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Improving language without words: First evidence from aphasia

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ABSTRACT

The pervasiveness of word-finding difficulties in aphasia has motivated several theories regarding management of the deficit and its effectiveness. Recently, the hypothesis was advanced that instead of simply accompanying speech gestures participate in language production by increasing the semantic activation of words grounded in sensory-motor features, hence facilitating retrieval of the word form. Based on this assumption, several studies have developed rehabilitation therapies in which the use of gestures reinforces word recovery. Until now, however, no studies have investigated the beneficial effects of gesture observation in word retrieval.

Here, we report whether a different modality of accessing action-motor representation interacts with language by promoting long lasting recovery of verb retrieval deficits in aphasic patients.

Six aphasic participants with a selective deficit in verb retrieval participated in an intensive rehabilitation training that included three daily sessions over two consecutive weeks. Each session corresponded to a different rehabilitation procedure: (1) “action observation”, (2) “action observation and execution”, and (3) “action observation and meaningless movement”. In the four participants with lexical phonologically based disturbances, significant improvement of verb retrieval was found only with “action observation” and “action observation and execution”. No significant differences were present between the two procedures. Moreover, the follow-up testing revealed long-term verb recovery that was still present two months after the two treatments ended.

In support of a multimodal representation of action, these findings univocally demonstrate that gestures interact with the speech production system, inducing long-lasting modification at the lexical level in patients with cerebral damage.

1. Introduction

The hypothesis that gestures play an important role in lexical retrieval dates back to the beginning of the twentieth century (DeLaguna, 1927; Dobrogaev, 1929; Mead, 1934). In the earliest published study, Dobrogaev (1929) reported that speakers instructed to inhibit facial expressions and gestural movements of the extremities found it difficult to produce articulate speech. More recently, Rimé (1982) and Rauscher, Krauss, and Chen (1996) showed that preventing gestures affected speech fluency adversely; in fact, the effects were similar to those found when word retrieval was prevented by other means (i.e., when subjects were requested to use rare or unusual words).

More evidence supporting the interaction between gestures and lexical retrieval comes from studies of brain-damaged patients. Hadar, Wenkert-Olenik, Krauss, and Soroker (1998) reported that aphasics whose speech problems primarily concerned word retrieval tended to gesture more than both normal controls and other aphasics whose problems lay at a conceptual level. About 70% of the gestures of patients with word retrieval difficulties were associated with a hesitation or an erroneous production. Thus, viewed in relation to speech, it appears that aphasic patients have involved a compensatory strategy by increasing gesture production.

According to these data, gestures and speech are two separate communication systems and gestures function as an auxiliary support when verbal expression is temporally disrupted or word retrieval is difficult (Hadar, 1989; Hadar et al., 1998; Krauss & Hadar, 1999).

Based on this assumption, several studies have proposed rehabilitation therapies in which the use of simple gestures or

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pantomime paired with verbal production improved word recovery (Code & Gaunt, 1986; Hanlon, Brown, & Gerstman, 1990; Raimer, Singletary, Rodriquez, Ciampitti, Heilman, & Rothi, 2006; Rodriquez, Raymer, & Rothi, 2006; Rose, Douglas, & Matyas, 2002). Code and Gaunt (1986) wanted to examine whether combining gesture and speech would improve or hindered the production of either or both systems in a patient with severe apraxia and aphasia. They found significant improvement in the patient's ability to produce a small range of useful hand signs, especially on those enhanced through word-cued gesture (i.e., where the word equivalent to the gesture was cued by the therapist and the gesture was required as response) and gesture-cued word (where the therapist gave the gesture and the patient was required to produce the word as response) facilitations. Additionally, there was some indication that access to single-word production was facilitated when the patient was cued with an appropriate hand sign, and access to hand signs was likewise facilitated when the patient was cued with an appropriate word. In the Hanlon et al.'s work (Hanlon et al., 1990) the effects of different unilateral gestural movements on naming to confrontation were examined. It was hypothesized that activating the hemiplegic right arm to execute a communicative but non-representational pointing gesture would have a facilitatory effect on aphasics' naming ability. Results showed that gestures produced through activation of the proximal (shoulder) muscolature of the right paralytic limb facilitated naming performance.

Gestures paired with verbal production have frequently been used to treat naming impairments in patients with aphasia (Pashek, 1998; Raimer & Thompson, 1991; Richards, Singletary, Koehler, Crosson, & Rothi, 2002; Rose et al., 2002). Rose and colleagues (Rose & Douglas, 2001; Rose et al., 2002) noted that gestural treatment using pantomimes was more effective in individuals with a phonologically based word retrieval impairment than in those with semantically based word failure. Raimer et al. (2006) examined the effect of pantomime paired with verbal training for noun and verb retrieval in a group of aphasic participants. Effects were evaluated in spoken naming to pictured objects and actions. Results showed that naming improvements were present for trained nouns and verbs but not for untrained words.

Contrary to the assumption of a functional separation between gestures and speech, another hypothesis suggests that the two systems are closely linked to the same conceptual representation (McNeill, 1992).

In line with Martin et al.'s proposal (Martin, Wiggs, Ungerleider, & Haxby, 2000), it is assumed that the semantic representation of a concept is composed not only of stored information about the features defining that concept, such as its typical form, color and motion but also of the motor movement associated with its use. Semantic representation of word concepts can be encoded in both propositional and non-propositional formats, and words whose retrieval is facilitated by gestures are more likely to be analogically encoded in sensory-motor features (Krauss, Chen, & Gottesman, 2000; Krauss & Hadar, 1999). In the embodied cognition view, there is "no language module" and the representation of a concept is crucially dependent upon sensory-motor processes related to that concept (Barsalou, 1999; Gallese & Lakoff, 2005; Rizzolatti & Craighero, 2004).

Several lines of evidence have already demonstrated a strong connection between language and action, particularly with regard to language comprehension. Words mediating actions performed with different motor districts (e.g. the feet 'kick', the hands 'pick' and the mouth 'licks') enhance the same neural substrates involved in executing those actions (Binkofski & Buccino, 2006; Fadiga, Craighero, Buccino, & Rizzolatti, 2002; Hauk & Pulvermuller, 2004; Pulvermuller, Hauk, Nikulin, & Ilmoniemi, 2005; Rizzolatti, Fogassi, & Gallese, 2001). Similarly, in a behavioural study Sato, Mengarelli, Riggio, Gallese, and Buccino (2008) found slower responses with the right hand when subjects had to categorize hand-action-related verbs semantically than when the task involved foot-action-related verbs.

Conversely, it has been showed that gesture execution influences word comprehension and production also when subjects are simply asked to observe the performed action (Bernardis & Gentilucci, 2006; Gentilucci & Dalla Volta, 2008; Gentilucci, Dalla Volta, & Gianelli 2008). These results are in accordance with the hypothesis of a shared motor representation for the execution and observation of actions (the so-called "mirror neuron" theory) (Rizzolatti & Arbib, 1998; Rizzolatti, Fadiga, Fogassi, & Gallese, 1999). This motor representation, by matching observation with execution, makes it possible for individuals to recognize and understand the meaning of actions performed by others (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti et al., 1996). Accordingly, brain-imaging studies have indicated that Broadmann's area 44 (BA44) which is located in the pars opercularis of the inferior frontal gyrus, together with the superior temporal sulcus and the inferior parietal lobule, may serve as a core neural network for action understanding (Binkofsky et al., 1999; Buccino et al., 2001; Fadiga, Fogassi, Pavesi, & Rizzolatti,1995; Rizzolatti, Fogassi, & Gallese, 2000; Zadeh, Koshi, Zaidel, Mazziotta, & Iacoboni 2006). This fronto-parietal network has reciprocal connection in the underlying white matter located in the superior longitudinal fasciculus (SFL). The most inferior branch of SFL originates from the rostral portion of the inferior parietal lobule (Broadmann's area 40) and terminates in ventral area 6, area 44 and are 9/46 (Petrides & Pandia, 2002).

In Gentilucci et al.'s works (Bernardis & Gentilucci, 2006; Gentilucci & Dalla Volta, 2008; Gentilucci, Dalla Volta, & Gianelli 2008), the execution of meaningful gestures modified the voice spectra of words that had the same meaning, but not of meaningless words (i.e., pseudo-words). Moreover, observing a meaningful gesture affected verbal responses in the same way as executing the same gesture. The authors concluded that the spoken word and the symbolic gesture are coded as a single signal by a unique communication system.

Nevertheless, it is still an open question to what extent this interaction works and at which level of the language production system gestures might exert their influence.

The more traditional view has suggested that gestural information might contribute to the construction of the speaker's communicative intention and might affect lexical retrieval only indirectly (Hadar & Butterworth, 1997; Hadar et al., 1998; Hanlon et al., 1990); more recent works, however, have indicated that gestures and language production closely interact at least at a motor/articulatory level (Bernardis & Gentilucci, 2006; Gentilucci & Dalla Volta, 2008; Gentilucci, Dalla Volta, & Gianelli 2008).

In this study, we investigated whether observing gestures exert its influence in the language production system also at a lexical level by promoting long-lasting recovery of word retrieval deficits in aphasic patients.

As far as we know, no other studies have previously addressed this issue. In most of the previous treatments, gestures were combined with a verbal cue (Pashek, 1998; Raimer & Thompson, 1991; Richards et al., 2002; Rose et al., 2002) and when they were used as the only facilitation, they were not semantically related with the action (Hanlon et al., 1990). With regard to gesture observation, while the studies univocally addressed their crucial role for language comprehension, no studies have been reported on the relationship between gestures and lexical retrieval. Specifically, we were interested in exploring whether "the observation of semantically congruent actions" and/or "the observation and execution of semantically congruent actions" would improve verb-finding difficulties in a group of anomic patients.

Table 1
Sociodemographic and clinical data of the four aphasic subjects into of the six aphasic subjects.

Participants	Sex	Age	Educational level	Type of Aphasia	Time post-onset	Verb naming (BADA)	Verb comprehension (BADA)	Token test
M.B.	M	65	13	Nonfluent	1 Year and six months	18/28	20/20	24/36
U.P.	M	74	13	Nonfluent	5 Years and 8 months	20/28	20/20	27/36
R.M.	M	49	13	Nonfluent	1 Year and 7 months	14/28	20/20	21/36
M.P.	F	53	16	Nonfluent	2 Years	12/28	20/20	33/36
P.A.	M	53	17	Fluent	3 Years and 8 months	8/28	15/20	15/36
V.F.	F	75	8	Fluent	1 Year and 3 months	6/28	16/20	16/36

It is well known that in aphasic patients word-finding difficulties are the most pervasive symptom of language breakdown and that naming disorders lead to a wide variety of errors because of damage to different stages of name processing. Generally, anomic difficulties are due to inability to retrieve either the semantic word representation or the phonological word form (Basso, Marangolo, Piras, & Galluzzi, 2001; Howard, Patterson, Franklin, Orchardisle, & Morton, 1985; Levelt & Meyer, 2000; Marangolo & Basso, 2006). Semantic impairments lead to difficulties in both word comprehension and production, whereas lexical phonological disturbances result in spoken word retrieval impairments with preserved word comprehension (Lambon Ralph, Moriarty, & Sage, 2002; Wilshire & Coslett, 2000).

To further evaluate the proposal of Rose et al. (2002) that gestural facilitation effects are greater for individuals with phonologic than semantic word retrieval failures, we contrasted the effect of treatments found in two semantically word retrieval impaired participants with the results obtained in four participants with lexical phonological disturbances.

To measure long-lasting beneficial effects, three follow-up sessions were carried out one week, one month and two months after the end of each treatment condition.

2. Materials and methods

2.1. Participants

Six chronic aphasic participants (4 males and 2 females) classified as right-handed according to the Edinburgh Inventory (Odfield, 1971) were included in the study. Five patients had suffered a single left cerebrovascular accident (CVA) at least one year prior to the investigation. The sixth patient reported a severe traumatic injury three years prior to the investigation. All were native Italian speakers with no previous neurological, psychiatric, or substance abuse history. The data analyzed in the current study were collected in accordance with the Helsinky Declaration and the Institutional Review Board of the Ospedale Riuniti Torrette in Ancona, Italy. Prior to participation, all patients signed informed consent forms.

2.2. Clinical data

The aphasic disorders were assessed using standardized language tests (the Battery for the analysis of aphasic disorders, BADA test, Miceli, Laudanna, Burani, & Capasso, 1994; Token test, De Renzi & Faglioni, 1978).

Four out of six patients were classified as nonfluent aphasics because of their very reduced spontaneous speech with short sentences and frequent anomia. They had no articulatory difficulties with preserved word repetition. In a task requiring the ability to match an auditory presented verb to one of two semantically related pictures (Verb Comprehension task), their comprehension was intact. For commands and auditory sentences, their comprehension ranged from moderate (M.B., R.M.) to low severity (U.P.). The fourth patient (M.P.) had no language comprehension difficulties (29/36 cut-off score, Token test, De Renzi & Faglioni, 1978) (see Table 1). The two other patients were classified as fluent aphasics because of their rich but not informative speech with frequent word substitutions and anomia. In the verb comprehension task, they were still marginally impaired. Verbal comprehension difficulties were also present for commands and auditory comprehension sentences (Token test).

In a naming task, all patients had verb-retrieval deficits (see Table 1).

On the ideative, ideomotor, bucco-facial tests (De Renzi, Motti, & Nichelli, 1980) and on the Gait Apraxia test (Della Sala, Spinnler, & Venneri, 2005), no patient revealed an apraxia disorder. Furthermore, the patients had no difficulty on a test of gesture comprehension (Smania et al., 2006).

M.B. is a 65-year-old right handed man with 13 years of schooling. He suffered a hemorrhage of the left middle cerebral artery in March 2008, which led to aphasia. In September 2009, his speech was poor and he frequently showed word-finding difficulties, which were also still present in the naming tasks of the BADA test (noun naming: 23 correct responses out of 30 stimuli; verb naming: 18 correct responses out of 28 stimuli). His word comprehension was normal (noun comprehension: 40 correct responses out of 40 stimuli; verb comprehension: 20 correct responses out of 20 stimuli). His comprehension of complex commands largely recovered (Token test score, 24/36; cut-off 29/36).

U.P. is a 74-year-old right handed man with 13 years of schooling. He suffered an occlusion of the left middle cerebral artery in January 2004, which led to aphasia. In September 2009, his speech was poor and he frequently showed word-finding difficulties. These difficulties were also moderately present in the naming tasks of the BADA test (noun naming: 25 correct responses out of 30 stimuli; verb naming: 20 correct responses out of 28 stimuli). His word comprehension was normal (noun comprehension: 40 correct responses out of 40 stimuli; verb comprehension: 20 correct responses out of 20 stimuli). His comprehension was almost normal also for complex commands (Token test score, 27/36; cut-off 29/36).

R.M. is a 49-year-old right handed man with 13 years of schooling. He suffered a hemorrhage of the left middle cerebral artery in February 2008, which led to aphasia. In September 2009, his speech was poor and he frequently showed word-finding difficulties. These difficulties were also still present in the naming tasks of the BADA test (noun naming: 14 correct responses out of 30 stimuli; verb naming: 14 correct responses out of 28 stimuli). His word comprehension was normal (noun comprehension: 40 correct responses out of 40 stimuli; verb comprehension: 20 correct responses out of 20 stimuli). His comprehension of complex commands was still moderately compromised (Token test score, 21/36; cut-off 29/36).

M.P. is a 53–year-old right handed woman with 16 years of schooling. She suffered an ischemia of the left middle cerebral artery in September 2007, which led to aphasia. In September 2009, her speech was poor and she showed word-finding difficulties. These difficulties were also still present in the naming tasks of the BADA test (noun naming: 25 correct responses out of 30 stimuli; verb naming: 12 correct responses out of 28 stimuli). Her word comprehension was normal (noun comprehension: 40 correct responses out of 40 stimuli; verb comprehension: 20 correct responses out of 20 stimuli) also for complex commands (Token test score, 33/36; cut-off 29/36).

P.A. is a 53-year-old right handed man with 17 years of schooling. He reported a severe traumatic injury in January 2006, which led to aphasia. In September 2009, his speech was fluent and he showed severe word substitutions and word-finding difficulties. On oral naming task of the BADA test, he performed poorly (noun naming: 3 correct responses out of 30 stimuli; verb naming: 8 correct responses out of 28 stimuli). His word comprehension was still compromised (noun comprehension: 32 correct responses out of 40 stimuli; verb comprehension: 15 correct responses out of 20 stimuli) also for complex commands (Token test score, 15/36; cut-off 29/36).

V.F. is a 75-year-old right handed woman with 8 years of schooling. She suffered an ischemia of the left middle cerebral artery in June 2008, which led to aphasia. In September 2009, her speech was fluent and she showed severe word substitutions and word-finding difficulties. On oral naming task of the BADA test, she performed poorly (noun naming: 2 correct responses out of 30 stimuli; verb naming: 6 correct responses out of 28 stimuli). Her word comprehension was still compromised (noun comprehension: 34 correct responses out of 40 stimuli; verb comprehension: 16 correct responses out of 20 stimuli) also for complex commands (Token test score, 16/36; cut-off 29/36).

2.3. Materials

Before the training, a list of 128 transitive ($N = 103$, e.g. to bite, to comb) and intransitive ($N = 25$, e.g. to dance) videotaped actions were selected. The actions were presented to the patients on a PC screen once a day for three consecutive days and they had to respond within 15 s. The verbs the patients could not name and for which they always produced an omission were selected (U.P. 84/128; M.B. 68/128; R.M. 92/128; M.P. 44/128; P.A. 124/128; V.F. 116/128).

In order to investigate if gestural facilitation effects are greater for individuals with phonologic than semantic word retrieval failures (Rose et al., 2002), for each patient the selected stimuli were presented for comprehension tasks. As previously stated, in general, semantic impairments cause difficulties in both word comprehension and production, whereas lexical phonological disturbances lead to difficulties only in spoken word retrieval.

Table 2
Proportion of correct responses for each fluent participant by treatment and time of assessment and McNemar's test results.

	Control			Treatment 1			Treatment 2			Treatment 3		
	Baseline	2 Weeks	McNemar's *p*-value	Baseline	2 Weeks	McNemar's *p*-value	Baseline	2 Weeks	McNemar's *p*-value	Baseline	2 Weeks	McNemar's *p*-value
P.A.	.07	.03	1	.00	.07	.500	.03	.07	1	.07	.03	1
V.F.	.00	.03	1	.13	.06	.687	.00	.06	.500	.10	.06	1

Notes: Number of observations (i.e., number of verbs) per cell: $N = 29$ for P.A. and $N = 31$ for V.F.
In italics statistically significant *p*-values at the .01 level, indicating a significant increase in the proportion of correct responses.

Table 3
Proportion of correct responses for each nonfluent participant by treatment and time of assessment.

	U.P.				M.B.				R.M.				M.P.			
	Contr.	Treat1	Treat2	Treat3	Contr.	Treat1	Treat2	Treat3	Contr.	Treat1	Treat2	Treat3	Contr.	Treat1	Treat2	Treat3
Baseline	.10	.05	.14	.14	.12	.12	.12	.18	.13	.00	.00	.09	.27	.00	.18	.18
2 Weeks	.33	.62	.67	.38	.24	.53	.47	.24	.30	.61	.65	.35	.45	.82	.73	.64
F/U 1 Week	.29	.57	.81	.33	.35	.47	.47	.35	.35	.57	.74	.35	.55	.91	.73	.64
F/U 1 Month	.19	.43	.52	.33	.24	.71	.65	.35	.30	.48	.52	.30	.45	.82	.73	.64
F/U 2 Months	.29	.43	.57	.33	.18	.76	.71	.24	.35	.52	.61	.35	.45	.82	.73	.64

Note: Total number of observations: $N = 420$ (21 per cell) for U.P., $N = 340$ (17 per cell) for M.B., $N = 460$ (23 per cell) for R.M., $N = 220$ (11 per cell) for M.P. Legend: Contr. = control list, Treat = treatment, F/U = follow-up

2.3.1. Verb comprehension tasks

2.3.1.1. Action verb comprehension. The patients were shown one selected picture at a time. Each picture was presented twice, once with the spoken correct word and once with a spoken semantically related word. The action of kissing, for instance, was presented once with *kissing* and once with *hugging*; the action of tasting once with *tasting* and once with *cooking*. The patient had to say whether the word corresponded to the picture or not. Responses were considered correct if the correct word was accepted and the semantically related word was rejected. The four nonfluent patients made no errors on this task, whereas the two fluent patients made several semantic errors (70/124; 83/116, respectively for P.A. and V.F.).

2.3.1.2. Description of verb meaning. The patients had to explain the meanings of the selected verbs any way they could. The four nonfluent patients always correctly mimed the action and/or used unambiguous words to explain the verb meaning, whereas the two fluent patients were not always able to describe the meaning of the action (92 errors out of 124 selected stimuli; 103 errors out of 116 selected stimuli, respectively for P.A. and V.F.).

2.3.1.3. Grammaticality judgements. For each patient, each selected action was presented with three written sentences and they had to point to the correct one. In one sentence all the correct obligatory arguments were present (e.g. the girl waters the flowers), in one sentence an incorrect obligatory argument was included (e.g., the girl waters the car), in one sentence an argument was governed by an incorrect preposition (e.g., the girl waters for the flowers). Again, while the nonfluent patients made no errors on this task, the fluent patients were severely compromised (122 errors out of 124 selected stimuli; 88 errors out of 116 selected stimuli, respectively for P.A. and V.F.).

In summary, the results on the comprehension tasks indicated that the source of verb retrieval breakdown differed in our aphasic group. While for the nonfluent patients anomic difficulties seemed to arise from an inability to retrieve the word at the phonological level, a semantically based word retrieval impairment was suggested by difficulty across the three tasks in the two fluent aphasics. In order to contrast the beneficial effects from the treatments in the two populations, the selected verbs were subdivided into four lists of 21 actions for U.P. ($N = 84$), 17 actions for M.B. ($N = 68$), 23 actions for R.M. ($N = 92$), 11 actions for M.P. ($N = 44$), 31 actions for P.A. ($N = 124$) and 29 actions for V.F. ($N = 116$) controlled for length and frequency of use. One list served as a control measure and each of the remaining three lists was used for a different rehabilitation procedure.

2.4. Procedure

2.4.1. Treatment

Each participant was asked to participate in an intensive language training, which included three daily sessions of 30–45 min each (depending on the number of stimuli to be treated) for two consecutive weeks.

In each session, one of the following rehabilitation procedures was adopted: (1) "action observation", in which the patient first observed the therapist actually execute an action and then had to produce the corresponding verb; (2) "action observation and execution", in which the patient first observed the therapist actually execute the action and then had to perform the observed action and produce the corresponding verb; and (3) "action observation and meaningless movement", in which the patient first observed the action and then had to produce an unrelated and meaningless movement and produce the corresponding verb. For all treatments, the therapist manually recorded the answers. If the patient failed to produce an answer or produced an incorrect verb, after 15 s, the therapist presented the subsequent action. At the end of each treatment (after two weeks), the patient was asked to rename the videotaped actions belonging to the three training lists and to the non-trained one.

2.4.2. Follow-up

To measure long-lasting beneficial effects, in the nonfluent patients, three follow-up sessions were carried out at one week, one month and two months after the end of each treatment procedure. For personal reasons, the two fluent patients (P.A. and V.F.) were unable to participate in the follow-up sessions.

3. Results

Given the small number of fluent patients ($N = 2$) and the fact that for both of them we had only two time points (*baseline* and *after 2 weeks*), we used a non-parametric approach to evaluate their increase in response's accuracy for the three treatments. In particular, we conducted a series of McNemar's tests (i.e., a non-parametric test used to compare paired proportions; Seagle & Castellana, 1988) on the proportion of correct responses for each participant by treatment and time of assessment. As shown in Table 2, neither of the two patients benefited from the treatments. In all experimental conditions, there was no increase in response's accuracy after two weeks from the end of the treatments.

In the nonfluent group, statistical analyses were performed in three steps.[1]

First, for each patient we conducted descriptive analyses (see Table 3 and Fig. 1) on response accuracy by type of treatment and time. As shown in Fig. 1, all patients showed an improvement in response accuracy for treatment 1 (based on "action observation" and treatment 2 (based on "action observation and execution"), which still persisted two months after the end of the two treatments.

Second, a generalized mixed model approach (Baayen, 2008; Jaeger, 2008; Pinheiro & Bates, 2000) was used to evaluate the effect of treatment on participants' responses. As each patient was administered different items and as each treatment included different items, we conducted a series of logistic mixed mod-

[1] All analyses were performed using R software (R, 2009). For generalized mixed effect models we used the R package *lme 4* (Bates & Maechler, 2009). For meta-analysis we used the *rmeta* package (Lumley, 2009).

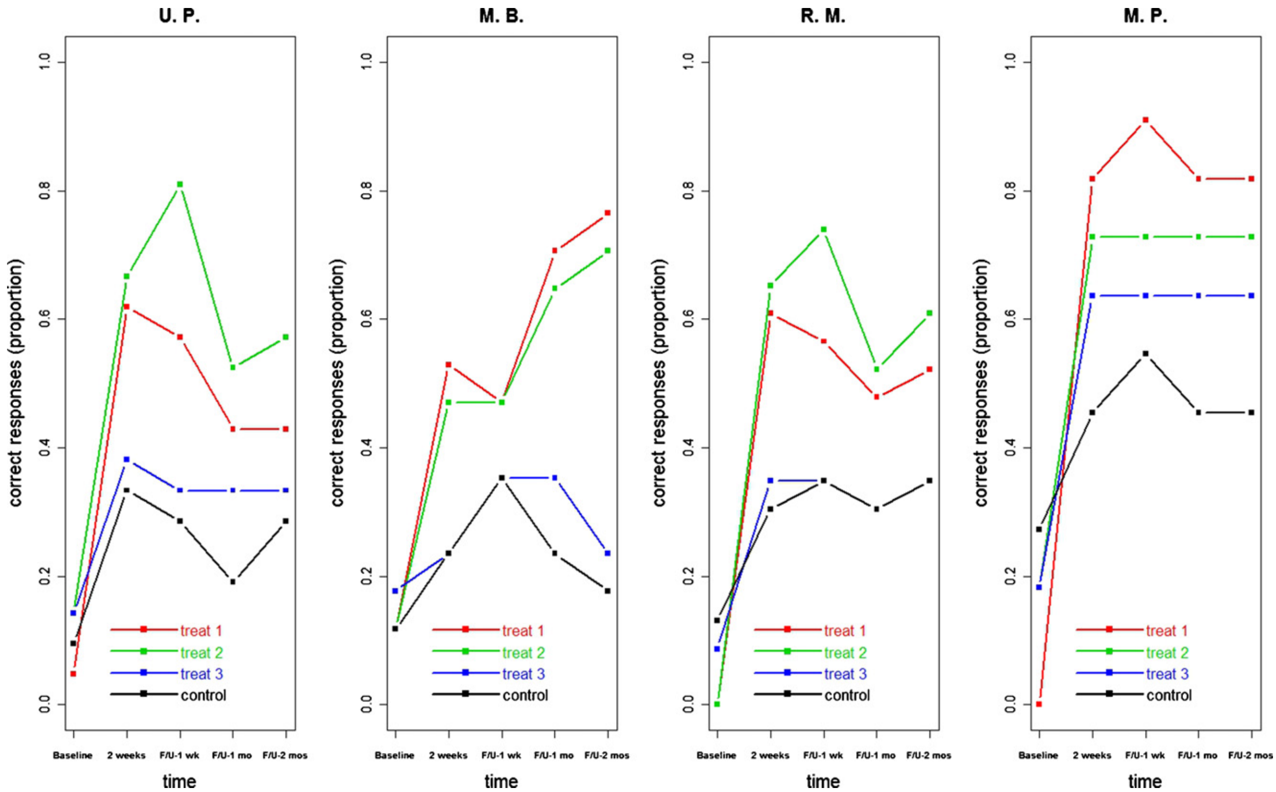


Fig. 1. Percentage of correct responses for each nonfluent subject as a function of treatment (treat 1 = action observation, treat 2 = action observation and execution, treat 3 = action observation and meaningless movement) and time (F/U (follow-up) 1 wk (1 week), F/U 1 mo (1 month), F/U 2 mos (2 months).

els for each participant using the item as random effect. From a theoretical perspective, the rationale for conducting separate models is that each patient represents a single case study; from a statistical perspective, treating the patients in this study as random effects in a global model could have led to distortions in the results because of the small sample size ($n = 4$). Thus, to test our hypotheses we estimated four nested logistic mixed models. In Model 1 (M1), the dependent variable was accuracy of response (0 = incorrect, 1 = correct); the fixed effects were accuracy of response at baseline, time point (2 weeks after baseline, 1 week follow-up, 1 month follow-up, 2 months follow-up), treatment (0 = control, 1 = treatment 1, 2 = treatment 2, 3 = treatment 3 (action observation and meaningless movement)), type of verb (transitive vs. intransitive), and two- and three-way interactions among time, treatment and type of verb; the random effect was the item. Model 2 (M2) was identical to M1, except for the three-way interaction, which was removed. Model 3 (M3) included only the main effects of time, treatment, type of verb, and the covariate (i.e., accuracy of response at baseline). Model 4 (M4) included only the main effects of treatment and the covariate. The covariate was always considered in order to remove the effects of participants' baseline level of performance. The best-fitting model was selected using the BIC criteria (Raftery, 1995; Wagenmakers, 2006), i.e., the model with the smallest BIC is considered the most appropriate model for reproducing the observed data. As can be seen in Table 4, M4 was the best-fitting model for all participants, indicating that time and type of verb had no effect on participants' performance after controlling for baseline level. Table 5 presents the four final models.

Table 4
BIC values for models tested.

Models	U.P.	M.B.	R.M.	M.P.
M1	524.90	469.00	534.00	338.10
M2	499.90	426.20	496.10	314.10
M3	425.80	360.20	413.10	242.30
M4	*414.70*	*342.90*	*396.40*	*224.10*

Note: Numbers in italics the minimum value of BIC, indicating the best-fitting model, for each subject.

Table 5
Summary statistics for the best-fitting model by subject.

Predictors	U.P.			M.B.			R.M.			M.P.		
	χ^2 (3)	*B*	*Z*	χ^2 (3)	*B*	*Z*	χ^2 (3)	*B*	*Z*	χ^2 (3)	*B*	*Z*
Accuracy at baseline		.71	.84		.53	.70		2.48	1.38		.89	1.07
Treatment	14.24**			15.47**			13.77**			8.97*		
Treatment 1		1.78	2.38*		2.45	3.28**		2.91	2.43*		2.66	2.94**
Treatment 2		2.60	3.44***		2.14	2.89**		3.91	3.23**		1.60	1.96*
Treatment 3		.42	.56		.35	.45		.20	.87		1.99	1.22

Note: Control list was used as baseline category.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 6
Results of the meta-analysis by treatment.

Treatments	Summary odds ratio	*p*-Value	95% Confidence interval	
			Lower limit	Upper limit
1	3.37	<.001	1.69	6.71
2	4.02	<.001	2.00	8.07
3	1.30	.470	.64	2.65

Overall, treatment had a significant effect on accuracy of response across all participants. In particular, treatments 1 and 2 were significantly and positively associated with an improved performance, whereas treatment 3 had no significant effect. For each participant, planned comparisons were performed to assess whether treatment 1 and 2 had differential effects on participants' performance. Results indicated that the two treatments did not differ from each other in terms of their effect on accuracy of response (all $ps > .20$).

Third, we adopted a meta-analytic approach (Borenstein, Hedges, Higgins, & Rothstein, 2009) to obtain a global measure of the effect size of each type of treatment (i.e., a summary effect). Given the small number of participants, we performed a fixed-effect meta-analysis, as suggested by Borenstein et al. (2009). Analyses were conducted only on the 2-month follow-up data in order to obtain the most conservative evaluation of treatment efficacy. Using the procedure suggested by Borenstein et al. (2009), we calculated the summary odds ratio, its level of significance and the associated confidence interval for each treatment (see Table 6 for summary of results and Appendix). As can be seen in Table 6, only treatments 1 and 2 had a positive significant effect on performance, confirming the results obtained in step 2.

In summary, results clearly show that, for the nonfluent aphasics verb production improved to the same degree by "observing" and by "observing plus executing the action" and for both rehabilitation procedures this improvement was long-lasting and still present also at two months after the end of the treatment. Both the two fluent patients did not benefit from the treatments.

4. Discussion

As stated in the introduction, although the pervasiveness of word finding difficulties in aphasia has led to the development of several therapeutic strategies where the use of pantomime reinforces verb retrieval, until now all studies have reported that facilitation occurred primarily in the presence of a verbal cue (Raimer et al., 2006; Rodriquez et al., 2006; Rose et al., 2002).

In the present study, six aphasic patients underwent an intensive language training of three daily sessions (30–45 min for each session depending on the number of stimuli to be treated) using different rehabilitation procedures. The choice to use such an intensive training was in accordance with a recent proposal which suggests that, for stroke patients with aphasia, intense therapy over a short amount of time has greater impact on recovery than less intense therapy over a long period of time (Bhogal, Teasell, Speechley, & Albert, 2003).

Three main results should be considered: (1) in nonfluent patients, verb retrieval deficits improved as a result of "action observation" and "action observation and execution" treatments, (2) no significant differences were found between the two treatments, and (3) for both procedures, the improvement still persisted two months after the end of treatment.

Two opposite views have been proposed to explain the relationship between gestures and speech. The first posits that the two systems are separate domains and that gestures might interact either at an early stage, when the message to be conveyed is being prepared for linguistic formulation ('conceptual gestures') or during later stages, when the retrieval of lexical items momentary fails ('lexical gestures') (Hadar et al., 1998; Hanlon et al., 1990; Krauss & Hadar, 1999). In Krauss and Hadar model (1999), lexical gestures reflect how the speech production system makes use of the gesture production system for word retrieval purposes. In their view, gestures are activated by lexical retrieval failures. They contend that such failures often initiate a re-run of lexical selection and that during such re-runs the lexical system attempts to gather more cues for lexical selection by activating non-propositional representations at a conceptual level. These non-propositional representations, in turn, interact with the gesture production system lead to the corresponding movement. In this way, gesture-related information contributes to the construction of the speaker's communicative intention; however, it affects lexical retrieval only indirectly (Krauss & Hadar, 1999).

More recently, Krauss et al. (2000) proposed a different interpretation. In agreement with and embodied cognition viewpoint (Barsalou, 1999; Gallese & Lakoff, 2005), the authors argued that semantic representation of the word concept can be encoded in both propositional and non-propositional formats. Words whose retrieval is facilitated by gestures are more likely to be analogically encoded in sensorimotor features. The number of lexical gestures accompanying retrieval of a word will be related to the degree to which the word's semantic representation is grounded in sensory-motor features: the more a word is grounded in sensory-motor features, the more gesturing will accompany its retrieval. Therefore, in their model gesturing must always be performed in order for facilitation to occur (Krauss et al., 2000).

Accordingly, what appears evident from the literature is that aphasics' ability to name seems to benefit from intentionally performing a gesture prior to name (Hadar et al., 1998; Hanlon et al., 1990; Krauss & Hadar, 1999). In the same vein, compared to those who can gesture, normal speakers prevented from gesturing speak less rapidly and make more speech errors because of difficulty in lexical retrieval (Rauscher et al., 1996).

However, if movement is a necessary prerequisite to enhance naming we should have found either an improvement in verb retrieval only when patients were asked to observe and then to perform the action or, at least, a stronger and/or more lasting effect in this condition than in the simple observation of gestures. Indeed, in the former condition, the actual execution of the action should have reinforced verb retrieval.

Contrary to this expectation, in our nonfluent aphasic patients we found no significant difference between the two treatments and in both conditions the effects were present also two months after the end of treatment.

The single participant design allowed us to examine not only the positive effects of gestural treatments but also the type of patient for whom the treatments were effective. In our study, the two fluent patients with severe verb semantic impairments did not benefit from the treatments. Rose et al. (2002) noted that gestural treatment using pantomimes was more effective in individuals with phonologically based word retrieval impairment than those with semantically based word retrieval failure. They proposed that the advantage that gestural training provides for patients with phonologic impairments relates to the fact that the kinesic motor system provides activation directly to the phonologic stages of word retrieval, and not to the earlier conceptual-semantic stages. Accordingly, Rodriquez et al. (2006) reported positive effects of gestural treatment for one patient with a phonologic moderate impairment for verbs. Three other participants with semantic impairments did not improve their spoken verb naming abilities. Raimer et al. (2006) showed no improvements in their participant with severe fluent aphasia and semantically based word retrieval impairments.

Thus, it seems likely that patients with severe semantically based word retrieval impairments and fluent aphasia may not improve in verb naming following gestural treatments.

We believe that our data might be more easily reconcile with the hypothesis of an unique communication system ("embodied system") that is equally active in the execution and/or observation of actions (Rizzolatti & Arbib, 1998; Rizzolatti & Craighero, 2004).

In agreement with a multimodal concept representation, we argue that in our work observation of the performed action is sufficient to activate its corresponding sensory-motor representation, which serves as input at the lexical level and facilitates word

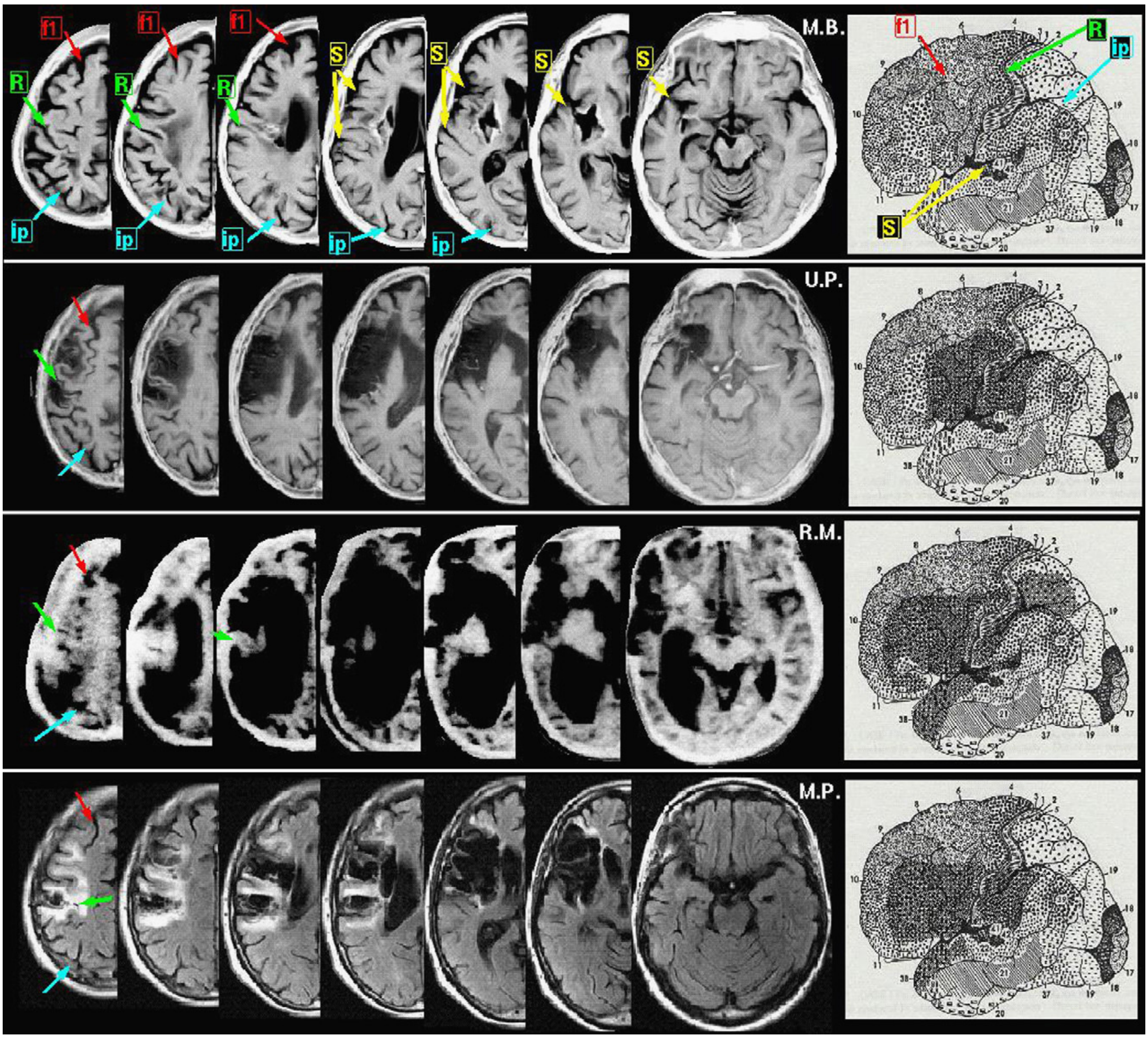


Fig. 2. Analysis of the patients' brain lesions. M.B.'s lesion is localized into the left insula sparing most of the cortex but including the extreme capsule, the external capsule, part of the internal capsule, the claustrum, the putamen and part of the ventrolateral thalamus. A lesion is also present below the central and the post-central gyri in the periventricular white matter area adjacent to the body of the lateral ventricle. In addition, the white matter lesion seems to affect part of the inferior portion of the SFL (superior longitudinal fasciculus), i.e., the connection between the inferior parietal and the fronto-opercular region. U.P.'s lesion extends in the inferior part of the precentral gyrus, the pars opercularis and the caudal part of the pars triangularis of the inferior frontal gyrus. Ventrally, it reaches the most posterior part of the latero-orbital cortex of the frontal lobe. Dorsally, the lesion includes part of the middle frontal gyrus sparing the cortex close to the superior frontal sulcus up and around the central gyrus. Posteriorly, it occupies the rostral part of the supramarginalis gyrus and the rostral cortex of the intraparietal sulcus. The cerebral intraparenchymal damage includes the SFL, the insular cortex, the extreme capsula, the claustrum, the external capsule up to the putamen.
R.M.'s lesion extends in the inferior frontal gyrus including the pars opercularis, pars triangularis and pars orbitalis, the latero-orbital cortex up to the sulci orbitalis lateralis and transversus. Posteriorly, the lesion includes the inferior part of the pre-central and the post-central gyri partially sparing the cortex around the central sulcus. Dorsally, it affects part of the middle frontal gyrus and the anterior part of the superior frontal sulcus up to the central gyrus. Dorso-caudally the lesion comprises the rostral portion of the intraparietal sulcus and part of the superior parietal cortex. A damage of the inferior rostral part of the gyrus supramarginalis is also evident. Malacic cortex is present in the temporo-parietal junction. The underlying white matter including the SFL, the insular cortex, the extreme capsule, the claustrum, the external capsule and the putamen is also damaged. Finally, a lesion affects the superior temporal gyrus from the sulcus acusticus up to the polaris temporalis gyrus. M.P.'s lesion extends in the inferior frontal gyrus including the pars opercularis, pars triangularis and pars orbitalis, the latero-orbital cortex up to the sulci orbitalis lateralis and transversus. Posteriorly, the lesion includes the inferior part of the pre-central and the post-central gyri partially sparing the cortex around the central sulcus. Dorsally, it affects part of the middle frontal gyrus and the anterior part of the superior frontal sulcus up to the central gyrus. The lesion also occupies the rostral part of the supramarginalis gyrus. The underlying white matter including the SFL, the insular cortex, the extreme capsule, the claustrum, the external capsule, the putamen, the internal capsule up to the thalamus is also damaged. Finally, a lesion affects the superior temporal gyrus anteriorly to the sulcus acusticus up to the most posterior part of the polaris temporalis gyrus.

retrieval. Therefore, contrary to Rose et al.'s explanation (2002), we suggest that the kinesic motor system activated by the real execution of the action or by its observation directly interacts with the semantic system influencing verb retrieval. In our fluent patients, the presence of a damage in the verb semantic representation prevented them to activate its sensory-motor features and subsequently the recovery of the corresponding phonological word form.

The hypothesis that the sensory-motor attributes of the action are activated during observation is further confirmed by the third condition in which patients were asked to observe an action and then to perform an unrelated movement. Indeed, in this condition, once the sensory-motor attributes of the action were mentally activated a successive meaningless movement interfered with this activation enabling the patient to produce the correct word.

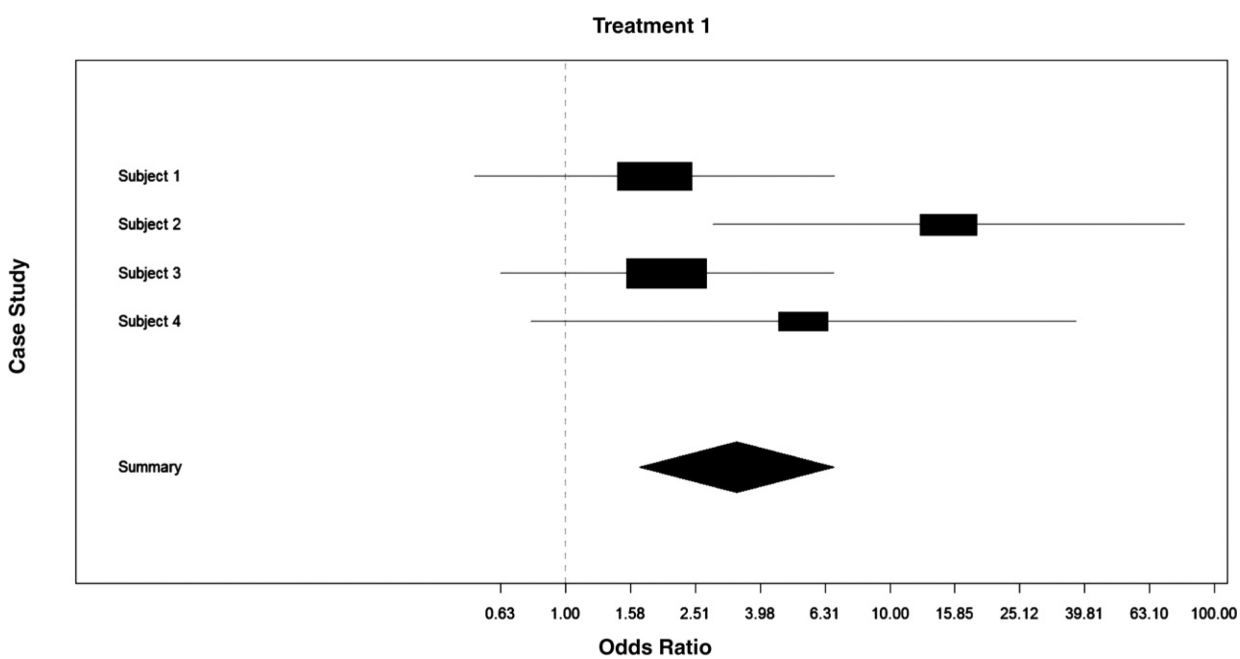
One final point regards the neural substrates which have supported the recovery in our nonfluent patients. If the crucial system is the mirror neuron system and this system, due to the close interaction between gesture and language (Rizzolatti & Arbib, 1998), is left lateralized, we might expect that our left patients who have benefited from gestural facilitation show this neural circuit undamaged. Our patients' lesion analysis did not confirm this prediction. As shown in Fig. 2, three out of four patients had damage to part of this circuit and, specifically, to Broca's area (pars opercularis, Broadmann's area 44), which serves as a core network for gesture execution and observation (Binkofsky et al., 1999; Buccino et al., 2001; Fadiga et al., 1995; Rizzolatti et al., 2000; Zadeh et al., 2006). The fourth patient (M.B.) had a subcortical lesion who likely compromised the SFL, i.e., the white matter pathway linking the inferior parietal to the fronto-opercular regions.

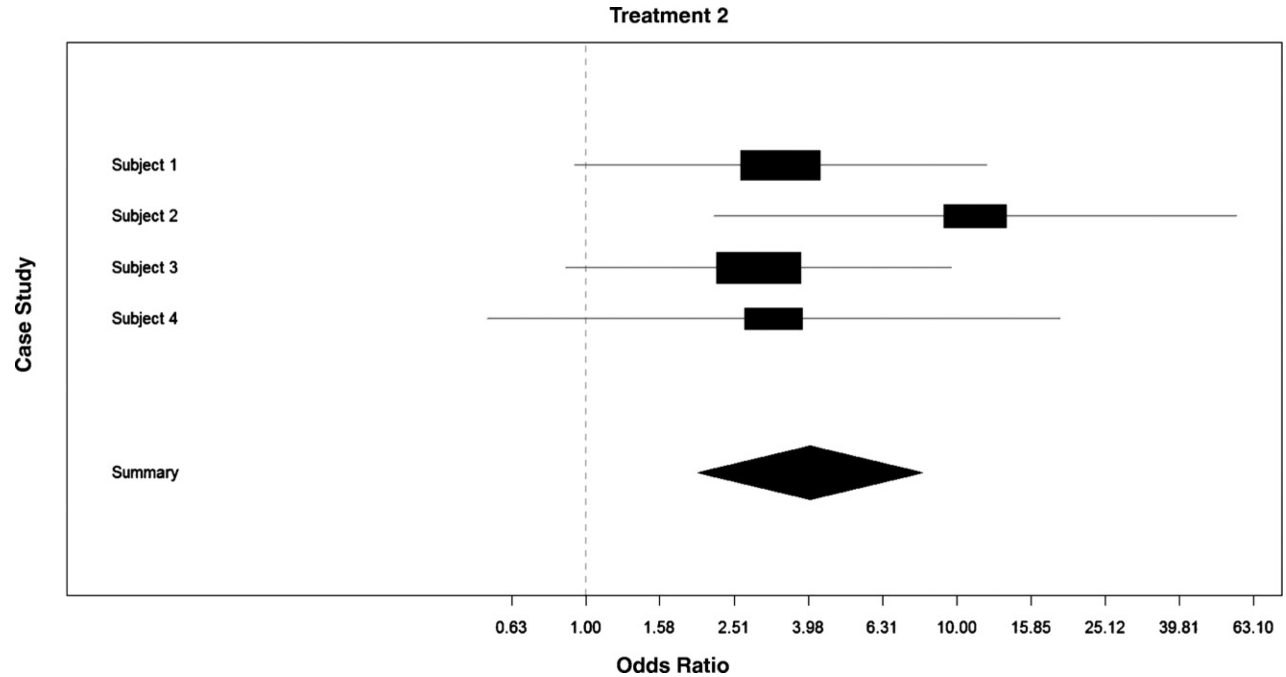
However, it has been recently claimed that the human fronto-parietal mirror neuron system is bilaterally distributed in its activity and that both hemispheres, having mirror neurons properties, contribute to the processing of action observation and imitation (Zadeh et al., 2006).

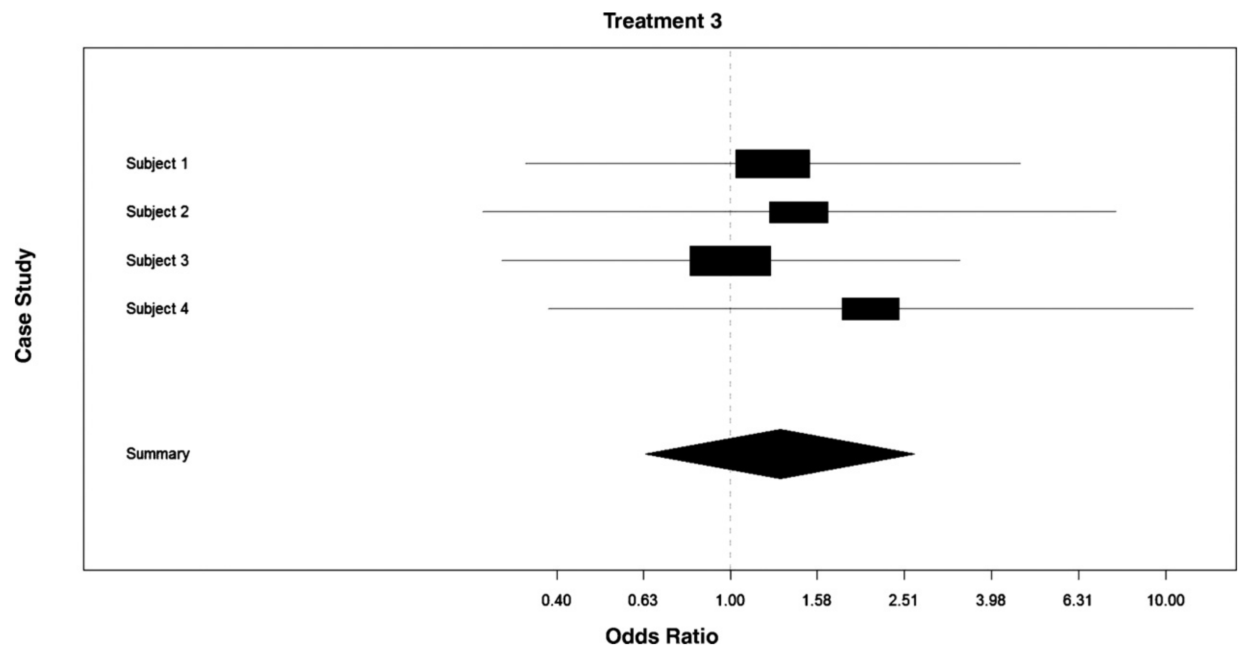
As our data are strictly behavioural, they do not allow us to draw any definitive conclusions regarding the neural substrates involved in word recovery. However, in line with Zadeh et al.'s proposal (2006), we cannot exclude the hypothesis that our nonfluent patients might have benefited from an activation of the homologous right mirror circuit which lead them to improve verb retrieval.

In our knowledge, this is the first neuropsychological demonstration that language production is improved by simply observing actions. We believe that these data provide clear evidence that gestures interact closely with language, leading to a lasting modification in the speech production system. Moreover, they are potentially relevant for planning new therapeutic interventions for language rehabilitation.

Appendix A. Forest plot representing the results of the meta-analyses







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