Neural basis of generation of conclusions in elementary deduction

- supplementary online material -

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Effects of negation

In the main analyses we did not consider a further possible factor that was embedded in the stimuli in order to make them superficially different among each other. This further factor relates to the number and position of negations in either the second or the third premise. The negation status of the first premise is determined by the status of the other two: this is a structural need in integrable

Table 1 Examples of premises belonging to different level of the three factors: integrability, type of problem and negation. For the sake of simplicity only P_1 and P_2 are presented, but the same classification can be extend to P_3 in a straightforward way.

		Conditional	Disjunctive
integrable	N 1	There is a square If there is a square then there is a triangle	There is not a square Either there is a square or there is a triangle
	N2	There is a square If there is a square then there is not a triangle	There is not a square Either there is a square or there is not a triangle
	N3	There is not a square If there is not a square then there is a triangle	There is a square Either there is not a square or there is a triangle
	N4	There is not a square If there is not a square then there is not a triangle	There is a square Either there is not a square or there is not a triangle
non-integrable	N 1	There is a rectangle If there is a square then there is a triangle	There is not a rectangle Either there is a square or there is a triangle
	N2	There is a rectangle If there is a square then there is not a triangle	There is not a rectangle Either there is a square or there is not a triangle
	N3	There is not a rectangle If there is not a square then there is a triangle	There is a rectangle Either there is not a square or there is a triangle
	N4	There is not a rectangle If there is not a square then there is not a triangle	There is a rectangle Either there is not a square or there is not a triangle

sentences and a methodological choice in non integrable sentences (in order to make them a perfect mirror of the integrable counterpart). In particular, for this factor “negation” four basic levels can be identified. In the first level the premise do not contain any negation (see N1 in Tab. 1), in the second level the premise contain one negation in the consequent (i.e. what follows if the inference is valid, see N2), in the third level premises contain one negation in the antecedent (see N3), and in the fourth premises contain two negations.

In order to explore the possible effects of negation, we firstly considered whether negative or positive existential sentences were equally easy to be integrated with the succeeding conditional/disjunctive sentences. Thus, we explored whether existential positive or negative sentences (respectively EP and EN) produced different rates of error or required more time to be integrated with the succeeding sentences.

Table 2 Problem types with the existential sentence positive and negative. The abbreviations refer to the examples in Tab. 1

	Existential Positive (EP)	**Existential Negative (EN)**
Conditional	N1 + N2	N3 + N4
Disjunctive	N3 + N4	N1 + N2

Two ANOVAs were run, both having as independent factors “type of problem” and “sign of the existential sentence” (see Tab. 2). In the first ANOVA, we introduced as dependent variable accuracy (Fig. 1). None of the factors was significant. More specific paired t-tests comparing EP vs. EN within each level of type of problem factor, produced the same result [cond: t (13) = 0.21, p = 0.84; disj t (13) = 0.92, p = 0.37]. In the second ANOVA, we introduced as dependent variable the integration time (Fig. 1). In this case we obtained a significant effect for the factor “type of problem” [F(1,13) = 69.2, $p < 0.001$], meaning that the integration of disjunctive sentences takes longer than integration of conditional sentences. Again the specific paired t-tests comparing EP vs. EN were not significant (cond: t (13) = 0.53, p = 0.59; disj t (13) = 0.50, p = 0.49].

Analyses on the effect of the sign of the existential sentence were also run on neuroimaging data. We investigated, for either conditional or disjunctive problems, whether the integration of sentences preceded by an existential positive or an existential negative sentence activated different brain areas. We re-run first level analyses in order to obtain, for each subject, four contrast images (all representing a integrable > non-integrable contrast) corresponding to each cell of a 2 x 2 ANOVA design with factors type of problem (conditional or disjunctive) and sign of the existential sentence (positive or negative). With these contrast images, we then run a second level analysis, using a 2x2 ANOVA with factors type of problem and sign of the existential sentence. The latter factor was not significant in anywhere (at $p < 0.001$ uncorrected). Furthermore, we performed on the same contrast images a Region of Interest (ROI) analysis, using as ROIs the two active clusters we found in the main analysis (Fig. 2 of the paper). We extracted from each subject the average activity related to the integration of premises preceded by either an existential positive or negative sentence, in either conditional or disjunctive problems. Thus eight indexes of regional activity were available for each subject (Fig. 2). We introduced these indexes in a 2x2x2 ANOVA with factors cluster (frontal or parietal), type of problem (conditional or disjunctive) and sign of the existential (positive or negative). Only the factor “type of problem” was significant, meaning that a higher brain activity was necessary to integrate disjunctive than conditional premises.

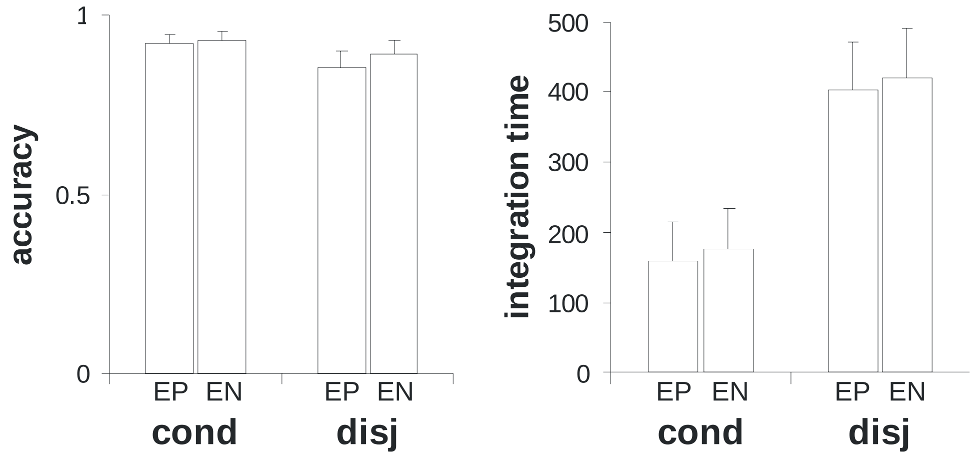

Figure 1 Accuracy rate (on the left) and integration time (on the right) for either conditional or disjunctive problems with existential positive (EP) or existential negative (EN) sentences.

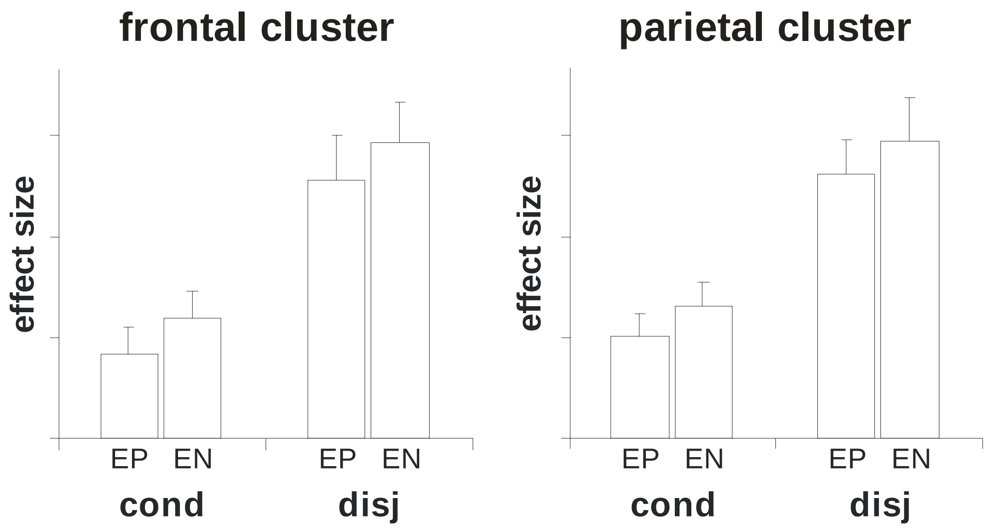

Figure 2 Average activity in the two clusters identified by the main analysis (see Fig. 2 in the paper). The plots separate the integration effect due to premises preceded by an existential positive (EP) or an existential negative (EN), a conditional inference (cond) or a disjunctive inference (disj).

In a second set of analyses related to negation, we explored whether the presence of a variable number of negations (from zero to two) in an integrable or non integrable premise has an impact on the time required to process the sentence itself. Thus we evaluated the processing time in premises containing zero (see N1 in Tab. 1), one (N2+ N3) or two (N4) negations, either in conditional or in disjunctive problems. As can be noticed in Fig. 3, the number of negations in the premises produced a monotonical increase in the time required to process the sentence both in the integrable and in non-integrable sentences. The factor "number of negations" was highly significant when introduced in a 3 (negations) x 2 (integrability) x 2 (connective) ANOVA with dependent variable processing time [$F(2,26) = 59.1$, $p < 0.001$]. Also other main effects were, as expected, highly significant [integrability: $F(1,13) = 26.7$, $p < 0.001$; type of problem: $F(1,13) = 29.8$, $p < 0.001$]. Interestingly the interaction number of negations x integrability was not significant, meaning that the effect of negations was present in both integrable and non integrable premises. This conclusion is confirmed by specific one-way ANOVAs on the negation factor in both integrable and non-integrable sentences [non-integrable $F(2,26) = 37.9$, $p < 0.001$; integrable: $F(2,26) = 45.1$, $p < 0.001$]. Finally, we report that the effect of negation was also present during processing of the first sentence. Negative P1 required on average 957 ms (SD = 192) to be processed while positive P1 required 806 ms (SD = 163). The difference is significant [$t\ (13) = 9.4$, $p < 0.001$].

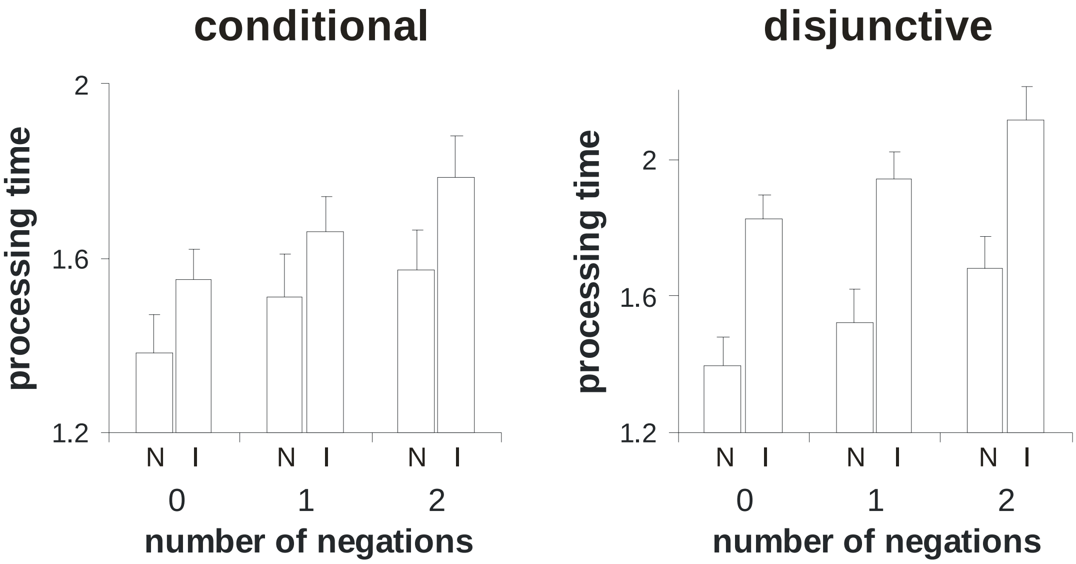

Figure 3 Processing time for either conditional (on the left) or disjunctive (on the right) premises containing different numbers of negations. N: non-integrable sentences; I: integrable sentences.

A comment on the logical equivalence of conditionals and disjunctions

From a logical standpoint, disjunctive premises such as “not p or q” or “p or q” are equivalent – respectively - to “if p then q” and “if not p then q”. If logical equivalence directly translates into psychological equivalence, then some of those sentences might be mentally translated one into the other. For example, subjects confronting integrable disjunctive trials N3 (Tab. 1, Supplementay Material) might mentally translate them into integrable conditional trials N1. However, there is evidence in previous literature that logical equivalence does not map directly on psychological equivalence. For example, Johnson-Laird and Tagart (1969) investigated subjects’ interpretation of the conditional “If P then Q” and its equivalent disjunctive “Not P or Q” using a truth-table evaluation task. They found that instances containing a negation of the antecedent as one component were most likely to be classified as irrelevant for conditionals, whereas for disjunctives these instances were most likely to be classified as true. More recently, Richardson and Ormerod (1997), by using a rephrasing task, falsified the long-held assumption that “if not p then q” conditionals are spontaneously read as “p or q”. Finally, a very recent unpublished study by Manfrinati, Giaretta and Cherubini found an interesting directional effect: 40% of subjects accepted problems with the logical structure “if not p then q, therefore p or q”, vs 75% ($p < .05$) who accepted similar problems, but with the inverse order “p or q; therefore, if not p then q”. In a control task, where the subjects were not asked to evaluate entailment relationships, but the perceived equivalence of the two sentences, only 30% of participants accepted that “p or q” and “if not p then q” had the same meaning, replicating and strengthening Richardson and Ormerod’s conclusion. In the light of these studies, we think that it is not likely that subjects in our experiments spontaneously translated disjunctions into conditionals, or conditionals into disjunctions. As further evidence for this claim, consider the previously reported results that the pattern of performance for “p; not p or q” problems was not distinguishable from the performance with the other subclass of disjunctive problems, while it was different from the performance on conditional problems (Figures 1, above). The same is true for brain activation measures (Figure 2 above).

Effect of Training and Practice

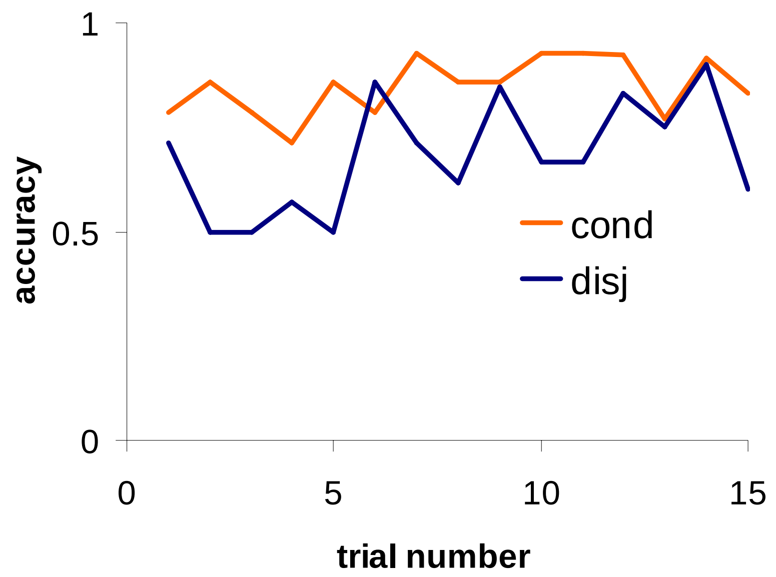

Figure 4 Average accuracy during the first 30 trials of the training. The plot shows accuracy separated for conditional (cond) and disjunctive (disj) problems. The random level was 25%.

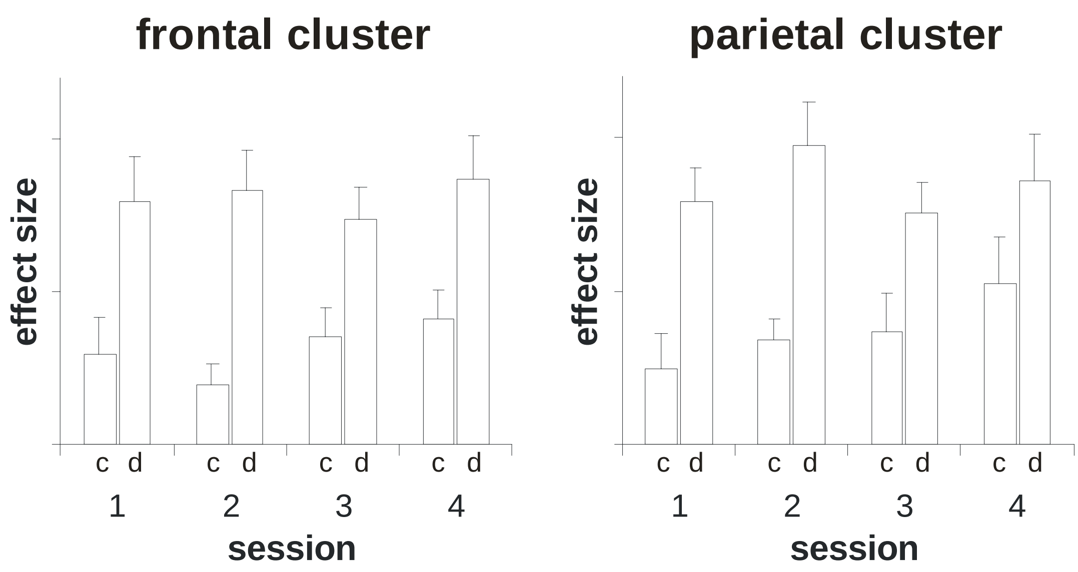

Figure 5 Average activity in the two clusters identified by the main analysis (see Fig. 2 in the paper). The plot shows the activation due to premise integration in each of the four *f*MRI sessions. c: conditional problems; d: disjunctive problems. In an ANOVA 4 (session) x 2 (problem type) x 2 (cluster) ANOVA, we found significant only the factor problem type [F(1,13) = 46.7, $p < 0.001$]. Neither the main effect of session [F(1,13) = 0.89, $p = 0.45$] or the interaction session x problem type were [F(1,13) = 0.99, $p = 0.40$] were significant.

Control study on learning rate during training

Training procedure may have induced ad-hoc, task-specific associative strategies for responding to the task. The hypothesis is that subjects actually did not rely on the logical properties of the connectives in the premises (if, then, or, not). Instead they created, during training, schemata of solution tailored on the specific requirement of our task. If this hypothesis is correct, training on a task identical to the one in the main experiment, but substituting all connectives in the premises with invented words, should attain a learning curve and a final performance similar to the one observed in the main experiment.

Methods

We recruited 10 graduate and undergraduate students from the University Milano-Bicocca. In this control study we administered the training phase of the deductive task used for the main *f*MRI experiment. The procedure and materials were identical to the training of the main experiment, except that all logical connectives in the stimuli were replaced by a phonologically plausible, equal length non-word. “Se” (if) was replaced by “ra”, “allora” (then) by “porenu”, “oppure” (or) by “mofito” and “non” (not) by “lop”. As in the training for the *f*MRI experiment, correctness feedback was given after each trial. For error trial, feedback consisted of presenting again the whole problem along with the correct response. Subjects were told that initial responses were necessarily random, but they had to try to learn from the feedbacks the underlying structure of the trials, in order to maximize their correct responses. The training phase ended on reaching a 90% correct response rate in 20 consecutive trials. A minimum of 30 trials was administered. If the subjects did not attain the criterion after 160 trials, the experiment was interrupted.

Results and discussion

Overall, the performance in the non-word version of the training was worse than the performance in the training preceding the *f*MRI experiment. The non-word training lasted on average 130 trials (SD: 45; median: 160[1]) and 36 minutes (SD: 13; median: 40 minutes). The median time in the training of the *f*MRI experiment was 13.2 minutes, and the median number of trial was 40. Only four subjects out of ten attained the criterion, while every subject attained it in the *f*MRI version. Average accuracy in the last 30 trials of the non-word version of the training was 0.59 (SD: 0.18) and 0.55 (SD: 0.14), respectively for conditional-like and disjunctive-like problems. The difference between problem types was not significant. By contrast, in the *f*MRI version of the training we

[1] The median is equal to the maximum number of trials administered because more than half of the subjects did not attain the criterion.

obtained 0.92 (SD: 0.7) and 0.72 (SD: 0.07), respectively for conditional and disjunctive problems. The difference between problem types was significant [$t(11) = 6.7$, $p < 0.001$]. The difference in accuracy over the last 30 trials between the two training types was significant both for conditional [$t(22) = 5.91$, $p < 0.001$] and disjunctive problems [$t(22) = 3.64$, $p = 0.006$]. When asked at the end of the experiment, none of the subjects was able to "translate" the non-words in the corresponding Italian logical connective.

The results show that even though few subjects could acquire task-specific strategies for solving the task without recourse to the background knowledge concerning logical connectives in natural language, most subjects did not manage to do it even after 160 trials (by far more than the median 40 trials required in the training procedure of the fMRI experiment). This finding corroborates the idea that subjects in the fMRI experiment actually used what they knew about the meaning of the natural language connectives, instead of trying to devise task-specific strategies.

Table 3 Brain activations related to deductive reasoning observed in preceding studies. For each study we considered only the main effect of reasoning against a baseline. Overlapping activations with the present study were emphasized.

	L-BA 44/45	**L-BA 6**	**L-BA 40**	**Other Left Hemisphere**	**Right Hemisphere**	**Task type**
Osherson et al., 1998		●		18, basal ganglia, cerebellum	basal ganglia, cerebellum	Concrete Syllogisms
Goel et al., 1997	●			19, 47		Concrete syllogisms and conditional
Goel et al., 1998	●			21, 22, 24, 32, 46, 47		Concrete syllogisms
Goel et al., 2000	●			7, 18, basal ganglia	18, 45, basal ganglia	Abstract syllogisms
	●			21, 22, basal ganglia	cerebellum, basal ganglia	Concrete syllogisms
Goel and Dolan, 2003	●	●		17, 18, cerebellum, 21, 22, 38	17, 18, basal ganglia	Concrete syllogisms
Goel and Dolan, 2004	●	●		18, 19, 37, 39, basal ganglia, cerebellum	6, 7, basal ganglia	Concrete syllogisms
Noveck et al., 2004				7, 19, 37		Simple propositional reasoning (modus ponens)
		●		7, 32, 47		Complex propositional reasoning

Monti et al., under revision		●	●	7, 8, 10, 11, 47, 48	6, 8, 10, 47	Complex propositional reasoning
Goel et al., 1998	●			8, 21	21	Spatial relational reasoning
	●			8, 9, 10, 21		Non-spatial relational reasoning
Goel and Dolan, 2001				7, cerebellum	7, 17, 18, cerebellum	Abstract relational reasoning
Acuna et al., 2002		●	●	8, 7, 9, 39, 46, insula, basal ganglia	6, 7, 8, 9, 24, 32, 39, 40, 46, insula, thalamus	Relational reasoning
Knauff et al., 2003				7, 21, 38, 46, 47	6, 7, 21	Relational reasoning
Ruff et al., 2003				9, 38	32, 46, 48, cerebellum	Relational reasoning
Goel et al., 2004		●	●	4, 7, 9, 11, 18, 19, 46, basal ganglia	7, 11, 18, 19, 47, basal ganglia	Unfamiliar Relational reasoning
Fangmeier et al., 2006				10	Basal ganglia	Relational reasoning, integration phase

BA: Brodmann Area; L: Left. All numbers in the fifth and sixth column refers to Brodmann Areas.

Table 4 Full list of the studies used for the literature revision on the "language complexity" effect. We selected the set of studies that contrasted the comprehension of "linguistically complex" versus "linguistically simple" verbal sentences (Friederici et al., 2006). In the former type of sentences is assumed that additional rule-based operations (e.g. "syntactic movement") are necessary to correctly map the meaning onto the form of the stimulus. On the first column the figure representing the study in Fig. 6 (supplementary material) is reported. Notice that in Fig. 6 we plotted only points with the x coordinate < -12.

	Study	Talairach coordinates			Cerebral region
		x	y	z	
■ (blue square)	Stromswold et al., 1996	-46	9	4	left inferior frontal operculum
■ (cyan square)	Caplan et al., 1998	10	6	52	supplementary motor area
		-2	6	40	cingolate cortex
		-42	18	24	left inferior frontal gyrus
■ (brown square)	Caplan et al., 1999	-52	18	24	left inferior frontal gyrus
■ (green square)	Dapretto and Bookheimer, 1999	-44	22	10	left inferior frontal gyrus
■ (purple square)	Caplan et al., 2000	-46	36	4	left inferior frontal gyrus
● (blue circle)	Cooke et al., 2002	-48	-68	-8	inferior occipital cortex
		-4	-92	-8	lingual gyrus
		28	-68	-20	right cerebellum
● (cyan circle)	Roder et al., 2002	-45	12	16	left inferior frontal gyrus
		-47	-45	9	left middle temporal gyrus
		-44	3	36	left precentral gyrus
		-2	6	50	supplementary motor area
		31	19	2	right insula
● (brown circle)	Ben-Shachar et al., 2003	-45	23	7	left inferior frontal gyrus
		-53	-42	7	left middle temporal gyrus
		55	-33	8	right superior temporal gyrus
● (green circle)	Ben-Shachar et al., 2004	-43	21	7	left inferior frontal gyrus
		-41	11	27	left inferior frontal gyrus
		-56	-42	7	left middle temporal gyrus
		58	-31	6	right superior temporal gyrus
● (purple circle)	Bornkessel et al., 2005	-43	14	18	left inferior frontal gyrus
		-52	-43	18	left superior temporal gyrus
		-47	-58	24	left middle temporal gyrus

	-35	5	35	left precentral gyrus
	-35	-1	50	left precentral gyrus
	-28	-58	38	left occipital cortex
	41	-43	50	right inferior parietal
	-40	-58	0	left inferior temporal
	17	-79	15	right calcarine cortex
◆ Fiebach et al., 2005	-44	21	11	left inferior frontal gyrus
	45	21	10	right inferior frontal cortex
	-46	17	4	left inferior cortex
	-54	7	28	left precentral gyrus
	-54	-27	-1	left middle temporal gyrus
	-52	-46	6	left middle temporal gyrus
	45	-18	-3	right superior temporal gyrus
	-18	-18	12	left thalamus
◆ Grewe et al., 2005	-32	20	2	left insula
	-52	14	15	left inferior frontal gyrus
	44	26	18	right inferior frontal gyrus
◆ Friederici et al., 2006	-49	10	4	left inferior frontal gyrus

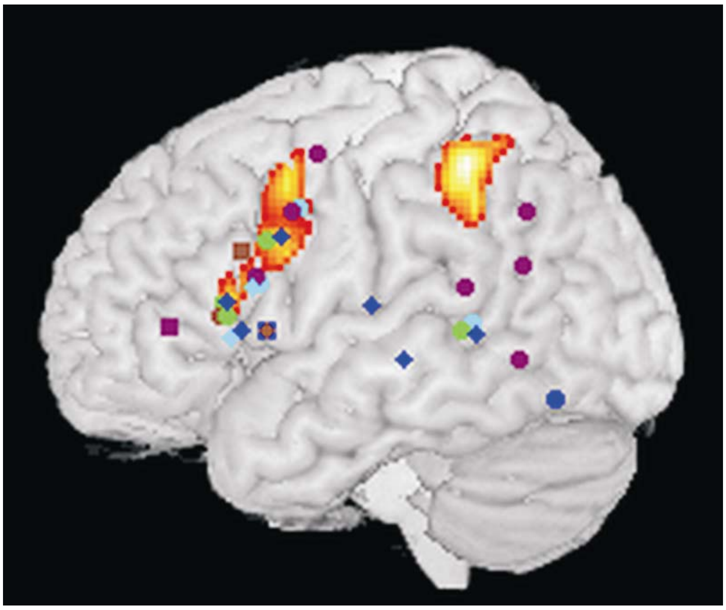

Figure 6 Foci of activations from thirteen experiments on rule-based manipulations during language comprehension are plotted along with an overlay of the activations obtained in this study onto a 3D rendered canonical brain image. Each combination of shape (diamond, circle, square) and color represents a single study (see Tab. 4 online for a full list). Foci are plotted only if their x-coordinate was less than -12 mm, in order to avoid lateral projection of medial foci.

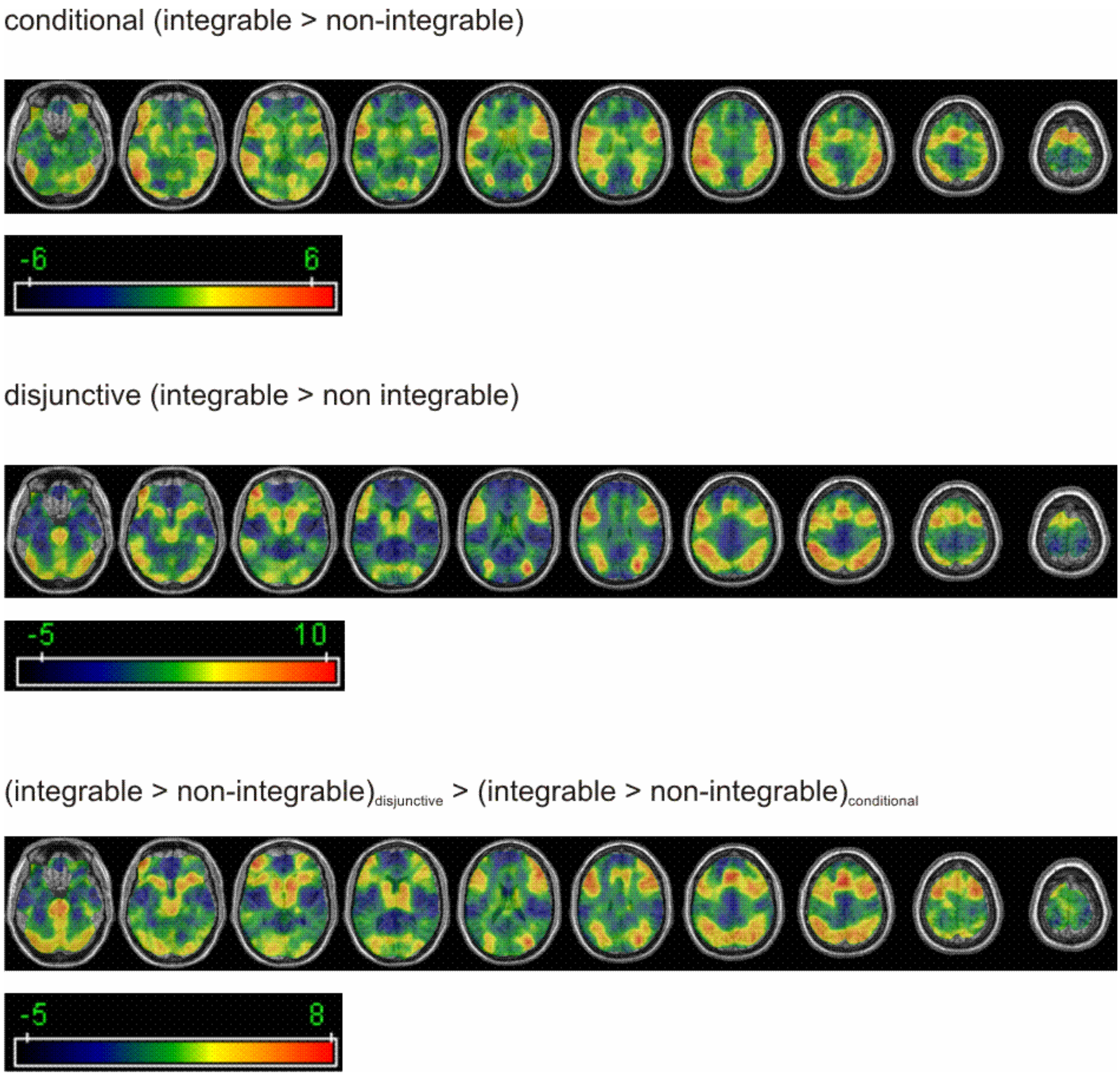

Figure 7 Unthresholded t-maps for each basic contrast we used in the conjunction analysis. Relevant scale is reported under each plot. Talairach z-coordinates (Talairach and Tournoux, 1988) of each transverse slice are -17, -7, 3, 13, 23, 33, 43, 53, 63, 73.

REFERENCES

Acuna, B.D., Eliassen, J.C., Donoghue, J.P., Sanes, J.N., 2002. Frontal and parietal lobe activation during transitive inference in humans. Cerebral Cortex 12, 1312-1321.

Ben-Shachar, M., Hendler, T., Grodzinsky, Y., Kahn, I., Ben-Bashat, D., 2003. The Neural Reality of Syntactic Transformations: Evidence from Functional Magnetic Resonance Imaging. Psychological Science 14, 433.

Ben-Shachar, M., Palti, D., Grodzinsky, Y., 2004. Neural correlates of syntactic movement: Converging evidence from two fMRI experiments. NeuroImage 21, 1320.

Bornkessel, I., Zysset, S., Friederici, A.D., von Cramon, D.Y., Schlesewsky, M., 2005. Who did what to whom? The neural basis of argument hierarchies during language comprehension. Neuroimage 26, 221-233.

Caplan, D., Alpert, N., Waters, G., 1998. Effects of syntactic structure and propositional number on patterns of regional cerebral blood flow. Journal of Cognitive Neuroscience 10, 541.

Caplan, D., Alpert, N., Waters, G., 1999. PET studies of syntactic processing with auditory sentence presentation. Neuroimage 9, 343-351.

Caplan, D., Olivieri, A., Alpert, N., Waters, G., 2000. Activation of Broca's area by syntactic processing under conditions of concurrent articulation. Human Brain Mapping 9, 65.

Cooke, A., Zurif, E.B., DeVita, C., Alsop, D., Koenig, P., Detre, J., Gee, J., Pinango, M., Balogh, J., Grossman, M., 2002. Neural basis for sentence comprehension: grammatical and short-term memory components. Hum Brain Mapp 15, 80-94.

Dapretto, M., Bookheimer, S.Y., 1999. Form and content: dissociating syntax and semantics in sentence comprehension. Neuron 24, 427-432.

Fangmeier, T., Knauff, M., Ruff, C.C., Sloutsky, V., 2006. FMRI evidence for a three-stage model of deductive reasoning. Journal of Cognitive Neuroscience 18, 320-334.

Fiebach, C.J., Lohmann, G., Von Cramon, D.Y., Friederici, A.D., Schlesewsky, M., 2005. Revisiting the role of Broca's area in sentence processing: Syntactic integration versus syntactic working memory. Human Brain Mapping 24, 79.

Friederici, A.D., Fiebach, C.J., Schlesewsky, M., Bornkessel, I.D., von Cramon, D.Y., 2006. Processing Linguistic Complexity and Grammaticality in the Left Frontal Cortex. Cereb Cortex.

Goel, V., Buchel, C., Frith, C., Dolan, R.J., 2000. Dissociation of mechanisms underlying syllogistic reasoning. Neuroimage 12, 504-514.

Goel, V., Dolan, R.J., 2001. Functional neuroanatomy of three-term relational reasoning. Neuropsychologia 39, 901-909.

Goel, V., Dolan, R.J., 2003. Reciprocal neural response within lateral and ventral medial prefrontal cortex during hot and cold reasoning. Neuroimage 20, 2314-2321.

Goel, V., Dolan, R.J., 2004. Differential involvement of left prefrontal cortex in inductive and deductive reasoning. Cognition 93, B109-121.

Goel, V., Gold, B., Kapur, S., Houle, S., 1997. The seats of reason? An imaging study of deductive and inductive reasoning. Neuroreport 8, 1305-1310.

Goel, V., Gold, B., Kapur, S., Houle, S., 1998. Neuroanatomical correlates of human reasoning. Journal of Cognitive Neuroscience 10, 293-302.

Goel, V., Makale, M., Grafman, J., 2004. The hippocampal system mediates logical reasoning about familiar spatial environments. Journal of Cognitive Neuroscience 16, 654-664.

Grewe, T., Bornkessel, I., Zysset, S., Wiese, R., von Cramon, D.Y., Schlesewsky, M., 2005. The emergence of the unmarked: a new perspective on the language-specific function of Broca's area. Hum Brain Mapp 26, 178-190.

Johnson-Laird, P.N., Tagart, J., 1969. How implication is understood. American Journal of Psychology 82, 367-373.

Knauff, M., Fangmeier, T., Ruff, C.C., Johnson-Laird, P.N., 2003. Reasoning, models, and images: behavioral measures and cortical activity. Journal of Cognitive Neuroscience 15, 559-573.

Monti, M., Osherson, D.N., Martinez, M.J., Parsons, L.M., under revision. Functional Neuroanatomy of Deductive Inference. Cerebral Cortex.

Noveck, I.A., Goel, V., Smith, K.W., 2004. The neural basis of conditional reasoning with arbitrary content. Cortex 40, 613-622.

Osherson, D., Perani, D., Cappa, S., Schnur, T., Grassi, F., Fazio, F., 1998. Distinct brain loci in deductive versus probabilistic reasoning. Neuropsychologia 36, 369-376.

Richardson, J., Ormerod, T.C., 1997. Rephrasing between Disjunctives and Conditionals: Mental Models and the Effects of Thematic Content. The Quarterly Journal of Experimental Psychology: Section A 50, 358-385.

Roder, B., Stock, O., Neville, H., Bien, S., Rosler, F., 2002. Brain activation modulated by the comprehension of normal and pseudo-word sentences of different processing demands: a functional magnetic resonance imaging study. Neuroimage 15, 1003-1014.

Ruff, C.C., Knauff, M., Fangmeier, T., Spreer, J., 2003. Reasoning and working memory: common and distinct neuronal processes. Neuropsychologia 41, 1241-1253.

Stromswold, K., Caplan, D., Alpert, N., Rauch, S., 1996. Localization of syntactic comprehension by positron emission tomography. Brain and Language 52, 452.

Talairach, J., Tournoux, P., 1988. Co-planar stereotaxic atlas of the human brain. Thieme, New York.