998; Daniele et al., 1994; Hillis et al., 2005; Zingeser & Berndt, 1990). However, several studies have failed to support such a double dissociation, and instead consistently report greater difficulty for processing action/verb relative to object/noun stimuli in both healthy and brain-injured individuals, regardless of lesion type or site (e.g., Arévalo et al., 2011, 2007, 2005, 2002; Bak et al., 2006; Collina et al., 2001; De Bleser & Kauschke, 2003; Han et al., 2007; Jonkers & Bastiaanse, 1998; Kambanaros, 2008; Luzzatti et al., 2002; Rhee et al., 2001).

Neuroimaging studies conducted mostly with healthy participants have also addressed the action/verb versus object/noun question. While some English-language fMRI studies targeting grammatical distinctions have reported discrete activations for noun versus verb processing (Shapiro et al., 2006; Tyler et al., 2008), most studies (in English and other languages) looking both at this distinction and the distinction between actions and objects as concepts, have reported mostly shared, overlapping networks (e.g., Buckner et al., 2000; Li et al., 2004; Siri et al., 2008; Sörös et al., 2003; Tyler et al., 2003, 2001; Vigliocco et al., 2006; Warburton et al., 1996). Perani et al. (1999) reported shared networks for the two categories plus additional activation for verb stimuli in left dorsolateral frontal cortex, superior parietal cortex, and anterior middle temporal cortex.

One important issue in this line of research is how one approaches the question, i.e., is one comparing and contrasting the grammatical entities of nouns versus verbs or the semantic concepts of objects versus actions? Some authors have suggested that each of these questions may lead to different findings. For example, in a task targeting the grammatical distinction, Shapiro et al. (2006) asked participants to produce phrases in response to words and pseudowords using three different experiments. In addition to regions activated for both nouns and verbs (areas within the inferior prefrontal and premotor cortex, middle temporal gyrus and temporal-occipital junctions), they identified three regions in which activation was greater for one word category relative to the other (verbs: left middle frontal gyrus (BA 9) and left superior posterior parietal cortex (BA 7); nouns: left middle fusiform gyrus (BA 20)). Interestingly, in both Tyler et al. (2004) and Longe et al. (2007), nouns and verbs presented as stems both activated a similar overlapping left hemisphere network; however, when presented as inflected forms, verbs resulted in greater activation than nouns in LIFG (BA 44/45/47; Tyler et al., 2004) or in both LIFG (BA 44/45/47) and LMTG (BA 21) (Longe et al., 2007). In Longe et al. (2007), inflected nouns also activated these two regions, but not as strongly as inflected verbs. Similarly, Tyler et al. (2008) presented participants with noun-verb homophones either as single stems or preceded by an article in order to form either a noun phrase or a verb phrase. The only significant difference they found was greater activation for verb phrases relative to noun phrases in left posterior MTG (BA 22/39). Taken together, these results suggest that category membership alone is not sufficient to explain activation differences across categories, and that nouns and verbs activate different neural regions only if they engage grammatical functions to different degrees.

Finally, in a study by Siri et al. (2008), participants were presented with 3 types of stimuli: infinitive verbs, inflected verbs and action nouns. Results showed that activation in the left inferior frontal gyrus (BA 44, pars opercularis) was greatest for action nouns, followed by inflected verbs and finally by infinitive verbs, suggesting that linguistic/morphological complexity may be a more efficient recruiter of brain activity than simply category membership. The authors suggest that the often reported greater activation for verbs relative to nouns may actually be due to verbs' greater morphosyntactic complexity and/or to the greater processing and task demands imposed by verbs relative to nouns in most tasks. They conclude that when all factors are controlled, nouns and verbs are processed by a common neural system, and that differences in activation reflect increasing linguistic and/or general processing demands.

Other authors have also suggested that category dissociations (noun/verb and others) may be directly influenced by the relative degree of processing demand or by the type of task (e.g., Berlingeri et al., 2008; Caramazza & Hillis, 1991; Price et al., 2003; Rogers et al., 2005). Berlingeri et al. (2008) compared noun and verb processing in two different tasks -- grammatical class switching and picture naming; they found task-dependent differences between noun and verb retrieval such that greater activation in LIFG (pars triangularis) was observed for the word category/task combinations which were most difficult to process, namely nouns in the grammatical class switching task and verbs in the picture naming task. Similarly to Siri et al. (2008), the authors concluded that the increased activity in LIFG reflects an increase in task demands, rather than verb or action processing per se.

In the current study, we tested participants on actions and objects as concepts, rather than the lexical/grammatical distinction of nouns and verbs, and we further explored our main question by using three very diverse tasks: picture-naming, word reading and word repetition. Our main goal was to address the following key questions: 1) will object and action stimuli activate different brain regions?, 2) will the different tasks result in different object/action activation patterns?, and 3) will activation patterns be affected by the difficulty level of the stimuli? If actions and objects do indeed recruit distinct, non-overlapping regions of cortex, then at least one of the tasks in this multidimensional study should uncover this putative double-dissociation. If instead we observe no category dissociations (or a unidirectional dissociation) across tasks, then we would suggest that actions and objects are processed by a mostly overlapping network (and we may identify some regions which are more activated for one of the two categories). Finally, if any observed dissociations vary significantly across tasks, we would suggest that relative degrees of activation are best explained by the nature of the particular task(s) (e.g., level of semantic difficulty) rather than by category membership per se.

This last point highlights the importance of testing stimuli across different tasks in order to tease out task-dependent effects from the real question of category differences. Although the many authors cited above have tackled this very issue (e.g., Berlingeri et al., 2008; Shapiro et al., 2006; for a review, see Price, 1998), the current study is the first to test three previously well-studied tasks in the same group of healthy participants. The three tasks assessed in this experiment are tasks which have commonly been used in neuropsychological and neuroimaging experiments and which involve different degrees of processing complexity as well as different processing modalities (i.e., visual and auditory). For this reason, the stimulus items used here were previously normed across languages and populations in all three tasks, and this data, along with information regarding several other important variables (e.g., word frequency, age of acquisition, picture visual complexity) are contained in the larger corpus of stimuli used by our lab and others

(CRL-IPNP[1], Bates et al., 2000, 2003; D'Amico et al., 2001; see *Stimuli* below, and Appendix A and B).

In decreasing order of difficulty, we rank the three tasks as 1) picture-naming, 2) word repetition and 3) word reading. Specifically, picture-naming involves the greatest amount of semantic processing, since it requires one to accurately recognize the picture and retrieve the word most commonly associated with it. This process is highly complex and involves several processing stages (e.g., Kambanaros, 2008; Laine & Martin, 1996). Relative to generation tasks such as picture-naming, word repetition is a less demanding procedure (Péran & Démonet, 2008), and, just like reading, mostly requires the knowledge and ability to process letter-sound association rules.

Relative to reading, however, repetition is arguably more demanding, since the lack of visual input in this task requires one to retain the word in memory (albeit briefly) before producing it. Devlin et al. (2002) have argued that one can achieve relative good reading performance without complex processing or high comprehension (as long as enough phonological memory is available), while Price (2000) found that visual regions showing activity during reading also showed positive activity during repetition, suggesting that in order to repeat, participants may be visualizing the words they are hearing in order to process them. Furthermore, Church et al. (2008) tested children and adults on reading and repetition and found that both groups were equally accurate on both tasks but were significantly slower on repetition. Finally, Paulesu et al. (2000) have suggested that reading may be inherently easier in orthographically-transparent languages such as Italian.

Finally, complexity was also manipulated in our task through the selection of items on either side of the difficulty spectrum, a variable which is contained in our corpus. The CRL-IPNP includes a difficulty parameter which was assessed on the basis of naming speed: items on the fast end of the response time (RT) spectrum make up the 'easy' items, while those on the slow end make up the group of 'difficult' items. We took advantage of this difficulty distinction in order to select a well-balanced set of items. For more information, see **Materials and methods**/*Stimuli*, below.

As mentioned above, although several authors have explored the neural substrates of these three tasks across different studies, no neuroimaging studies to date have compared action and object processing across picture-naming, reading and repetition on the same group of participants, which makes the current study a unique and valuable contribution to this line of inquiry.

[1]CRL-IPNP: the Center for Research in Language-International Picture Naming Project, University of California, San Diego (Bates et al., 2003, 2000)

Materials and methods

Participants

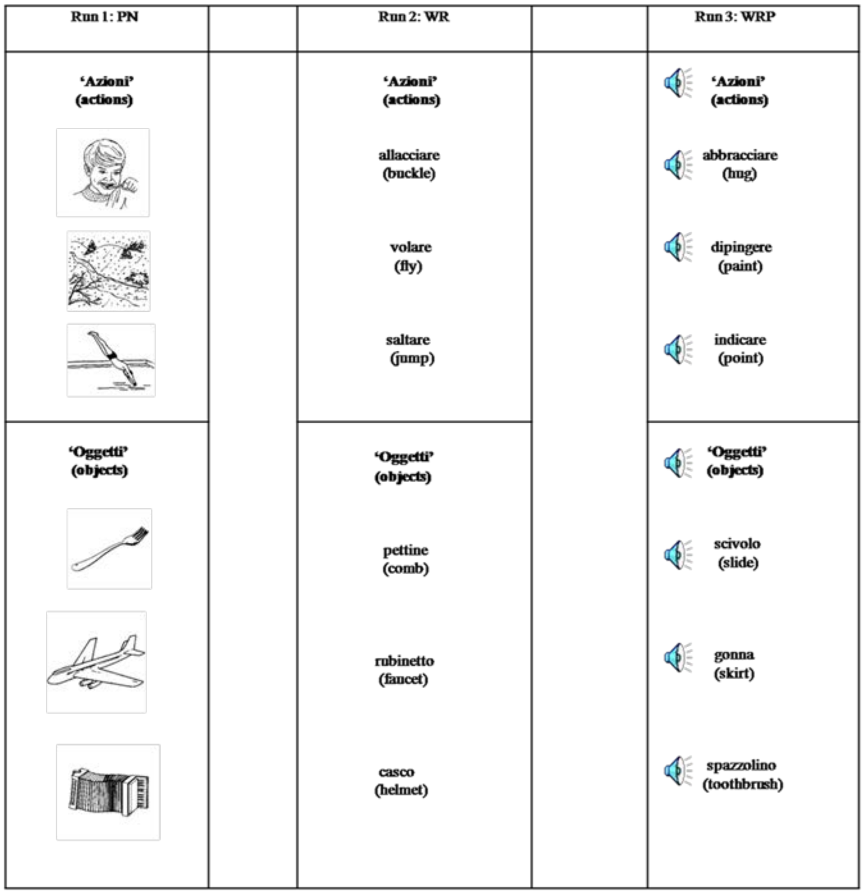
A group of 12 healthy individuals were selected for this study (5 males and 7 females). All were neurologically intact, right-handed native speakers of Italian between the ages of 18 and 30 (mean age = 21) with no significant exposure to another language before the age of 12. They were recruited from the San Raffaele Institute community in Segrate (Milan, Italy) and prior to participation, signed consent forms approved and used by San Raffaele Hospital and by the University of California, San Diego. The study was conducted in compliance with the Declaration of Helsinki. All participants had normal (or corrected to normal) vision and hearing and did not take any medications. They received monetary compensation for their participation in the study.

Stimuli

Our materials were derived from a carefully-controlled corpus of 795 items that has been normed in seven different languages across international sites (CRL-IPNP, Bates et al., 2000, 2003). Each picture was assigned its own target name, which was the name produced by the largest number of participants for that picture in the picture-naming (PN) task. The target names were then used to create the reading (WR) and repetition (WRP) paradigms. The subset of items used in this study was obtained from the Italian corpus that was normed on healthy, adult native speakers of Italian (D'Amico et al., 2001). This set consisted of 192 black-and-white line drawings as well as the written and recorded versions of the same stimuli (for presentation in the WR and WRP portions of the task, respectively). Ninety-six items represented actions and 96 represented objects (for a complete list, see Appendix A and B). Items included only those which elicited a high level of naming accuracy and response times (RT) that fell within two standard deviations of the mean. All picture and word stimuli were digitized and presented on a white background using the Presentation experiment driver (www.neurobs.com).

Our set of object and action items were matched for word frequency in Italian (actions/verbs: 1.19, objects/nouns: 1.22; $F(1,1) = 0.0153$, $p = 0.90$). Also, during item selection, we excluded ambiguous or visually-complex pictures. Thus, even though pictures of actions/verbs were inevitably more visually-complex than pictures of objects/nouns, both sets of items had high 'goodness of depiction' ratings, thus lowering overall ambiguity (see Bates et al., 2003, 2000 for details on these measures; also see Bird et al., 2000, Frattali, 2005, and Székely et al., 2005, for issues on orthogonalization of noun and verb names). The IPNP includes a difficulty parameter which was assessed on the basis of naming speed: items on the fast end of the response time (RT) spectrum make up the 'easy' items, while those on the slow end make up the group of 'difficult' items. We

***Figure I. Simplified example of experimental runs*.**
Each participant completed 9 runs (3 in picture-naming, 3 in reading and 3 in repetition), which were presented one at a time. Each run consisted of eight blocks of (action or object) stimuli; each block consisted of 8 stimulus items and was preceded by either the written or spoken words for actions (Azioni) or objects (Oggetti), in order to indicate which type of stimulus would be viewed/heard. For the repetition condition (WRP), participants heard the words while the screen remained blank. For simplicity, this figure depicts only 3 runs, 2 action or object blocks per run, and 3 items per block.



took advantage of this difficulty distinction in order to select a well-balanced set of items: half of the items from each word category were taken from the 'easy' group and half were taken from the 'difficult' group. However, our action and object items were not matched on word length (average number of letters: actions: 7.85, objects: 6.75, $F(1,1) = 20.82$, $p<.0001$; average number of syllables: verbs: 3.44, nouns: 2.81, $F(1,1) = 42.28$, $p<.0001$). We discuss this point further in the Discussion.

Procedure

The experiment was a blocked design consisting of 9 runs (or sessions), each presenting 64 items organized into 8-item blocks. Each run presented stimuli in only one of the three conditions (PN, WR or WRP), and each block consisted of items from one of four groups: easy objects, easy actions, difficult objects, or difficult actions; this resulted in an equal number of items from each conceptual and difficulty category within each run. Also when choosing the items in each block, we took careful consideration to include items which were not strongly related to each other semantically (e.g., cigarette and ashtray, running and walking), in order to minimize, as much as possible, the chance of participants forming deliberate mental associations. Runs were presented in one of three different pre-randomized orders and each condition was presented three times. Total run time was approximately one hour, including actual testing time, time lags between runs and structural scan acquisition (see Figure I (above) for a simplified schematic of the experimental procedures).

Images (pictures and words) were presented via a computer-controlled projection system that delivered a visual stimulus to a translucent screen placed at the foot of the magnet bore. Participants viewed the images through a mirror system attached to the top of the head coil, and were asked to overtly name each picture and read each word as it appeared on the screen. They heard aurally-presented words for the WRP portion of the task while the screen remained blank. In the PN condition, participants were asked to produce the most concise single word that described the action or object depicted in the picture. In the case of WR and WRP, they were asked to read or repeat the word as it was presented. Participants were instructed to produce names of actions in the infinitive form (e.g., 'mangiare', 'bere', 'dormire', i.e., 'eat', 'drink', 'sleep') and before entering the scanner, they were trained to minimize jaw and tongue movements while naming. At the beginning of each run, the word 'Azioni' ('actions') or 'Oggetti' ('objects') appeared on the screen to indicate how to respond for that particular run. During scanning, participants spoke into a plastic tube attached to the head coil which transmitted the sound outside the scanner room. A small microphone connected to the computer was placed inside the other end of the tube. Participants' responses were thus monitored to make sure they were accurately carrying out the task.

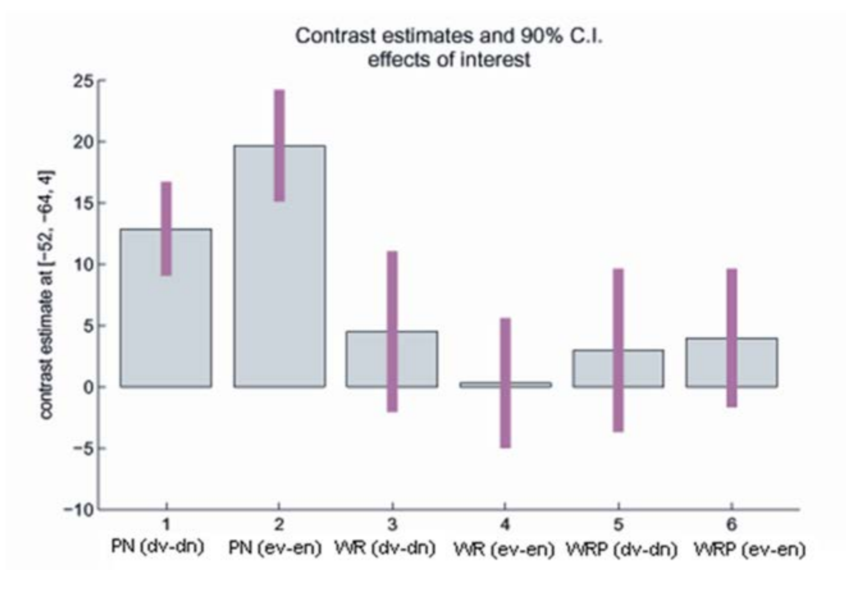
Imaging Parameters and Analysis

Images were acquired on a standard clinical Philips 3T whole body scanner. Spin-echo T1 weighted oblique images were acquired to check head position inside the scanner and to define the functional image volumes. Functional images were collected with an EPI BOLD sequence covering the entire brain (98 repetitions, 34 slices, 4 mm slice thickness, TE 30 ms, TR 2.5 s, flip angle 85 degrees, FOV 240x240). All participants also underwent an MPRAGE acquisition with T1-weighted volumetric spoiled gradient echo MRI scans using the following parameters: matrix 256x256, flip angle 15, slice thickness 1 mm, TR 11 ms, TE 4.6 ms.

Data were analyzed using the program SPM2 (Statistical Parametric Mapping, Wellcome Department of Cognitive Neurology, London, www.fil.ion.ucl.ac.uk). Scans were realigned to the first volume of the first sequence, corrected for slice timing, normalized, and spatially smoothed with an 8 mm FWHM Gaussian kernel. The resulting time-series was high-pass filtered to remove low frequency drifts in the BOLD signal, and the BOLD response for each block was modeled with the canonical hemodynamic response function (HRF). Movement parameter estimates produced by the realignment procedure were entered as confound regressors in the first-level single-subject design matrices, in order to correct for potential movement artifacts caused by the overt naming task.

Contrast images were then combined into a second-level random effects analysis (mixed effects model) as well as a 2 (word type) x 3 (task) x 2 (difficulty) ANOVA, in order to determine whether any regions were significantly more active for one word category over the other (overall as well as within each task and level of difficulty). Differences for objects and actions were measured for difficult and easy items in PN, WR, and WRP. Due to the large amount of activation produced across tasks and participants, we report all planned contrasts which were significant at an FDR corrected level of $p<.05$, with clusters containing at least 100 voxels.

Figure II. 90% Confidence Interval plot for the variables of interest.
This plot, using as reference the largest significant cluster in the overall action > object comparison (Talairach: -52, -64, 4; MNI: -52, -62, 7; left middle temporal gyrus; BA 37; see Table I), reveals that the action > object difference was most significant in PN relative to the other two conditions. Contrasts: PN (dv-dn) = difficult actions – difficult objects in PN; PN (ev-en) = easy actions – easy objects in PN; WR (dv-dn) = difficult actions – difficult objects in WR; WR (ev-en) = easy actions – easy objects in WR; WRP (dv-dn) = difficult actions – difficult objects in WRP; WRP (ev-en) = easy actions – easy objects in WRP.



Results

Our first question was whether processing object versus action items would activate different brain regions. A cluster by cluster analysis for overall effects of interest (at 90% confidence interval) revealed that actions produced significant additional activation over objects (see Figure II, above). Table I (below) lists the coordinates where the overall (i.e., collapsed across tasks) positive 'action minus object' effect was present. Regions of greater relative activation for actions included the posterior middle temporal gyrus bilaterally, the middle superior temporal gyrus bilaterally, the left precentral gyrus, the right fusiform gyrus, and the right cerebellar paravermis. In contrast, there were no regions showing significantly greater activation for objects relative to actions.

Our second question was whether the type of task would influence object versus action activations. To test this, we

Table I: list of significant clusters and their MNI coordinates for the main effect of word type.
All clusters were positive, revealing that these areas (at an FDR corrected level of $p<.05$, 100 voxel minimum) were all significantly more active for actions compared to objects (collapsed across task and difficulty).

Area Name	**Cluster (Ke)**	**F-value**	**Voxel p (FDR-corr)**	**x**	**y**	**z**
L middle temporal gyrus	1019	16.55	0.000	-51	-62	7
L precentral gyrus	210	8.10	0.000	-36	0	48
L superior temporal gyrus	103	7.69	0.001	-61	-6	4
R middle temporal gyrus	774	13.45	0.000	50	-67	14
R fusiform gyrus	230	8.49	0.000	42	-42	-15
R cerebellar paravermis	152	8.20	0.000	14	-73	-23
R superior temporal gyrus	156	7.96	0.001	50	-12	-3

Figure III. Glass brain and overlay plots of action > object activation in PN (relative to the other two tasks).
There were more areas significantly activated for actions relative to objects in PN. At no time did objects produce greater activation than actions. Left side of the figure is left side of the brain.

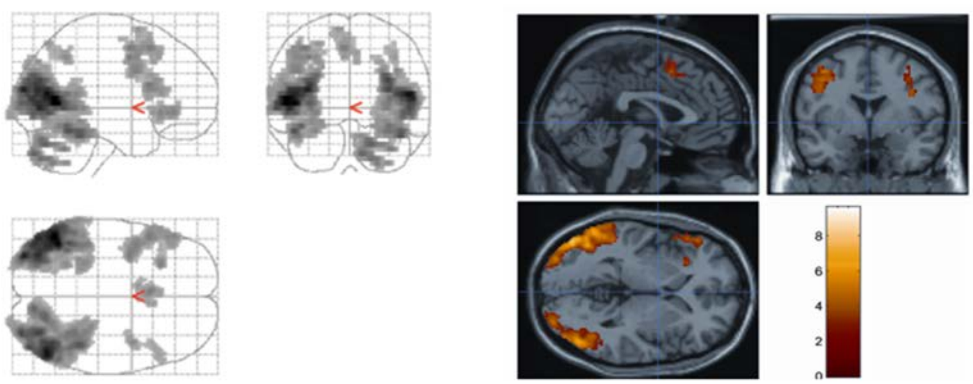
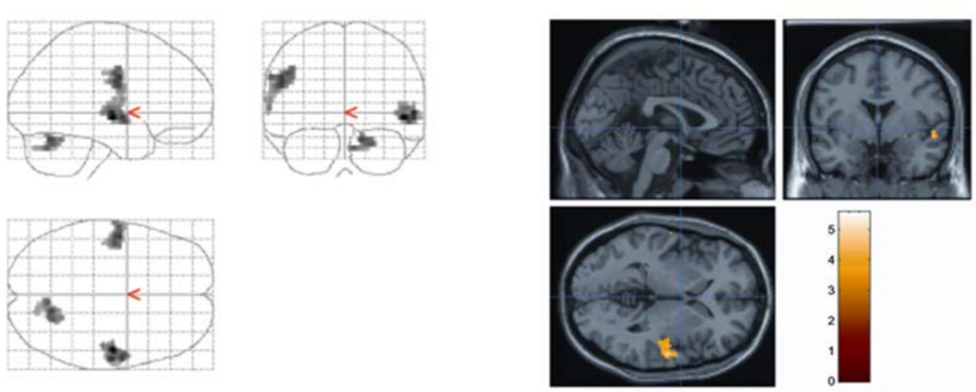


Figure IV. Glass brain and overlay plots of action > object activation in WRP (relative to PN and WR).
As for PN (and unlike for WR), this main effect revealed regions that were significantly more activated for actions relative to objects. However, the activation contrast (or difference score) was lower in WRP relative to PN. Left side of the figure is left side of the brain.



used nested contrasts to compare object versus action differences within each task. The action > object activation reached significance in PN and in WRP (stronger in PN), but not in WR (see Figure II, above). Figures III and IV (below) display significant action > object activation in PN and WRP, respectively. Action > object regions for PN included the posterior middle temporal gyrus (bilaterally), the left precentral gyrus, the right fusiform gyrus, and the right cerebellar paravermis. For WRP, action > object activation was seen in the right posterior middle temporal gyrus.

Finally, we asked whether item difficulty (collapsed across condition and word category) would influence activation. While some clusters tended toward greater activation for difficult relative to easy items, the main effect of difficulty did not reach significance. These results are further explored in the Discussion.

Tables comparing overall activity in each task relative to the other two (collapsed across word type and difficulty) are available in the Appendix but will not be discussed here.

Discussion

This is the first neuroimaging study to compare action (verb) and object (noun) processing across three diverse and highly-studied tasks (picture-naming, reading and repetition) on the same group of healthy participants. Our findings did not reveal regions which discretely process one category versus the other. While there were regions significantly more activated for actions relative to objects in two of the tasks (picture-naming and repetition), no regions elicited greater activation for objects relative to actions. The action > object regions included the posterior middle temporal gyrus bilaterally, the middle superior temporal gyrus bilaterally, the left precentral gyrus, the right fusiform gyrus, and the right cerebellar paravermis. Therefore, these findings argue against the notion of distinct, non-overlapping object versus action areas. Further, they suggest additional activation may be a result of increasing processing demands, since it was seen only for actions, and in the two most challenging tasks (PN and WRP).

These findings complement those of several other Italian language studies. In their lexical decision task, Perani et al. (1999) found shared networks for the two word categories, along with additional activation for verb stimuli in left dorsolateral frontal cortex, superior parietal cortex, and anterior middle temporal cortex (but no noun-only activations). By testing their participants on infinitive verbs, inflected verbs and action nouns, Siri et al. (2008) found that nouns and verbs are largely processed by a common neural system, and suggested that activation differences are a result of increasing linguistic and/or general processing demands (rather than word category). Finally, Berlingeri et al. (2008) tested noun and verb processing in two different tasks: picture naming and grammatical class switching. These authors found greater activation in left inferior frontal gyrus for the word category which was most difficult for each particular task (i.e., verbs in PN and nouns in grammatical class switching). They concluded that additional activity is a reflection of increasing task demands rather than category membership per se.

In a naming study conducted by Martin et al. (1996) using PET, activation in the left middle temporal gyrus was observed during naming of verbs and the tools used to carry out action verbs. These authors suggested that the left MTG may play a role in storing information about visual motion associated with using objects. It is important to note that MTG activation in our study was observed for action repetition as well as action picture-naming. This suggests that this area may be involved in the retrieval of conceptual information about actions, and is not strictly associated with the processing of pictorial stimuli. In an fMRI task comparing syntactic versus semantic processing of written words, Friederici et al. (2000) found that the semantic task selectively activated the left pars triangularis of the inferior frontal gyrus (BA 45) and the posterior part of the left middle/superior temporal gyrus (BA 21/22/37). Finally, although Shapiro et al. (2006) reported distinct, non-overlapping areas of activation for nouns versus verbs as their main finding, they also reported that the majority of the cortical tissue activated was involved in both noun and verb processing, including inferior prefrontal and premotor cortex, middle temporal gyrus, and temporal-occipital junction.

One interpretation for increased activity associated with action relative to object stimuli (as well as poorer performance on actions on several behavioral studies conducted with healthy and patient populations; e.g., Arévalo et al., 2011; 2007; 2005; 2002) is that actions (verbs) entail a higher degree of complexity for a number of reasons discussed in this paper. In the case of the PN task in the current study, higher ambiguity and visual complexity of the pictorial depiction of action relative to object items may explain some of the activation differences. In WRP, the relatively greater activation for repeating actions versus objects may reflect the higher conceptual demands of processing an event which happens over time versus a static object. We predicted that there would be no significant differences in reading action versus object stimuli in an orthographically-transparent language such as Italian, and this prediction was supported by the lack of activation differences between actions and objects in the WR task.

Another finding unique to this study was relatively greater activation in the right middle temporal gyrus for actions in the WRP task. A number of studies have found that acoustic phonetic information (including active maintenance and silent rehearsal) is processed bilaterally in the temporal lobes (Buchsbaum et al., 2001; Hickok & Poeppel, 2004), and more recent work has found that integrating acoustic information over longer timescales may recruit the right hemisphere more than the left hemisphere (Hickok & Poeppel, 2007). Furthermore, Johnsrude et al. (2000) and Zatorre et al. (2002, 2001) have found that lesions to right -- but not left -- primary auditory cortical areas lead to deficits in perceiving pitch and prosody. The increased activation in the right temporal lobe for repeating action words in Italian may reflect 1) a small but significant difference in word length between our action and object stimuli (see **Methods and materials**/*Stimuli*) and/or 2) the larger role played by pitch and prosody in this language (relative to English). For example, most simple verbs in English (often favored in these types of studies due to their high frequency and familiarity) are one- or two-syllable words in their infinitive form (e.g., 'sing', 'listen', 'run', 'pet'). In Italian, infinitive forms are three-, four- or five-syllable words (i.e., 'cantare', 'ascoltare', 'correre', 'accarezzare') with varied stress patterns (i.e., 'canTAre', 'ascolTAre', 'COrrere', 'accareZZAre'). Likewise, English nouns like 'top', 'funnel', and 'stocking' translate as 'trottola', 'imbuto', and 'calza' (pronounced 'TROttola, 'imBUto' and 'CALza').

During on-line word-processing in Italian, which syllable is stressed can help one determine, for example, whether the word refers to a noun (and whether it appears in the singular or plural form) or whether it is a verb (in its infinitive form or in any of a number of possible conjugated forms). For example, the forms 'PETtine', 'PETtini', 'pettiNAre', 'PETtino', and 'PETtinano' correspond to the English forms 'comb' (noun, singular), 'combs' (noun, plural), 'comb' (verb, infinitive form), [I] 'comb' (verb, first person singular form), and [they] 'comb' (verb, third person plural form). The word form and stress patterns in English do not vary at all, and the lexical category each of these forms belongs to can only be deduced from outside contextual cues. Therefore, stress and prosody most likely play a greater role in processing Italian relative to English words. This linguistic difference may therefore explain the WRP activation differences between Price et al.'s (2003) and our study.

Finally, there was no significant effect of difficulty across tasks. Based on behavioral findings, we expected to observe differences in activation between items classed as 'easy' versus 'difficult', at least in PN, the task originally used to create the difficulty classification (Bates et al., 2003, 2001). However, a closer look at the difficulty variable may lead us to rethink our assumptions. As mentioned above, difficulty in this study was determined based on the average response time (RT) for each picture item tested in the original norming study with college-aged control participants. Items classified as 'difficult' were those on the slow end of the RT continuum, while items classified as 'easy' were on the fast end. Would differences in naming speed (always within a normal range) be detected by these tasks in fMRI? While a 'difficult' item may be processed more slowly, it may not require a healthy participant to change his/her processing strategies or recruit different or additional cortical regions/networks. In other words, variations within a narrow processing speed range (as was the case for our stimuli) may not be detectable by measures of cortical activity, at least using the present tasks and tools.

Several studies reviewed in this paper (e.g., Siri et al., 2008; Tyler et al., 2008) as well as other imaging and neuropsychological work (some from our own lab, e.g., Arévalo et al., 2007, 2010; Aziz-Zadeh et al., 2006; Saccuman et al., 2006; Tettamanti et al., 2005) have also explored the notion of motor networks being involved in the processing of action-related concepts, whether these are usually represented as actions/verbs or objects/nouns. In other words, objects with motor affordances (e.g., manipulable objects) may recruit the same brain regions dedicated to actions/verbs. The current study was not designed with this question in mind and therefore does not speak to this issue directly, but the findings here complement such work and should be taken into consideration when reviewing these types of studies as well as in the preparation of future similar work.

In sum, our findings suggest that the regions and networks subserving the processing of action versus object concepts are not doubly dissociable. The relatively greater cortical recruitment associated with the processing of pictures (PN) and spoken words (WRP) representing actions/verbs relative to those representing objects/nouns most likely reflects the fact that increasingly challenging tasks place disproportionately greater demands on the more conceptually complex category (i.e., actions). The fact that we did not see category differences for the third task (i.e., WR), suggests that actions and objects as concepts are not necessarily processed by different regions. Furthermore, all dissociations were consistently unidirectional (i.e., action > object), and a true double dissociation would require a bidirectional split.

Conclusion

This is the very first study in which a rich set of previously normed stimuli were adapted to three very diverse processing tasks and tested on the same group of healthy participants. In support of previous work testing paradigms similar to portions of the current experiment, our results show that actions and objects are not processed separately by discrete brain regions, and that greater relative activity is observed for the conceptually more complex category (i.e., actions) when tasks increase in complexity (i.e., picture-naming and word repetition, relative to word reading).

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Appendix A: target names for all 96 object items.
English translation: English translation of the word in Italian; Difficulty: easy or difficult (see text for explanation of difficulty distinction); RT: average response time for each picture collected during previous norming study with healthy young native speakers of Italian; OVC: objective visual complexity of each picture, measured by the number of pixels in each black and white line drawing (relevant for Picture-Naming); Word frequency: frequency of each word in the Italian language; Age of Acquisition: age at which each word is normally acquired by native speakers of Italian

Objects (Oggetti)	English translation	Difficulty	RT	OVC	Word frequency	Age of Acquisition
AEREO	Airplane	easy	877	16810	3.045	3.34
ALTALENA	Swing	easy	937	21224	0	2.57
ANELLO	Ring	easy	842	7652	2.485	3.4
BAMBINO	Boy	easy	959	15675	4.942	1.7
BANDIERA	Flag	easy	807	9461	2.079	3.82
BIBERON	Babybottle	easy	895	8529	1.946	1.92
BICICLETTA	Bicycle	easy	802	24322	1.946	3
BOTTIGLIA	Bottle	easy	814	6551	2.485	2.74
CAMPANA	Bell	easy	902	11109	0	3.34
CANDELA	Candle	easy	786	8385	2.079	3.54
CANGURO	Kangaroo	easy	888	14555	0	4.08
CAROTA	Carrot	easy	971	13201	1.609	3.44
CASCO	Helmet	easy	887	15650	0	5.42
CAVALLO	Horse	easy	839	18397	3.784	2.68
CHIAVE	Key	easy	784	7493	2.833	3.12
CHITARRA	Guitar	easy	798	12032	1.386	4.33
CUORE	Heart	easy	694	7316	3.829	2.86
DITO	Finger	easy	861	5370	2.197	1.84
ELEFANTE	Elefant	easy	879	24858	0	3.14
FANTASMA	Ghost	easy	937	23538	1.386	3.58
FIOCCO	Bow	easy	979	14836	0	3.48
FIORE	Flower	easy	786	15082	3.401	1.84
FONTANA	Fountain	easy	1010	32442	1.609	3.5
FORCHETTA	Fork	easy	752	8818	0	2.46
FORMAGGIO	Cheese	easy	984	12988	2.996	2.98
FRECCIA	Arrow	easy	859	5990	2.708	4.1
GONNA	Skirt	easy	880	7277	1.792	2.74
GUANTO	Glove	easy	846	11509	0	3.32
IMBUTO	Funnel	easy	938	6468	0	4.1
LAMPADINA	Lightbulb	easy	780	10034	0	3.62
LEONE	Lion	easy	809	32267	0	2.82
MARTELLO	Hammer	easy	984	9533	0	3.82
NASO	Nose	easy	728	4703	2.079	1.74
ORECCHIO	Ear	easy	712	9033	2.996	2.14
OSSO	Bone	easy	856	14370	1.386	3.28
PESCE	Fish	easy	815	12019	2.773	2.64
PETTINE	Comb	easy	709	28324	0	2.72
PIOGGIA	Rain	easy	926	20795	3.258	2.4
RANA	Frog	easy	899	14773	0	2.98
ROSSETTO	Lipstick	easy	864	6029	3.045	4.12
SECCHIO	Bucket	easy	914	14552	0	3.02
SIRINGA	Needle	easy	966	10658	0	4.57
SPAZZOLINO	Toothbrush	easy	930	8597	0	2.76
TAMBURO	Drum	easy	827	39085	0	3.7

TAPPETO	Rug	easy	895	13474	4.407	3.68
TELEFONO	Telephone	easy	713	19758	5.088	2.8
TROMBA	Trumpet	easy	981	13615	0	4.4
UOVO	Egg	easy	783	10440	2.303	2.64
ANCORA	Anchor	difficult	1141	14010	0	4.54
BAMBOLA	Doll	difficult	1060	26607	0	1.8
BASTONE	Cane	difficult	1156	5668	1.946	3.52
BRACCIO	Arm	difficult	1045	6270	2.773	2.34
CALZA	Pants	difficult	1057	16152	2.565	2.84
CANNONE	Cannon	difficult	1013	17678	1.609	4.6
CASTELLO	Castle	difficult	1029	22746	2.303	2.8
CHIESA	Church	difficult	1026	34595	3.555	3.34
CILIEGIA	Cherry	difficult	1210	4325	0	3.14
COCCODRILLO	Crocodile	difficult	1052	14874	0	4
CORONA	Crown	difficult	1056	23655	0	3.73
DELFINO	Dolphin	difficult	1026	9949	0	4.28
DINOSAURO	Dinosaur	difficult	1240	12393	0	4.76
DOCCIA	Shower	difficult	1039	20173	1.792	3.64
DRAGO	Dragon	difficult	1047	19272	0	3.52
FRAGOLA	Strawberry	difficult	1018	16771	0	2.98
GALLINA	Chicken	difficult	1070	12886	0	2.74
GUFO	Owl	difficult	1048	15316	0	4.36
LUCCHETTO	Lock	difficult	1166	9706	0	5.4
LUMACA	Snail	difficult	1020	16426	0	3.28
LUPO	Wolf	difficult	1299	15672	1.609	2.64
MAIALE	Pig	difficult	1122	10411	2.773	3.14
MANETTE	Handcuffs	difficult	1158	21347	0	5.02
MICROFONO	Microphone	difficult	1181	9962	3.401	5.1
MOSCA	Fly	difficult	1111	11935	0	2.98
MUCCA	Cow	difficult	1018	17300	2.197	2.48
NUVOLA	Cloud	difficult	1335	11916	0	2.72
PALA	Shovel	difficult	1043	11955	0	3.76
PAPPAGALLO	Parrot	difficult	1028	18115	0	3.76
PAVONE	Peacock	difficult	1097	62243	0	4.58
PECORA	Sheep	difficult	1297	12385	1.386	3.1
PINGUINO	Penguin	difficult	1157	20074	0	4.64
RINOCERONTE	Rhinoceros	difficult	1126	18320	0	4.96
RUBINETTO	Faucet	difficult	1166	17509	1.386	3.6
SCALA	Ladder	difficult	1122	27602	3.526	3.06
SCIMMIA	Monkey	difficult	1041	18988	0	3.2
SCIVOLO	Slide	difficult	1134	20613	0	2.74
SCOIATTOLO	Squirrel	difficult	1305	21975	0	4.06
SEGA	Saw	difficult	1071	11302	1.792	4.66
SELLA	Saddle	difficult	1048	10307	1.609	4.98
SPADA	Sword	difficult	1056	10243	1.386	3.32
STIVALE	Boot	difficult	1050	8857	1.386	3.72
TOPO	Mouse	difficult	1036	13250	1.386	2.78
TROTTOLA	Top	difficult	1283	10581	0	3.46
VASO	Vase	difficult	1130	20221	1.792	3.22
VENTILATORE	Fan	difficult	1028	35152	0	5.3
VIOLINO	Violin	difficult	1090	8571	0	5.3
VULCANO	Volcano	difficult	1180	54995	0	4.64

Appendix B: target names for all 96 action items.
See Appendix A above for more information

Actions (Azioni)	**English translation**	**Difficulty**	**RT**	**OVC**	**Word frequency**	**Age of Acquisition**
ABBAIARE	Bark	easy	1071	18031	0	2.95
ABBRACCIARE	Hug	easy	1182	16095	0.69	2.9
ACCAREZZARE	Pet	easy	1164	17815	0	3
AFFOGARE	Drown	easy	1045	20210	0	4.2
BACIARE	Kiss	easy	1030	31961	0	2.4
BALLARE	Dance	easy	1083	30516	2.08	2.65
BERE	Drink	easy	797	25613	2.197	1.5
CAMMINARE	Walk	easy	1078	14385	1.95	1.7
CANTARE	Sing	easy	1156	23644	1.61	2.7
CAVALCARE	Ride	easy	1191	18320	0	4.3
CORRERE	Run	easy	1135	17276	1.39	2.25
DIPINGERE	Paint	easy	980	22022	0	4.5
DORMIRE	Sleep	easy	978	33733	3.47	2
FUMARE	Smoke	easy	995	17842	2.4	4.65
GUARDARE	Watch	easy	1206	25732	3.43	2.35
GUIDARE	Drive	easy	1051	35400	1.1	3.55
INDICARE	Point	easy	1132	16800	3.22	4.7
LEGGERE	Read	easy	1081	30065	4.22	3.25
MANGIARE	Eat	easy	1103	21812	4.37	1.25
MARCIARE	March	easy	1193	33014	0.69	5.45
MASSAGGIARE	Massage	easy	1190	21386	0	5.75
MISURARE	Measure	easy	1169	28509	1.95	4.95
MORDERE	Bite	easy	1179	24562	0	2.65
MUNGERE	Milk	easy	1210	28992	0	4.9
NUOTARE	Swim	easy	939	16766	0	3.15
PATTINARE	Skate	easy	1146	17040	0	4.6
PESARE	Weigh	easy	1101	22346	0.69	4.35
PESCARE	Fish	easy	1204	12729	1.39	4.05
PETTINARE	Comb	easy	1013	16924	0	2.85
PIANGERE	Cry	easy	978	22897	2.08	1.5
PIZZICARE	Pinch	easy	1165	17920	0	4.35
PREGARE	Pray	easy	1212	45299	1.39	2.85
REMARE	Row	easy	1200	31568	0	5.3
RIDERE	Laugh	easy	1133	39099	3.14	1.7
SBUCCIARE	Peel	easy	1192	14440	0	4.05
SCIARE	Ski	easy	1040	17193	0	4.85
SCIVOLARE	Slide	easy	1089	32449	2.2	3.45
SEMINARE	Plant	easy	1175	34133	0	5.05
SORRIDERE	Smile	easy	1142	40153	0.69	3.1
SPINGERE	Push	easy	1105	22838	1.1	3.1
SPREMERE	Squeeze	easy	1208	17216	0	4.65
STIRARE	Iron	easy	1138	13323	1.1	4.2
STRAPPARE	Tear	easy	1167	27082	0.69	3.75
SUONARE	Play	easy	1563	36542	1.61	2.4
TAGLIARE	Cut	easy	1703	29384	2.71	3.25
TUFFARSI	Dive	easy	1038	16005	0	4.5
VERSARE	Pour	easy	1062	26916	1.95	4

VOLARE	Fly	easy	1043	13178	2.3	3.05
ACCENDERE	Light	difficult	1359	20907	1.61	2.8
ALLACCIARE	Buckle	difficult	1144	23682	0	3.8
ARARE	Plow	difficult	1444	29785	0	5.65
ASCIUGARE	Dry	difficult	1307	42036	1.61	2.5
ASCOLTARE	Listen	difficult	1328	37439	3.04	3.25
ASPETTARE	Wait	difficult	1338	21443	3.09	2.95
ATTRAVERSARE	Cross	difficult	1552	30627	0.69	3.85
CADERE	Fall	difficult	1278	26229	3	2.15
CONTARE	Count	difficult	1368	16391	1.79	2.5
CUCIRE	Sew	difficult	1242	23884	0	4.3
DIRIGERE	Conduct	difficult	1349	13067	1.1	6.3
ERUTTARE	Erupt	difficult	1392	27002	0	6.5
ESPLODERE	Explode	difficult	1440	23934	1.1	5.1
FISCHIARE	Whistle	difficult	1239	19276	0.69	3.65
ILLUMINARE	Shine	difficult	1496	34381	1.39	5.05
INGINOCCHIARSI	Kneel	difficult	1433	14002	0	3.9
INNAFFIARE	Water	difficult	1254	32706	0	4.35
MACINARE	Grind	difficult	1475	17383	1.1	5.85
MEDITARE	Meditate	difficult	1394	19237	0	6.7
NASCONDERE	Hide	difficult	1323	25967	1.95	2.65
NEVICARE	Snow	difficult	1266	44104	0	3.35
OLIARE	Oil	difficult	1598	11309	0	6.4
OPERARE	Operate	difficult	1335	21850	2.48	5.4
PAGARE	Pay	difficult	1404	27841	4.03	4.45
PERQUISIRE	Arrest	difficult	1464	21843	0	7.3
PULIRE	Wash	difficult	1461	30285	1.61	3.2
PUNGERE	Sting	difficult	1666	23887	0	4
REGALARE	Give	difficult	1210	27760	2.08	3.2
RUGGIRE	Roar	difficult	1357	32379	0	4.75
SALTARE	Jump	difficult	1284	15496	1.1	2.85
SALUTARE	Wave	difficult	1371	15853	2.3	1.8
SALVARE	Rescue	difficult	1405	42839	2.3	4.45
SCOLARE	Strain	difficult	1540	11285	0	5.3
SCRIVERE	Write	difficult	1212	16774	4.06	3
SEDERSI	Sit	difficult	1315	18449	0.69	2.25
SEGARE	Saw	difficult	1250	38695	0	5.05
SERVIRE	Serve	difficult	1239	32192	2.4	5
SGOCCIOLARE	Drip	difficult	1253	3918	0	5.1
SPARARE	Shoot	difficult	1305	19808	1.1	3.95
SPOSARE	Marry	difficult	1292	23413	2.08	4.6
STENDERE	Hang	difficult	1233	37462	1.61	4.3
SUDARE	Sweat	difficult	1278	16947	0	4.05
SVEGLIARSI	Wake up	difficult	1400	26195	0.69	2.55
TIRARE	Pull	difficult	1340	30784	2.71	3.2
TOSARE	Sheer	difficult	1366	31758	0	6.35
TRAPANARE	Drill	difficult	1358	14929	0	6.7
ULULARE	Howl	difficult	1326	18071	0	5.35
VENDERE	Sell	difficult	1268	36299	3.18	4.2

Appendix C: list of clusters and their MNI coordinates for PN.
These areas (at an FDR corrected level of p<.05, 100 voxel minimum) were more active in the PN task relative to WR and WRP (collapsed across word type and difficulty).

Area Name	Cluster (Ke)	T-value	Voxel p (FDR-corr)	x	y	z
L cerebellar paravermis	5889	9.60	0.000	-16	-67	-17
L inferior frontal gyrus	904	6.68	0.000	42	1	29
L postcentral gyrus	485	6.47	0.000	-44	-8	34
L middle occipital gyrus	186	5.23	0.001	-32	-64	33
L hippocampal gyrus	1246	4.91	0.001	-18	-27	-5
R superior temporal lobule	101	5.99	0.000	51	-38	24
R superior frontal gyrus	442	5.79	0.000	4	5	55
R inferior parietal lobe	276	5.64	0.000	28	-50	39

Appendix D: list of clusters and their coordinates for WR.
These areas (at an FDR corrected level of p<.05, 100 voxel minimum) were more active in the WR task relative to PN and WRP (collapsed across word type and difficulty).

Area Name	Cluster (Ke)	T-value	Voxel p (FDR-corr)	x	y	z
L cerebellar paravermis	547	10.07	0.000	-20	-65	-17
L postcentral gyrus	360	7.01	0.000	-44	-10	30
R postcentral gyrus	443	7.02	0.000	57	-5	26

Appendix E: list of clusters and their coordinates for WRP.
These areas (at an FDR corrected level of p<.05, 100 voxel minimum) were more active in the WRP task relative to PN and WR (collapsed across word type and difficulty).

Area Name	Cluster (Ke)	T-value	Voxel p (FDR-corr)	x	y	z
L cerebellar paravermis	2517	10.15	0.000	-20	-65	-17
L superior temporal gyrus	710	7.61	0.000	-51	-16	1
R superior temporal gyrus	1481	12.10	0.000	51	-16	1
R precentral gyrus	153	5.52	0.000	50	-10	41

References

Arévalo, A. (2002). Teasing apart actions and objects: a picture naming study. *CRL Newsletter*, 14(2), May.

Arévalo, A.L., Baldo, J.V., & Dronkers, N.F. (2010). What do brain lesions tell us about theories of embodied semantics and the human mirror neuron system? *Cortex*, doi : 10.1016/j.cortex.2010.06.001

Arévalo, A., Lu, C.-C., Huang, B.-Y., Bates, E.A., & Dronkers, N.F. (2011). Action and object processing in brain-injured speakers of Chinese. *Neuropsychology*, 25(6), 792-805, doi: 10.1037/a0024272.

Arévalo, A., Moineau, S., Saygin, A., Ludy, C., & Bates, E. (2005). In search of Noun-Verb dissociations in aphasia across three processing tasks. *CRL Newsletter*, 17(1), March.

Arévalo, A., Perani, D., Cappa, S., Butler, A., Bates, E., & Dronkers, N. (2007). Action and Object Processing in Aphasia: from Nouns and Verbs to the Effect of Manipulability. *Brain and Language*, Jan, 100(1), 79-94.

Aziz-Zadeh, L., Wilson, S.M., Rizzolatti, G., & Iacoboni, M. (2006). Congruent embodied representations for visually presented actions and linguistic phrases describing actions. *Curr Biol*, 16, 1818-1823.

Bak, T.H., Yancopoulou, D., Nestor, P.J., Xuereb, J.H., Spillantini, M.G., Pulvermüller, F., & Hodges, J.R. (2006). Clinical, imaging and pathological correlates of a hereditary deficit in verb and action processing. *Brain*, 129, 321-332.

Bates, E., Andonova, E., D'Amico, S., Jacobsen, T., Kohnert, K., Lu, C-C., Székely, A., Wicha, N., Federmeier, K., Herron, D., Iyer, G., Pechmann, T., Devescovi, A., Orozco-Figueroa, A., Gutierrez, G., Hung, D., Hsu, J., Tzeng, O., Gerdjikova, G., Mehotcheva, T., & Pleh, C. (2000). Introducing the CRL International Picture-Naming Project (CRL-IPNP). *Center for Research in Language Newsletter*, 12(1). La Jolla: University of California San Diego.

Bates, E., Burani, C., D'Amico, S., & Barca, L. (2001). Word reading and picture naming in Italian. *Memory & Cognition*, 29(7), 986-999.

Bates, E., Chen, S., Tzeng, O., Li, P., & Opie, M. (1991). The noun-verb problem in Chinese aphasia (E. Bates, Ed.). *Brain & Language*, 41(2), 203-233.

Bates, E., D'Amico, S., Jacobsen, T., Szekely, A., Andonova, E., Devescovi, A., Herron, D., Lu, CC, Pechmann, T., Pleh, C., Wicha, N., Federmeier, K., Gerdjikova, I., Gutierrez, G., Hung, D., Hsu, J., Iyer, G., Kohnert, K., Mehotcheva, T., Orozco-Figueroa, A., Tzeng, A., & Tzeng, O. (2003). Timed picture naming in seven languages. *PsychonBullRev*, Jun, 10(2), 344-80.

Berlingeri, M., Crepaldi, D., Roberti, R., Scialfa, G., Luzzatti, C., & Paulesu, E. (2008). Nouns and verbs in the brain: grammatical class and task specific effects as revealed by fMRI. *Cognitive Neuropsychology*, 25(4), 528-58.

Bird, H., Howard, D., & Franklin, S. (2000). Why is a verb like an inanimate object? Grammatical category and semantic category deficits. *Brain & Language*, 72, 246-309.

Buchsbaum, B., Hickok, G., & Humphries, C. (2001). Role of Left posterior superior temporal gyrus in phonological processing for speech perception and production. *Cognitive Science*, 25, 663-678.

Buckner, R.L., Koutstaal, W., Schachter, D.L., & Rosen, B.R. (2000). Functional MRI evidence for a role of frontal and inferior temporal cortex in amodal components of priming. *Brain*, 123, 620-40.

Cappa, S.F., Binetti, G., Pezzini, A., Padovani, A., Rozzini, L., & Trabucchi, M. (1998). Object and action naming in AD and frontotemporal dementia. *Neurology*, 50, 351-5.

Caramazza, A., & Hillis, A.E. (1991). Lexical organization of nouns and verbs in the brain. Nature, 349, 788-790. Chen, S., & Bates, E. (1998). The dissociation between nouns and verbs in Broca's and Wernicke's aphasia: findings from Chinese. Special issue on Chinese aphasia. *Aphasiology*, 12(1), 5-36.

Church, J.A., Coalson, R.S., Lugar, H.M., Petersen, S.E., & Schlaggar, B.L. (2008). A developmental fMRI study of reading and repetition reveals changes in phonological and visual mechanisms over age. *Cerebral Cortex*, 18(9), 2054-2065.

Collina, S., Marangolo, P., & Tabossi, P. (2001). The role of argument structure in the production of nouns and verbs. *Neuropsychologia*, 39(11), 1125-37.

Cotelli, M., Borroni, B., Manenti, R., Alberici, A., Calabria, M., Agosti, C., Arévalo, A., Ginex, V., Ortelli, P., Binetti, G., Zanetti, O., Padovani, A., & Cappa, S. (2006). Action and object naming in frontotemporal dementia, progressive supranuclear palsy and corticobasal degeneration. *Neuropsychology*, Sept; 20(5), 558-65.

D'Amico, S., Devescovi, A., & Bates, E. (2001). Picture naming and lexical access in Italian children and adults. *Journal of Cognition and Development*, 2(1), 71-105.

Daniele, A., Giustolisi, L., Silveri, M.C., Colosimo, C., & Gainotti, G. (1994). Evidence for a possible neuroanatomical basis for lexical processing of nouns and verbs. *Neuropsychologia*, 32(11), 1325-1341.

De Bleser, R., & Kauschke, C. (2003). Acquisition and loss of nouns and verbs: parallel or divergent patterns? *Journal of Neurolinguistics*, 16(2-3), 213-29.

Devlin, J. T., Moore, C. J., Mummery, C. J., Gorno-Tempini, M. L., Phillips, J. A., Noppeney, U., et al. (2002). Anatomic constraints on cognitive theories of category specificity. *NeuroImage*, 15, 675-685.

Frattali, C. (2005). What's in a name? Commentary on Szekely et al., 2005, Timed action and object naming. *Cortex*, 41, 3-5.

Friederici, A.D., Meyer, M., & von Cramon, D.Y. (2000). Auditory language comprehension: an event-related fMRI study on the processing of syntactic and lexical information. Brain & Language, 75(3), 465-77.

Friederici, A.D., Opitz, B., & von Cramon, D.Y. (2000). Segregating semantic and syntactic aspects of processing in the human brain: an fMRI investigation of different word types. *Cerebral Cortex*, 10(7), 698-705.

Han, Z., Bi, Y., Zhou, Y., & Shu, H. (2007). Does real grammatical class effect in word production exist in isolating languages? *Brain & Language*, 103, 8-249.

Hickok, G., & Poeppel, D. (2007). The cortical organization of speech processing. *Nature Neuroscience Reviews*, May, Vol. 8, 393-402.

Hickok, G., & Poeppel, D. (2004). Dorsal and ventral streams: a framework for understanding aspects of the functional anatomy of language. *Cognition*, 92(1-2), 67-99.

Hillis, A.E., Tuffiash, E., Wityk, R.J., & Barker, P.B. (2005). Regions of neural dysfunction associated with impaired naming of actions and objects in acute stroke. *Cognitive Neuropsychology*, 19(6), 523-534.

Johnsrude, I.J., Penhune, V.B., & Zatorre, R.J. (2000). Functional specificity in right human auditory cortex for perceiving pitch direction. *Brain*, 123, 155-163.

Jonkers, R., & Bastiaanse, R. (1998). How selective are selective word class deficits?: Two case studies of action and object naming. *Aphasiology*, 12, 193-206.

Kambanaros, M. (2008). The trouble with nouns and verbs in Greek fluent aphasia. *Journal of Communication Disorders*, 41, 1-19.

Laiacona, M., & Caramazza, A. (2004). The noun/verb dissociation in language production: varieties of causes. *Cognitive Neuropsychology*, 21, 103-123.

Laine, M., & Martin, N. (1996). Lexical retrieval deficit in picture naming: implications for word production models. Brain & Language, 53, 283-314. Li, P., Jin, Z., & Tan, L.H. (2004). Neural representations of nouns and verbs in Chinese: an fMRI study. *NeuroImage*, 21, 1533-41.

Longe, O., Randall, B., Stamatakis, E.A., & Tyler, L.K. (2007). Grammatical categories in the brain: the role of morphological structure. *Cerebral Cortex*, 17, 1812-1820.

Lu, C.-C., Bates, E., Hung, D., Tzeng, O., Hsu, J., Tsai, C.-H., & Roe, K. (2001). Syntactic priming of nouns and verbs in Chinese. *Language and Speech*, 44(4), p. 437-471.

Luzzatti, C., Raggi, R., Zonca, G., Pistarini, C., Contardi, A., & Pinna, G. (2002). Verb- Noun double dissociation in aphasic lexical impairments: the role of word frequency and imageability. *Brain and Language*, 81, 432-444.

Martin, A., Wiggs, C.L., Ungerleider, L.G., & Haxby, J.V. (1996). Neural correlates of category-specific knowledge. *Nature*, 379, 649-652.

Miceli, G., Silveri, M., Villa, G., & Caramazza, A. (1984). On the basis for the agrammatic's difficulty in producing main verbs. *Cortex*, 20, 207-220.

Paulesu, E., McCrory, E., Fazio, F., Menoncello, L., Brunswick, N., Cappa, S.F., Cotelli, M., Cossu, G., Corte, F., Lorusso, M., Pesenti, S., Gallagher, A., Perani, D., Price, C., Frith, C.D., & Frith, U. (2000). A cultural effect on brain function. *Nature Neuroscience*, 3(1), 91-96.

Péran, P., & Démonet, J.-F. (2008). Paroxetine-induced modulation of cortical activity supporting language representations of action. Psychopharmacology, 195, 487-96.

Perani, D., Cappa, S.F., Schnur, T., Tettamanti, M., Collina, S., Rosa, M.M., & Fazio, F. (1999). The neural correlates of verb and noun processing: a PET study. *Brain*, 122, 2337-2344.

Price, C.J. (1998). The functional anatomy of word comprehension and production. *Trends in Cognitive Sciences*, 2(8), 281-287.

Price, C.J. (2000). The functional anatomy of language. Contributions from Neuroimaging. *Journal of Anatomy*, 197, 335-359.

Price, C.J., McCrory, E., Noppeney, U., Mechelli, A., Moore, C.J., Biggio, N., & Devlin, J.T. (2006). How reading differs from object naming at the neuronal level. *NeuroImage*, 29, 643-648.

Price, C.J., Noppeney, U., Phillips, J., & Devlin, J.T. (2003). How is the fusiform gyrus related to category-specificity? *Cognitive Neuropsychology*, 20, 561-574.

Price, C.J., Winterburn, D., Graud, A.L., Moore, C.J., & Noppeney, U. (2003). Cortic localisation of the visual and auditory word form areas: A reconsideration of the evidence. *Brain & Language*, 86, 272-286.

Rhee, J., Antiquena, P., & Grossman, M. (2001). Verb comprehension in frontotemporal degeneration: the role of grammatical, semantic and executive components. *Neurocase*, 7(2), 173-84.

Rogers, T.T., Hocking, J., Mechelli, A., Patterson, K., & Price, C. (2005). Fusiform activation to animals is driven by the process, not the stimulus. *Journal of Cognitive Neuroscience*, 17, 434-445.

Saccuman, M.C., Cappa, S.F., Bates, E.A., Arevalo, A., Della Rosa, P., Danna, M., & Perani, D. (2006). The impact of semantic reference on word class: an fMRI study of action and object naming. *Neuroimage*, 32(4), 1865-1878.

Shapiro, K.A., Moo, L.R., & Caramazza, A. (2006). Cortical signatures of noun and verb production. *PNAS*, 103(5), 1644-1649.

Siri, S., Tettamanti, M., Cappa, S.F., Della Rosa, P., Saccuman, C., Scifo, P., & Vigliocco, G. (2008). The neural substrate of naming events: effects of processing demands but not of grammatical class. *Cerebral Cortex*, 18(1), 171-177.

Sörös, P., Cornelissen, K., Laine, M., & Salmelin, R. (2003). Naming actions and objects: cortical dynamics in healthy adults and in an anomic patient with a dissociation in action/object naming. *NeuroImage*, 19, 1787-1801.

Székely, A., D'Amico, S., Devescovi, A., Federmeier, K., Herron, D., Iyer, G., Jacobsen, T., Arévalo, A., Vargha, A., & Bates, E. (2005). Timed action and object naming. *Cortex*, 41(1), 7-26.

Tettamanti, M., Buccino, G., Saccuman, M.C., Gallese, V., Danna, M., Scifo, P., Fazio, F., Rizzolatti, G., Cappa, S.F., & Perani, D. (2005). Listening to action-related sentences activated fronto-parietal motor circuits. *Journal of Cognitive Neuroscience*, 17(2), 273-81.

Tranel, D., Martin, C., Damasio, H., Grabowski, T.J., & Hichwa, R. (2005). Effects of noun-verb homonymy on the neural correlates of naming concrete entities and actions. *Brain & Language*, 92, 288-99.

Tyler, L.K., Bright, P., Fletcher, P., & Stamatakis, E.A. (2004). Neural processing of nouns and verbs: the role of inflectional morphology. *Neuropsychologia*, 42, 512-523.

Tyler, L.K., Randall, B., & Stamatakis, E.A. (2008). Cortical differentiation for nouns and verbs depends on grammatical markers. *Journal of Cognitive Neuroscience*, 20(8), 1381-89.

Tyler, L.K., Russell, R., Fadili, J., & Moss, H.E. (2001). The neural representation of nouns and verbs: PET studies. *Brain*, 124, 1619-1634.

Tyler, L.K., Stamatakis, E.A., Dick, E., Bright, P., Fletcher, P., & Moss, H. (2003). Objects and their actions: evidence for a neurally distributed semantic system. *NeuroImage*, 18(2), 542-557.

Vigliocco, G., Warren, J., Siri, S., Arcuili, J., Scott, S., & Wise, R. (2006). The role of semantics and grammatical clss in the representation of words. *Cerebral Cortex*, 16(12), 1790-6.

Warburton, E., Wise, R.J., Price, C.J., Weiller, C., Hadar, U., & Ramsay, S. (1996). Noun and verb retrieval by normal subjects. Studies with PET. [Review]. *Brain*, 119, 159-79.

Zatorre, R.J., & Belin, P. (2001). Spectral and temporal processing in human auditory cortex. *Cerebral Cortex*, 11, 946-953.

Zatorre, R.J., Belin, P., & Penhune, V.B. (2002). Structure and function of auditory cortex: music and speech. *Trends in Cognitive Sciences*, 6(1), 37-46.

Zingeser, L.B., & Sloan Berndt, R. (1990). Retrieval of nouns and verbs in agrammatism and anomia. *Brain and Language*, 39, 14-32.