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ABSTRACT

In this systematic review and meta-analysis, our aim was to identify and quantify evidence of action observation therapy (AOT) efficacy in managing language deficits in patients with aphasia. This study conducts two quantitative investigations: firstly, comparing the effects of AOT and conventional control therapy in different groups, and secondly, analyzing within AOT group to explore potential moderators of AOT effectiveness. Four databases were searched up until August 2023 to find studies utilizing AOT for aphasia management. Seven eligible studies were included. The main analyses revealed moderate evidence of improvement in naming tasks, with a large effect size (Hedge's g = 1.27, 95 %CI [0.44; 2.09], p = 0.003, I2 < 25) following AOT compared to control interventions. Furthermore, to be efficient, AOT should focus on human actions (e.g., running, jumping) rather than non-human actions (e.g., meowing or barking). These findings indicate that AOT is a promising alternative complementary approach for patients with aphasia. Future research should confirm the potential benefits of AOT with more randomized controlled studies and aim to clarify the minimal dose necessary and the possibility of transfer to various language tasks.

1. Introduction

Aphasia, defined as language disorder with several levels of severity, affects written and spoken language. Aphasia is characterized by difficulty in expression and understanding, occurring in the majority of cases with brain injury or stroke. The most common form of aphasia, "non-fluent aphasia", is characterized by difficulty to produce speech with minimal difficulty in understanding (Whitaker, 2007). The conventional reeducation of aphasia is based on intensive speech therapy, which for example uses repetition of words or simplification of language. Such therapy aims to improve the person's ability to communicate by restoring language abilities to the greatest possible extent and by teaching alternative means to communicate (e.g., pictures). Another commonly used rehabilitation strategy is word priming or speech supplementation using mime and pantomime. In addition, language disorders are very often associated with motor disorders (Bogliotti, 2012; de Partz and Pillon, 2014) making it difficult to initiate communication through the patient's motor skills. One of the alternative solutions to motor execution in aphasia rehabilitation therapies may be action observation.

In the 1990s, researchers evidenced the presence and the role of specific neurons, called mirror neurons, with the characteristic of being activated both when producing or when observing action (Rizzolatti and Arbib, 1998). These mirror neurons were first highlighted in non-human primates (di Pellegrino et al., 1992; Rizzolatti et al., 1996) and later, equivalent mirror activity was identified in humans (Fadiga et al., 1995), demonstrating a functional equivalence between the production and the observation of action (Caspers et al., 2010; Grèzes and Decety,

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2001; Hardwick et al., 2018; Iacoboni and Dapretto, 2006; Jeannerod, 2001; Molenberghs et al., 2012). Based on this neuronal equivalence, numerous studies have investigated the effects of action observation in motor learning (Blandin, 2002; Vogt and Thomaschke, 2007 for reviews), sport practice (D'Innocenzo et al., 2017; Faelli et al., 2019; Francisco et al., 2022; Weeks et al., 2000) and motor rehabilitation (Bidet-Ildei et al., 2022; Ertelt et al., 2007; Rizzolatti et al., 2021; Ryan et al., 2021; Sarasso et al., 2015; Sgandurra et al., 2013).

Overall, studies have indicated that action observation can be considered as an efficient therapy for motor learning and re-learning. Specifically, in rehabilitation, Action Observation Therapy (AOT) involves incorporating a period of action observation into conventional therapy. This can be done through direct observation of an actor, videos, or point-light sequences that depict an actor in motion. AOT has been regularly used in the last years and has demonstrated benefits for the rehabilitation of central and peripheral movement disorders (see Ryan et al., 2021; Sarasso et al., 2015 for systematic reviews and meta-analyses). The benefits of AOT are generally explained in terms of the reactivation of motor representations through the mirror neuron system, which encompasses the action observation/action execution matching system. The effects of this reactivation of motor representation can not only have direct benefits for neurological disorders (Ertelt, 2007) but could also impact peripheral motor disorders, such as orthopedic conditions, through a top-down effect (Bellelli et al., 2010). Interestingly, it has been shown that action observation could be also implied in cognitive functions such as action verb processing (see Bidet-Ildei et al., 2020 for systematic review of the link between action observation & language, and Courson and Tremblay, 2020 for a review of common network of action language processing with motor observation, imagery, and execution), numerical competencies (Bidet-Ildei et al., 2015) or episodic memory (Villatte et al., 2022). Moreover, while several experiments have shown an activation of the mirror neuron system during language processing (Aziz-Zadeh et al., 2006; Hauk et al., 2004; Tettamanti et al., 2005) the literature is divided on the role of this sensorimotor activation. In a radical embodied view, the sensorimotor system is seen as fundamental to semantic processing (Buccino et al., 2016), whereas in the radical computational view, sensorimotor activation is considered as background noise (Rothi et al., 1991) — not necessary but potentially providing a modulatory influence on language processing (Mahon and Caramazza, 2008). An intermediate tradition of research (called associationist) consists of accepting local area sub-task processing for language processing and integrating the aspect of distributed circuits for an inter-modal integration, which is relatively necessary for the production and understanding of language. In this way, action observation could play a positive role in priming language processing (Pulvermüller, 2005).

The conceptual role of sensorimotor activation in language processing is not yet clearly established. Nevertheless, the link between action observation and action language processing has captured researchers' interest. Consequently, over the past fifteen years, some studies have attempted to use action observation in the rehabilitation of language disorders and have shown promising results. However, heterogeneity of the stimuli (pictures, videos, etc.), conditions (whether associated with speech therapy or not), and rehabilitation program durations have made it difficult to conclusively demonstrate the benefits of action observation. In consequence, the primary objective of the present study was to conduct a comprehensive analysis of the literature on AOT for language disorders, specifically focusing on the common task of addressing "anomia". This was achieved through a systematic review of the literature and a twofold meta-analysis (inter-group: with control and intra-group: pre-post effect). A second aim was to investigate the role of AOT on other language skills (e.g. spontaneous speech). Finally, we will provide recommendations and perspectives for clinical practice and research.

2. Material and methods

This systematic review protocol was registered prior to the initiation of the review process on PROSPERO (n° CRD42022331380), and complies with the Cochrane guideline and PRISMA 2020 criteria.

2.1. Search strategy

The search strategy was conducted in accordance to the PICOs (population, intervention, comparison, and outcome) framework with: P (population/patients) adult; language disorder; I (interventions) dynamic action observation training/treatment; C (control) stimuli or conventional therapy; O (outcome criteria) functional recovery, cognitive score; S (study) controlled trials.

The electronic databases of PubMed, Scopus, EMbase & WebScience were searched until August 2023. The search equation consisted of associated termers, synonyms and keywords that were initially developed on PubMed before being adjusted to match other databases, without any need for additional filters. Search equation: ("left hemisphere injury" OR "right hemisphere injury" OR "brain damage" OR "brain lesion" OR "stroke" OR "aphasia" OR "apraxia" OR "language impairment" OR "hemipleg") AND ("action observation" OR "AOT" OR "action naming").

2.2. Eligibility criteria - according to the PICOs method

The exclusion criteria were (i) systematic review, meta-analysis, overview, case report, research protocol statement and communication abstract, (ii) no full text written in English, (iii) no language ability outcome or cognitive ability outcomes reported, no results on language abilities or results on cognitive abilities were reported, even as a related objective, (iv) child and teenager population, (v) temporary disorder evoked experimentally, or disorder already present at birth.

2.3. Study selection

After removing the duplicate two reviewers (VF, CBI) independently screened abstracts and titles using the online software Rayyan (https://www.rayyan.ai/). Then, the same reviewers confirmed the selection of relevant studies based on the full texts rather than previously defined inclusion and exclusion criteria. Any disagreements were resolved through discussion or, if necessary, in consultation with a third reviewer (MB).

2.4. Data collection process

During the full text screening process, data extraction (Table 1) was performed to gather characteristics of the included studies. The table of study characteristics was drawn up independently by two reviewers (VF, CBI). The intervention protocol was provided and the work load was calculated by multiplying the number of sessions per week, the time in minutes for the observation session and, finally, the number of weeks.

Evolution of the naming for action word production scores (i.e. the average of the responses just to name the stimuli) was extracted, as were the standard deviation and 95 % confidence interval. When the results were not explicitly reported in the text and available in graphics, we used WebPlotDigitizer following the recommendation of the Cochrane guidelines to extract the data (Li et al., 2019). We then fitted the data obtained with the description of the authors. All disagreements were resolved if necessary by discussion with CBI and by arbitration by MB.

2.5. Risk of bias and quality of evidence assessment

The Cochrane (Sterne et al., 2019) Risk of Bias Review Tool (RoB 2.0) was used to assess the risk of bias of each study. Five domains were assessed: (i) randomization process; (ii) deviations from intended

Table 1
Main characteristics of the 7-studies included.

Author (years)	Overall Population Groups Sample size (Women/ Men), Age	Type of Pain	Action observation treatment Duration of the intervention Number, durations and frequency of sessions Follow-up	Control treatment Control modalities Duration of the intervention Number, duration and frequency of sessions Self-intervention or not Follow-up	outcomes language recovery	Results After intervention After follow-up for only action naming tasks
Marangolo et al. (2010)	6 (2/4), 61.1 ± 11.41 y AOT same patient CG: same patient	Chronic aphasia 6 patients with non-fluent aphasia	**Treatment 1 (T1):** Observation of action executed by a therapist, and naming of the corresponding verb *T1: 2 wks* *1 daily session 30–35 min, 5/7d* *Follow-up: 1 wk; 1 month; 2 months*	**Treatment 3 (T3):** Observation of action executed by a therapist, and then had to perform another movement without meaning and produce the corresponding verb **Treatment 2 (T2):** Observation of action executed by a therapist, and then had to perform these actions and produce the corresponding verb *T2& T3: 2 wks* *1 daily session* *30–35 min, 5/7d* *Follow-up: 1 wk; 1 month; 2 mouths*	Proportion of correct naming of the stimuli used in their intervention	**At baseline:** T1 = T2 = T3 **After intervention: (E.I)** ↑↑ T1 = ↑↑ T2 while T3 no change is reported **Follow-up:** E.I = 1 wk = 1 month = 2 months
Marangolo et al. (2012)	7 patients (5/2) 54,85 ± 6,62 y	Chronic aphasia 7 patients with non-fluent aphasia	**T1) Observation of human action (e.g., walking, AO-H)** on Videotape (N=78), and production of the corresponding verb *T1: 2 wks* *1 daily session ≈20 min 5/7d* *Follow-up: 1 wk; 1 month; 2 months*	**T2) Observation of non-human action (e.g., barking, AO-NH)** on Videotape (N=32), and produce the corresponding verb *T2: 2 wks* *1 daily session ≈20 min 5/7d* *Follow-up: 1 wk; 1 month; 2 months*	Proportion of correct Scores in the naming of the stimuli used in their intervention BADA	**At baseline: (b0)** AO-H = AO-NH **After intervention: (E.I)** ↑ E.I >↑ b0 ↑ AO-H >↑ ↑ AO-NH *AO-NH (↑ E.I > b0)* **Follow-up:** E.I = 1 wk = 1 month = 2 months
Chen et al. (2015)	Patients: 6 patients (6 males)50,33 ± 8,4 y	1 transcortical mixed aphasia 2 non-fluent Broca Aphasia 3 transcortical-motor aphasia	**T1) Protocol ABA**Hand action observation combined with repetitionwatching the videoclip (e.g., cracking a peanut) and hearing the name of the object (e.g., peanut), then repeating them.one patient underwent fMRI after treatment *T1: 3wks1 daily session, 30 min, 6/7d, the ABA group practices protocol A the first and third week and protocol B the second. conversely for the BAB group*	**T2) Protocol BAB** Static object observation combined with repetition;the patient watches the video with the static object (e.g., a peanut) and hears the name of the object (e.g., a peanut), then repeats it.One healthy volunteer underwent fMRI *T2: 3wks1 daily session, 30 min, 6/7dthe BAB group practices protocol B the first and third week and protocol A the second. conversely for the ABA group*	Accuracy rate of language including Aphasia Quotient, spontaneousspeech, auditory comprehension, repetition, and naming tests of WAB + token test + picture naming test.	**After intervention:** (b0 = baseline) ABA: b0 < wk1 wk1 > wk2 wk2 < wk3 BAB: b0 < wk1 wk1 < wk2 wk2 > wk3

Table 1 (continued)

Author (years)	Overall Population Groups Sample size (Women/ Men), Age	Type of Pain	Action observation treatment Duration of the intervention Number, durations and frequency of sessions Follow-up	Control treatment Control modalities Duration of the intervention Number, duration and frequency of session Self-intervention or not Follow-up	outcomes language recovery	Results After intervention After follow-up

(*continued on next page*)

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Author (years)	Overall Population Groups Sample size (Women/ Men), Age	Type of Pain	Action observation treatment Duration of the intervention Number, durations and frequency of sessions Follow-up	Control treatment Control modalities Duration of the intervention Number, duration and frequency of sessions Self-intervention or not Follow-up	outcomes language recovery	Results After intervention After follow-up for only action naming tasks
Gili et al. (2017)	10 patients (4/ 6)59,33 ± 9,66 y	Chronic aphasia10 patients with non-fluent aphasia	**T1: to observe, and then to describe videoclip reproducing** a common real everyday lifecontext: e.g. a woman pulling a piece of luggage in a train station 5 patient started with this treatment and switched to T2 after 6 weeks *T1: 6 wks 1 daily sessions, 90 min, 5/7d*	**T2: to observe, and then to describe videoclip reproducing** a common everyday pantomimed life context: e.g. a woman who imitates looking in a mirror.5 patients started with this treatment and switched to T1 after 6 weeks *T2: 6 wks1daily sessions, 90 min, 5/7d*	Mean number of correct nouns/ verbs/ sentences; clusters of informative elements (C-Units) for describing the observed stimulus	**At baseline: (b0)**verbs = nouns = sentences = C-units**After intervention: (E.I)**↑ E.I >† b0verbs: T1 = T2nouns: T1 >† T2sentences: T1 = T2C-units: T1 = T2
Chen et al., 2019)	24 patients randomly divided into Group A 53,38 ± 2,7 y Group B 51,38 ± 4,1 y Group C 52,38 ± 4,54 y	Aphasia (fluent and non-fluent-speaking)	**Group A (T1):** Hand-action observation (e.g., flapping a fan) and repetition of the name of the action *T1: 2 wks 1 session, 35 min, 5/7d*	**Group B (T2):** Dynamic-object observation (e.g., a fan rotating on an automatic turnplate) and repetition of the name **Group C (T3):** Conventional speech therapy *T2&T3: 2 wks 1 session, 35 min, 5/7d*	Spontaneous speech, auditory verbal comprehension, repetition, and naming, and aphasia quotient of the WAB. .	**At baseline:** (b0) T1 = T2 = T3 **After 1wk intervention: (E.I)** T1 >† T2 T1 >† T3
You et al. (2019)	Patients: 42AOT (5/16)56.52 ±12.29 yCG (5/ 16)558.71 ±12.00 y	All patients had an apraxia of speech and almost all a non-fluent aphasia	**T1) observation of action** for 20 minutes, followed by 10 minutes of conventional therapy with 3 levels: 1) observation of a mouth and hearing him/her saying an action. 2) observation of the action and hearing a voice-over. 3) observation of someone doing an action (e.g., cutting an orange) and naming the action. T1: *4wks 2 daily sessions, 30 min, 5/7d*	**T2) conventional therapy (with no action observation),** 1) The integrated application of Schuell's. 2) Articulatory-kinematicapproaches *T2: 4wks2 daily sessions, 30 min, 5/7d*	Scores of information, fluency, comprehension, repetition, and naming part of WAB + BDAE	**At baseline: (b0)**T1 = T2**After intervention: (E. I)**↑ T1 >† ↑ T2
Francisco et al. (2023)	AO: 7(4/3)54 ± 7 yCG: 7 same patient, Crossover Study Design	AO/CG5 ischemic stroke + 1 haemorrhagic stroke + 1 brain trauma	**T1) observation of action** in addition to conventional therapy. The patient watched video clips of human actions (e. g., walking), using the unfocused Point-Light-Display paradigm and made a denomination task. **T2) observation of action** similar as T1 but with focused Point-Light-Display.*T1&T2: 3 Wks1 session, 10 min, 5/7d*	**T3) conventional therapy** Conventional therapy, with a classic action denomination task using contour images of the same actions (e.g., walking). *T3: 3 Wks1 session, 10 min, 5/7d*	Scores in the correct naming of action pictures.	**Picture naming**Baseline †< post-treatment†† T1=T2 >† CG

T = treatment/protocol; wk = weeks; n /7d = over a week of 7 days; b0 = baseline, before the intervention; E.I = end of the intervention; y= years; min = minutes; ↑ = increase (improvement); † = significant; >† = significantly better or worse. WAB: Western Aphasia Battery, BDAE: Boston Diagnostic Aphasia Examination.

interventions; (iii) missing outcome data; (iv) measurement of the outcomes; and (v) selection of the reported results. Following which, each domain was classified from "low risk of bias", to "high risk of bias" (Fig. 2). We investigated publication bias, assessing its asymmetry by using the funnel plot asymmetry rank correlation test (Begg and Mazumdar, 1994). Finally, the level of evidence was assessed using the Grades of Recommendations, Assessment, Development and Evaluation (GRADE) scale recommended by Cochrane (Schünemann et al., 2023). The GRADE model provides an overall assessment of the quality of research, classifying level of evidence into four levels, from high to very low (Table 2). This classification is based on the assessment of five criteria: risk of bias, inconsistency, indirectness, imprecision and publication bias.

2.6. Statistical analysis

Two analyses were conducted: the first was a comparison between the AOT group and the control group, and the second was a moderator

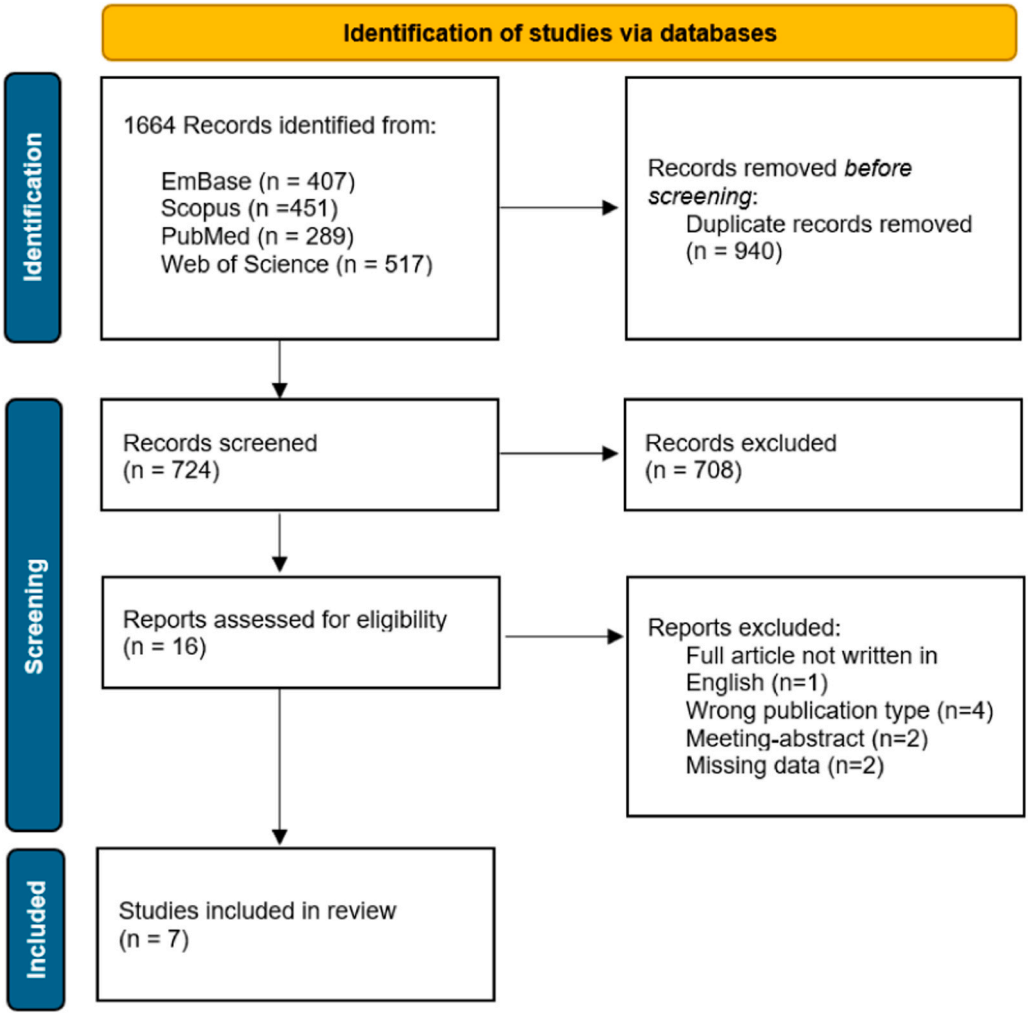

Fig. 1. Study selection flowchart.

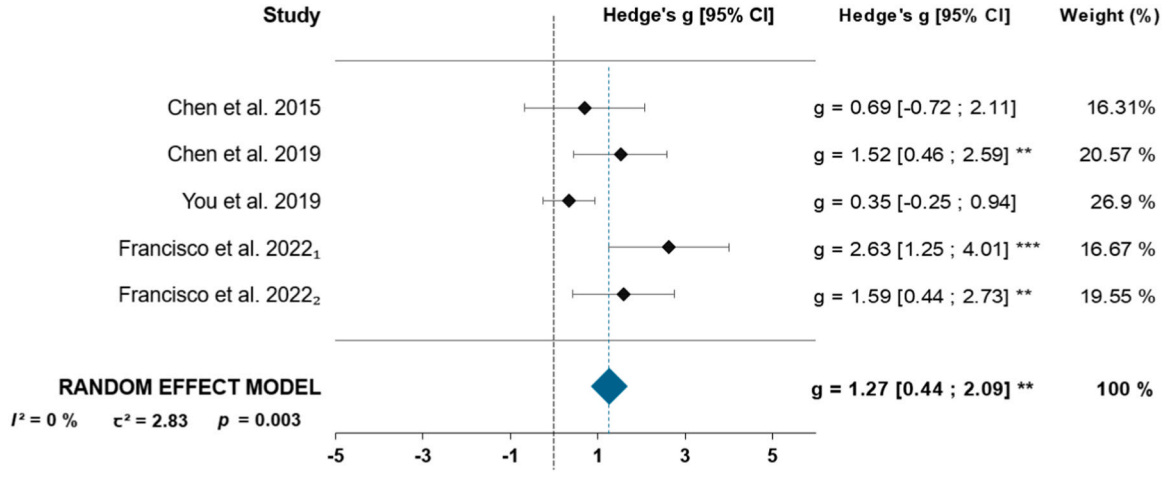

Fig. 2. : Forest plot of overall meta-analysis results: action observation versus conventional therapy. This forest plot displays the results in hedge's g with a 95 % confidence interval. The overall effect is represented by a diamond. I^2 is the heterogeneity of the studies,τ^2 = the variance between studies, * = a significant p-value < 0.05, ** = a significant p-value < 0.01, and *** = p-value <0.001.

analysis, which was an intra-group comparison (exclusively for the AOT group) between the pre- and post-therapy scores. In both cases, the analysis was performed using the performance scores from the action word naming task, isolated from the other tests or sub-test used in the experiments. Standardized Mean Differences (SMDs) of the naming task were calculated for each study group using Hedge's g. Considering the possible differences between the moderators used in the different studies, such as type of stimuli or intervention time, we chose a random-

Table 2
effect of moderators in meta-analysis.

	nb Patients	nb Groups	Hedge's *g*	95 % - CI	z - *test*	p-Value	I^2	p-Value of Q	p-Value of z
OVERALL	**89**	**12**	**1.8**	**[1.29; 2.31]**	**6.93**	**< 0.001**	**15.56**		
Population:									
APHASIA									**0.854**
Non fluent	**34**	**6**	**1.74**	**[0.86; 2.63]**	**3.86**	**< 0.001**	**12.97**		
Mixed	**55**	**6**	**1.84**	**[1.29; 2.39]**	**6.56**	**< 0.001**	**12.41**		
TIME STROKE								**0.365**	
Subacute	**31**	**3**	**2.22**	**[1.18; 3.26]**	**4.18**	**< 0.001**	**0,00**		
Chronic	**40**	**6**	**1.46**	**[0.83; 2.09]**	**4.54**	**< 0.001**	**8.09**		
Mixed	**18**	**3**	**2.35**	**[0.52; 4.19]**	**2.52**	**< 0.05**	**7.12**		
Intervention:									
MODE AO									**0.261**
Live	**26**	**4**	**1.51**	**[0.98; 205]**	**5.56**	**< 0.001**	**0,00**		
Video	**63**	**8**	**2.06**	**[1.27; 2.84]**	**5.13**	**< 0.001**	**16.24**		
Type of AO								**< 0.001**	
Human (pantonyme)	**5**	**1**	**2.73 (a.)**	**[1.40; 4.05]**	**4.05**	**< 0.001**	**0,00**		**(a.) < 0.05**
Human (real)	**63**	**8**	**1.62 (b.)**	**[1.17; 2.07]**	**7.08**	**< 0.001**	**12.01**		**(b.) < 0.05**
Non human	**7**	**1**	**0.56 (a.b.c)**	[−0.18; 1.31]	**1.48**	**0.14**	**0,00**		**(c.) < 0.05**
PLD	**14**	**2**	**3.21 (c.)**	**[1.48; 4.93]**	**3.65**	**< 0.001**	**0,00**		
ORAL PRODUCTION								**0.07**	
Denomination	**71**	**9**	**1.64 (a.)**	**[1.07; 2.22]**	**5.57**	**< 0.001**	**23.53**		**(a.) < 0.05**
Decribe	**10**	**2**	**2.83 (a.b.)**	**[1.86; 3.79]**	**5.75**	**< 0.001**	**0,00**		**(b.) < 0.05**
Repeat	**8**	**1**	**1.42 (b.)**	**[0.49; 2.36]**	**3.000**	**< 0.05**	**0,00**		
DOSE									**0.94**
< 6.25	**54**	**8**	**1.82**	**[1.11; 2.52]**	**5.08**	**< 0.001**	**13.96**		
> 6.25	**35**	**4**	**1.86**	**[1.00; 2.71]**	**4.26**	**< 0.001**	**15.65**		

effects model (DerSimonian and Laird, 1986). With inverse variance weighting, the standard mean deviation was used to obtain the overall effect and its confidence interval (95 %CI) for comparison with 0. The effect sizes of the moderators were compared using Q-test and z-test: to test the homogeneity of the variables, we performed a Q-test, once the null hypothesis was rejected, we compared them in pairs using a z-test. Cohen's criteria were used to interpret the magnitude of SMD: < 0.2, trivial; 0.2–0.5, small; 0.5–0.8, moderate; and > 0.8, large. The heterogeneity of effects is expressed by the statistic I^2, which can be simplified in 3 steps: 25 %, 50 %, 75 %, for respectively weak, moderate and strong heterogeneity. We performed a comprehensive meta-analysis (https://meta-analysis.com/), and completed for pairwise comparisons on excel matrix; for all results, a significant statement is defined at a p-value of 0.05.

3. Results

3.1. Study selection

All in all, 7 studies matched our search question (Fig. 1). One study lacked information on the raw quantitative results and was included in the systematic review aspect, but not in the meta-analysis. Three studies compared therapy combined with observation and conventional therapy. Four studies compared the added value of observation with different controlled conditions. Thereby, we performed an initial analysis comparing the effect of observation with conventional therapies (between-group comparisons for four studies), followed by a second meta-analysis with all included studies, testing different moderators of observation in the rehabilitation of speech and language disorders (within-group comparisons).

3.2. Study design and sample characteristics

The selected studies, summarized in Table 1, span from 2010 to 2023. They encompass different types of aphasia (chronic (Chen et al., 2019; Marangolo et al., 2010, 2012), subacute (Gili et al., 2017; You et al., 2019,) or mixed (Chen et al., 2015; Francisco et al., 2023), various forms of AOT (direct observation (Chen et al., 2019) and video observation (Chen et al., 2015; Francisco et al., 2022; Gili et al., 2017; Marangolo et al., 2012; You et al., 2019), diverse procedure durations (ranging from 1.11 hours (Francisco et al., 2023) to 45 hours (Gili et al., 2017) and various tasks associated with AOT (action denomination (Chen et al., 2015; Francisco et al., 2022; Marangolo et al., 2010, 2012; You et al., 2019), action description(Gili et al., 2017), repetition of the action name (Chen et al., 2019). Four studies compared AOT with conventional therapy (Chen et al., 2015; Chen et al., 2019; Francisco et al., 2023; You et al., 2019), while three studies compared it with a control condition (Gili et al., 2017; Marangolo et al., 2010, 2012).

3.3. Effectiveness of AOT compared with conventional therapy on naming task

The four studies (for 5 AOT groups) comparing AOT with conventional therapy for aphasia (Chen et al., 2015; et al., 2019; Francisco et al., 2023; You et al., 2019), involved 85 patients and 5 comparisons. One comparison (between AOT and control) was made for four studies (Chen et al., 2015; et al., 2019; You et al., 2019 and two comparisons (unfocused PLD vs control and Focused PLD vs control) for one study (Francisco et al., 2023_1 and Francisco et al., 2023_2). Overall, the results reported an advantage for AOT (Fig. 2). The comparison between action observation versus conventional therapy showed moderated evidence in improvement of the naming task for the AO, with large effect size (Hedge's $g = 1.27$, 95 %CI [0.44; 2.09], $p = 0.003$, $I^2<25$). While these studies confirm the superior effect of AOT, it should be noted that the effect size calculations reported in our analysis show non-significance for two comparisons. The first comparison concerned training in naming objects by observing their use or a static image (Chen et al., 2015) (Hedge's $g = 0.69$, 95 %CI [-0.72; 2.11], $p = 0.33$, $I^2<25$) and the

second was a comparison between a conventional (unspecified) 30-minute therapy and the same therapy over 10 minutes plus 20 minutes of AOT (You et al., 2019) (Hedge's $g = 0.35$, 95 %CI [-0.25; 0.94], $p = 0.25$, $I^2<25$).

3.4. Effect of moderators in meta-analysis

In this section we reported within-group comparisons of pre-post intervention changes (see Fig. 3). We found with low evidence an overall large effect of the AOT with Hedge's $g = 1.80$, 95 %CI [1.29; 2.31], $p < 0.001$, and as the heterogeneity is low (I^2 <25). Due to few studies (7 studies, 12 AOT groups), in a prospective approach, we have chosen to make sub-group analysis to look at the possible moderators of AOT efficiency (see details in Table 2).

3.4.1. Effectiveness of AOT according to population

The systematic review of studies reported that studies focused on one type of aphasia, non-fluent (Chen et al., 2015; Gili et al., 2017; Marangolo et al., 2010$_3$, 2012), or mixed (Chen et al., 2019; Francisco et al., 2023; Marangolo et al., 2010$_{1,2}$). No significant results were observed between non-fluent and mixed aphasia ($z = -0.18$, $p = 0.85$).

To investigate the effect of AOT according to the population condition, we grouped two studies including patients in subacute phase of aphasia (Gili et al., 2017; You et al., 2019), three including patients in chronic phase (Chen et al., 2019; Marangolo et al., 2010, 2012), and two including patients in both subacute and chronic phase (Chen et al., 2015; Francisco et al., 2023). The comparison between patient conditions showed no significant chronicity status effect (Q-test= 2.02, $p = 0.36$).

3.4.2. Effectiveness of AOT according to the intervention

3.4.2.1. Effectiveness of AOT mode. Two studies applied direct observation of the therapist (Chen et al., 2019$_1$; Marangolo et al., 2010), while the other five used video (Chen et al., 2015; Francisco et al., 2023; Gili et al., 2017; Marangolo et al., 2012; You et al., 2019). No difference between live observation and videotaped was observed ($z = -1.12$, $p = 0.26$).

3.4.2.2. Effectiveness of type of AOT. Five studies used contextualised human observation i.e., action produced in a normal environmental situation, which includes the character of the action and the objects with which it interacts (Chen et al., 2015; Chen et al., 2019; Gili et al., 2017$_1$; Marangolo et al., 2010, 2012$_1$; You et al., 2019), one of humans doing pantomime (Gili et al., 2017$_2$), one PLD focusing on specific body segment or important limbs of the action (Francisco et al., 2023$_1$), one general PLD (i.e., without any focus on body part) (Francisco et al., 2023$_2$), and one non-human action (Marangolo et al., 2012$_2$). Statistical analysis revealed a main effect of type of AOT (Q-test= 13.44, $p = 0.001$), showing less efficiency for the observation of non-human actions than real actions, such as human pantomime or PLD (respectively: $z = 2.39$, $p < 0.05$, $z = -2.79$, $p < 0.01$, $z = 2.76$, $p < 0.01$). No difference between human actions, whether contextualised or not, was reported (real = pantomime ($z = 1.55$, p =0.12); PLD = pantomime ($z = -0.43$, p =0.67); real = PLD ($z = 1.74$, p =0.08)).

3.4.2.3. Effectiveness of the associated oral production tasks. For the type of exercise associated with the AOT, the majority of the studies used the denomination of the action observed (Chen et al., 2015; Francisco et al., 2023; Marangolo et al., 2010, 2012; You et al., 2019), while one used the description (Gili et al., 2017), and another used an observation named by a voiceover and then repeated by the patient (Chen et al., 2019). A tendency was observed between type of exercises (Q-test= 5.26, $p = 0.07$) suggesting that describing the action observed would probably be a more effective exercise than naming (naming vs describe: z = 2.06, $p = 0.03$) or repeating after having heard the name of action (repeat vs describe: $z = 2.05$, $p = 0.04$).

3.4.2.4. Effectiveness of the program characteristics and intensity. All the studies involved five sessions per week, except for one which involved six sessions (Chen et al., 2015). The duration of the program was two weeks in four studies (Chen et al., 2019; Francisco et al., 2023; Marangolo et al., 2010, 2012), three weeks in one study (Chen et al., 2015), four weeks in one study (You et al., 2019), and six weeks in one study (Gili et al., 2017). AOT session duration also varied, ranging from less than 10 minutes (Chen et al., 2015; Francisco et al., 2023) to 90 minutes (Gili et al., 2017).

The intensity of the rehabilitation program was calculated according to the following equation: Intensity = (number of sessions × session time (minutes) × number of weeks) / 60. We then split studies presenting higher or lower intensity of 6.25 hours, which corresponds to the median of the intensity of the total volume dose calculated for every study (Iacobucci et al., 2015). The analysis reported no significant difference in intensity ($z = -0.07$, $p = 0.94$).

4. Secondary outcomes

Regarding the evaluation of transfer capacity, i.e., the effects of AOT on language tasks other than action verb denomination, Marangolo et al.

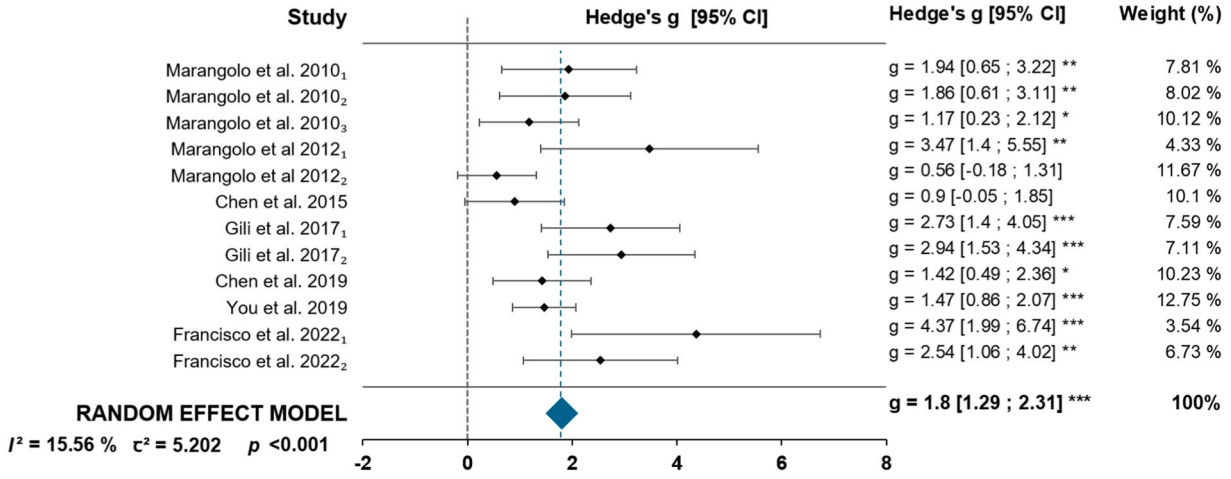

Fig. 3. : Forest plot of overall meta-analysis: results of action observation therapy (within group effect). This Forest plot displays the results in hedge's g with a 95 % confidence interval. The overall effect is represented by a diamond. I^2 is the heterogeneity of the studies, τ^2 = the variance between studies, and * = a significant p-value < 0.05, ** = a significant p-value < 0.01, and *** = p-value <0.001.

(2012) observed a significant improvement in the free description task after AOT for the naming task, without any significant improvement of the Battery for the Analysis of Aphasic Disorders. Following the AOT program, Gili et al. (2017) reported significant improvement in the number of nouns, verbs, sentences, and C-Units (clusters of informative elements) in their patients' action descriptions compared to the control group. This effect was more pronounced after real actions compared to pantomime observation.

Three studies (Chen et al., 2015; 2019, You et al., 2019) demonstrated significant improvement in spontaneous language, information richness, fluency, and comprehension among aphasic patients following the AOT program compared to patients undergoing a rehabilitation program without action observation. Specifically, Chen et al. (2015) observed a "v" curve for the "ABA" protocol or an inverted "v" curve of improvement for the "BAB" protocol, indicating benefits in favor of AOT intervention compared to conventional approach. Additionally, Chen et al. (2019) reported benefits on the WAB aphasia quotient for the AOT and conventional group, but not for the object-rotating observation group. While no difference in the global aphasia quotient between the AOT and conventional groups was reported, the fluency sub-test was greater in the AOT group. You et al. (2019) reported a significant improvement in WAB sub-tests (information, fluency, comprehension, repetition, naming) after the AOT program in both the AOT and the conventional groups, with greater benefits observed in the AOT group. In addition, the authors reported a significant improvement in aphasia severity assessed by the Boston Diagnostic Aphasia Examination (BDAE) in the AOT compared to the conventional group.

5. Methodological quality

The summary of the risk of bias for each study is presented in Fig. 4. For each study, two independent reviewers assessed each paper using five criteria: D1 Randomization, D2 Deviation from the intended interventions, D3 Missing outcome data, D4 Measurement of the outcome, and D5 Selection of the reported result. The results presented in Fig. 4 show the lower evaluation in each case. For example, if one reviewer rated the study by Marangolo et al., 2010 as 'low risk' for D2 but the other rated it as ''some concern'' was reported. Overall, our results showed low risk studies. The randomisation process, including random sequence generation, concealment and comparability of baseline data, was judged to be ''low risk of bias'' in all studies. However, five studies (Chen et al., 2015; Chen et al., 2019; Francisco et al., 2023; Gili et al., 2017; Marangolo et al., 2010), in which the protocol could be considered as laboratory research conditions rather than clinical trials, were classified as "some concerns" regarding criterion D2, "deviation from the intended interventions". In these studies, the AOT and conventional phases were counterbalanced to minimize the risk of patient losses due to chance, which raises reasonable doubts regarding patient naivety. Moreover, no study has proposed a double-blinded procedure that could control for placebo effects and experimenter biases, and more control studies will be necessary to definitively demonstrate the benefits.

The results of the two meta-analyses presented in this review were assessed using the GRADE method (Table 3). The first meta-analysis, comparing AOT and conventional therapy, showed moderate-quality evidence. The second meta-analysis, comparing within-group effect, showed low-quality evidence.

6. Discussion

This systematic review and meta-analysis, including seven studies involving a total of 85 patients with aphasia, aimed to assess the impact of action observation therapy (AOT) on action denomination tasks and the influence of various moderators. The main findings of this paper consist in comparisons between AOT and conventional therapy, which show greater improvement with AOT, particularly in naming tasks, with a transfer of improvement to other language assessments. It is also noted that any aphasic patient, regardless of chronicity or type, appears to benefit from the effects of AOT, provided that AOT with human action stimuli is used.

While conventional rehabilitation demonstrated significant improvement in action naming tasks post-intervention, our findings demonstrated that language rehabilitation involving action observation therapy (AOT) yielded greater recovery compared to conventional rehabilitation alone. We observed a large effect size and low heterogeneity, providing strong evidence to consider AOT as a relevant rehabilitation approach in aphasic patients. This effect of AOT is not very surprising if we consider the action-language link and the neuronal equivalence between the two activities (Bidet-Ildei et al., 2020). Several potential explanations can be evoked to explain the benefits. The first relates to an embodied conception of cognition, which considers that sensorimotor experience is directly involved in language processing (Barsalou, 2008). This can occur either through the activation of a common network of sensemaking (Bidet-Ildei et al., 2020; Rizzolatti et al., 1996) or through automatic functional connectivity between the two processes due to numerous common associations during

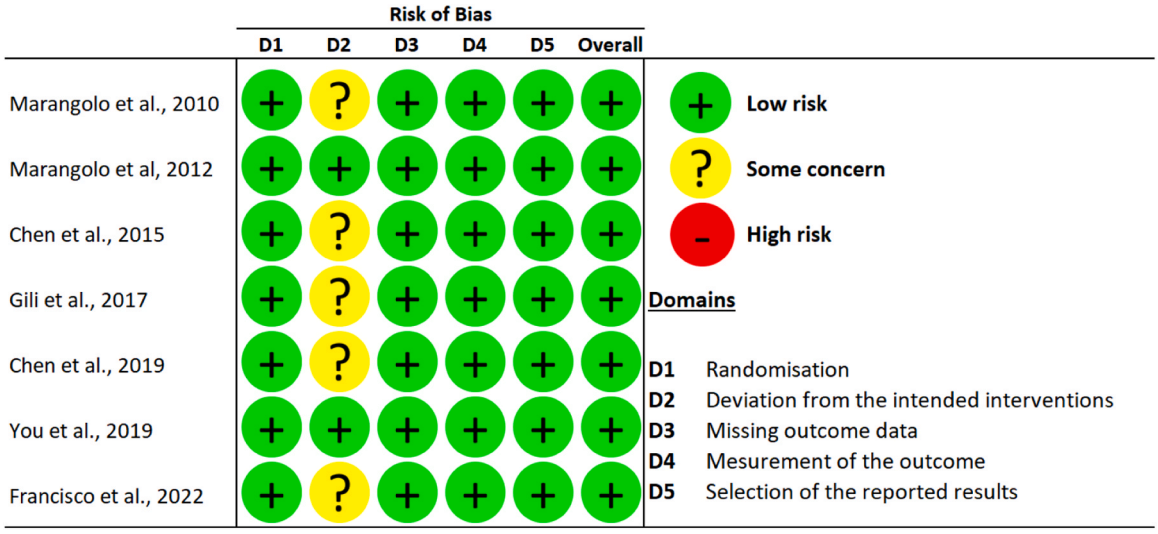

Fig. 4. Summary of risk of bias judgements for each study: D1 Randomisation, D2 Deviation from the intended interventions, D3 Missing outcome data, D4 Measurement of the outcome, D5 Selection of the report result.

Table 3
Summary of risk of bias judgements for each study.

GRADE assessment									
Quality assessment							Number of patients		
Number of studies	Studies design	Risk of bias	Inconsistency	Indirecteness	Imprecision	Other considerations	AOT	Control	Quality
Effectiveness of Action Observation vs. Control group, after intervention									
3 **1**	randomised trials crossover	not serious	not serious	not serious	not serious	low sample size, risk of publication bias	47	45	⊕⊕⊕ O Moderate
Effectiveness of moderator of Action Observation, after intervention									
3 **4**	randomised trials crossover	not serious	not serious	not serious	not serious	low sample size, risk of publication bias	89	n.a.	⊕⊕ OO Low

development (Pulvermüller, 2005; Pulvermüller and Fadiga, 2010). Another suggestion, proposed by Mahon and Caramazza (2005), is that the sensorimotor system is not essential but could have a modulatory influence – with sensorimotor indexing occurring subsequently after the concept has been fixed for a complete representation. They used neuropsychopathology (of apraxia and aphasia) to establish interesting evidence and pointed out a limitation, suggesting sense-making without an embodied view. The double dissociation between action recognition (failed or not) without (or not) motor or semantic deficit seems to depend on minimal necessary computation.

Finally, Briglia et al. (2018) combine an embodied and computational conception – but remaining in the embodied hypothesis – and propose that in a typical brain, nearly all modal inputs are used (without being limited to an all-or-nothing approach), accepting different ways of triggering the distributed system of access to meaning (see also Shebani et al., 2022 for another theory, which englobes an embodied and a disembodied view).

By investigating the time of stroke occurrence, we failed to determine any association with the AOT rehabilitation program, suggesting its applicability across a broad spectrum of aphasic patients. Furthermore, our analysis indicates that the program characteristics, particularly the duration of each session (ranging from 10 to 90 minutes) and the duration of the program (from 2 to 6 weeks), does not appear to modify the expected benefits following an AOT rehabilitation program. Thereby, it is safe to assume that two weeks is sufficient to observe significant short-term improvements (i.e., after the intervention) even it remains a minimum, and it is evidently encouraged to continue as long as improvement is noted. Notice that improvement through AOT could potentially persist or achieve better long-term outcomes by extending AOT programme duration. Nevertheless, no study has tested a such follow-up; this point will need to be examined by future research. However, due to the similar number of repetitions (5 or 6 times per week) applied in the different rehabilitation program, we were unable to assess the impact of the number of AOT repetitions over the course of rehabilitation. This finding suggests that five sessions a week provide significant benefits (Chen et al., 2015; Chen et al., 2019; Francisco et al., 2023; Gili et al., 2017; Marangolo et al., 2010, 2012; You et al., 2019). Overall, future studies are needed to determine optimal AOT program rehabilitation by adjusting therapy related to daily routine capability in real-world study design.

Reinforcing the previous added value of AOT in aphasic rehabilitation, our findings showed that both live sessions and videos provided similar clinical benefits, multiplying the possibilities of AOT application. However, the type of AOT proposed, i.e., contextual human movement, non-contextual ("pantomime", or, "PLD") human movement, or non-human movement appeared crucial. To be effective, AOT must be based on human movements with or without context (Francisco et al., 2023; Marangolo et al., 2012). This is consistent with behavioural and brain studies conducted on healthy controls, which have demonstrated that non-human movements fail to evoke connection between action observation and action language processing (Beauprez and Bidet-Ildei, 2018) and are not based on the activation of mirror neuron system (Chen et al., 2019; Martineau et al., 2008). In addition, our analysis did not reveal any significant benefits of specific context to manage aphasia. Previous studies with healthy controls have nonetheless suggested that context could play an important role between action observation and action language processing, demonstrating, for example, that the presentation of a human action in an unusual context (i.e., someone using a banana as a phone instead of an actual phone) did not prime the verb "phone" (Beauprez et al., 2018, 2019, 2020). In line with this observation, Gili et al. (2017) found evidence of plasticity and changes in brain connectivity following real-life contextualized AOT videos, compared to pantomime observation. These brain modifications positively correlated with improved language outcomes in patients with aphasia, suggesting that context could be beneficial for patients. Numerous studies have demonstrated neuropsychological evidence, with difficulty recognising pantomime, in various patients exhibiting apraxia, aphasia, or both (Gainotti and Lemmo, 1976; Heilman et al., 1982; Mahon and Caramazza, 2005; Negri et al., 2007). These findings, which may be seen as contradictory — at least from a radical embodied perspective — broadly support the possibility of a double dissociation between sensory-motor functions and language processing, or simply between action recognition and imitation. However the lack of evidence of recognition or naming, after observing the pantomime could be due to a possible misunderstanding of the gestures shown, to which a memory must be added (Durand et al., 2021). Indeed, Durand and colleagues., (2018, 2021) offered an interesting solution to the lack of naming/recognition of action, with aphasic patients. In this methodology, they used three sensorimotor strategies for triggering the language process for naming an action target. They first used action observation due to co-activation of the link between motor areas and classical language areas. Secondly, if necessary, they asked the patient to mimic the action observed, or thirdly (always if necessary), they asked for mental imagery of action in a personal context. The three sensorimotor strategies are congruent with neurophysiological evidence for inter-connection between tasks: action production, action observation, mental imagery, and language processing (Courson and Tremblay, 2020; Hardwick et al., 2018). This strategy, consisting of three steps to trigger conceptual processing, could also be accepted by the disembodied epiphenomenal hypothesis (Mahon and Caramazza, 2008) or embodied interaction hypothesis (Pulvermüller and Fadiga, 2010), but above all with memory modelisation of ATHENA (Briglia et al., 2018), which supposes that any entry could permit access to a meaningful representation within the contextual interaction. Future research should be conducted to investigate more specifically the relevance of context in AOT rehabilitation programs.

Concerning the language task associated with AOT, the analysis revealed that denomination or description of the action was more effective than simple repetition. This effect could be related to the generation effect, which is known to influence memory performance (Slamecka and Graf, 1978). According to the depth of processing theory (Craik and Fergus, 1979), memory performance is influenced by the level of processing during encoding: the deeper the processing, the stronger the memory trace. In this context, we can hypothesize that generating words associated with observed actions may be more

beneficial because it requires deeper processing compared to simple word repetition. In both hypotheses – disembodied epiphenomenal or embodied interaction – after retrieving the target concept, the different contexts indexed either during or after semantic processing "benefit" or "permit" semantic arborisation at the present node to the conceptual target (Kiran and Thompson, 2019; Thompson et al., 2013). In a second part, our review revealed that AOT could induce benefits not only for action verb denomination performances, but also in transfer for other types of words such as nouns, verb sentences (Gili et al., 2017), other types of language tasks such as spontaneous language, fluency, comprehension, repetition and information (Chen et al., 2015; Chen et al., 2019; You et al., 2019) or even in specific assessment of aphasia disorders such as BADE (You et al., 2019). These findings suggest that AOT could reactivate all the neural circuits of language processing (Pulvermüller, 2005; Pulvermuller and Fadiga, 2010). Interestingly, transfer effects could be influenced by context, illustrated by the higher effect in patients observing real actions compared to pantomime (Gili et al., 2017). Thereby, the presence of context may modulate the activation of language circuits (Beauprez et al., 2019; Durand et al., 2021).

6.1. Limitations

The limited number of studies and sample sizes represent a significant limitation. However, the results were sufficiently clear to safely suggest the added value of AOT in language rehabilitation programs for aphasic patients. Due to the small number of studies, we were unable to thoroughly investigate the role of AOT dosage and the influence of context on the effectiveness of AOT rehabilitation. This highlights a crucial area for future research. Moreover, only one of the included studies attempted to explore the role of somatotopy in the effectiveness of AOT by comparing focused and unfocused human point-light displays (Francisco et al., 2023). Although this study did not reach conclusive findings, further investigations are warranted to determine the involvement, from a somatotopic standpoint, of motor brain circuitry activation in action verb processing, as previously evidenced in healthy participants (Aziz-Zadeh et al., 2006; Beauprez and Bidet-Ildei, 2018; James and Maouene, 2009; Shebani et al., 2022; Tettamanti et al., 2005). Finally, another limitation is that no study proposes a strict double-blind procedure. However, this procedure is not entirely appropriate for measuring AOT benefits because AOT requires specific visualizations during the intervention. The only solution we see is that the speech therapist and the experimenter should be different individuals, and the experimenter should not know which type of intervention the patient received.

6.2. Perspective of AOT for future studies and clinical implications

All the included studies underscored the added value of action observation for action verb retrieval in aphasic patients. Moreover, AOT is simple to apply and highly cost-effective, making it suitable for use both within and outside medical facilities. Given the present analysis, we recommend using videos rather than static images as stimuli and associating these stimuli with the motor repertoire of the observers. Moreover, an intervention based on patient production (such as a language generation task) should be prioritized. Hence, employing AOT could be particularly beneficial for rehabilitating patients who present both motor and language disorders, which is often the case for individuals following a stroke (Kuriakose and Xiao, 2020). From a fundamental point of view, and in order to find ways of optimizing AOT, the motor repertoire effect (outlined above) needs to be examined, perhaps as much from the perspective of the observer's sensorimotor behavior as from the society in which they develop. This aligns with the suggestion of sensorimotor information indexed on abstract concepts. In fact, language is subject to gender stereotypes (Dewi and Ardaniah, 2016; Mohd Faeiz Ikram bin Mohd Jasmani et al., 2011), and action words could also be linked to an embodied hypothesis (Plaza et al., 2017). A second fundamental perspective can be related to investigating the transfer of improvement in language abilities to different language tasks. It involves the generalization/arborization of semantics obtained with AOT as opposed to another priming medium.

7. Conclusion

The current systematic review with meta-analysis showed that AOT is a genuinely interesting "alternative" (as opposed to an image medium when the objective is solely to target an action concept.) and complementary approach to conventional language rehabilitation of post-stroke patients presenting with aphasia. The results suggest that AOT rehabilitation programs provide a positive effect on the naming of action verbs and, presumably, on possible transfer to linguistic tasks. Although strong conclusions cannot be drawn from this review, the results clearly encourage consideration of AOT as part and parcel of language rehabilitation and underscore the need to conduct randomized controlled trials that could further demonstrate AOT efficacy.

Competing Interests

The authors declare no competing interests.

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References

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* (18), 1818–1823. https://doi.org/10.1016/j.cub.2006.07.060.

Barsalou, L.W., 2008. Grounded cognition. Annu. Rev. Psychol. *59*, 617–645. https://doi.org/10.1146/annurev.psych.59.103006.093639.

Beauprez, S.-A., Bidet-Ildei, C., 2018. The kinematics, not the orientation, of an action influences language processing. J. Exp. Psychol.: Hum. Percept. Perform. *44*, 1712–1726. https://doi.org/10.1037/xhp0000568.

Beauprez, S.-A., Toussaint, L., Bidet-Ildei, C., 2018. When context modulates the influence of action observation on language processing. PLOS ONE *13* (8), e0201966. https://doi.org/10.1371/journal.pone.0201966.

Beauprez, S.-A., Laroche, B., Perret, C., Bidet-Ildei, C., 2019. How action context modulates the action-language relationship: a topographic ERP analysis. Brain Topogr. https://doi.org/10.1007/s10548-019-00722-y.

Beauprez, S.-A., Blandin, Y., Almecija, Y., Bidet-Ildei, C., 2020. Physical and observational practices of unusual actions prime action verb processing. Brain Cogn. *138*, 103630 https://doi.org/10.1016/j.bandc.2019.103630.

Begg, C.B., Mazumdar, M., 1994. Operating Characteristics of a Rank Correlation Test for Publication Bias. Biometrics *50* (4), 1088–1101. https://doi.org/10.2307/2533446.

Bellelli, G., Buccino, G., Bernardini, B., Padovani, A., Trabucchi, M., 2010. Action Observation Treatment Improves Recovery of Postsurgical Orthopedic Patients: Evidence for a Top-Down Effect? Article 10. Arch. Phys. Med. Rehabil. *91* (10) https://doi.org/10.1016/j.apmr.2010.07.013.

Bidet-Ildei, C., Beauprez, S.-A., Badets, A., 2020. A review of literature on the link between action observation and action language: Advancing a shared semantic theory. N. Ideas Psychol. *58*, 100777 https://doi.org/10.1016/j.newideapsych.2019.100777.

Bidet-Ildei, C., Deborde, Q., Francisco, V., Gand, E., Blandin, Y., Delaubier, A., Jossart, A., Rigoard, P., Billot, M., David, R., 2022. The added value of point-light display observation in total knee arthroplasty rehabilitation program: a prospective randomized controlled pilot study. Med. (Kaunas., Lith.) *58* (7), 868. https://doi.org/10.3390/medicina58070868.

Blandin, Y., 2002. L'Apprentiss. Par. Obs. D. 'habiletéS. Mot.: Un. Process. D. 'Apprentiss. Sp. écifique ? *L'Ann. ée Psychol. 102* (3), 523–554. https://doi.org/10.3406/psy.2002.29605.

Bogliotti, C., 2012. Les troubles de la dénomination. Lang. Fr. *n°174* (2), 95–110.

Briglia, J., Servajean, P., Michalland, A.-H., Brunel, L., Brouillet, D., 2018. Modeling an enactivist multiple-trace memory. ATHENA: A fractal model of human memory. J. Math. Psychol. *82*, 97–110. https://doi.org/10.1016/j.jmp.2017.12.002.

Buccino, G., Colagè, I., Gobbi, N., Bonaccorso, G., 2016. Grounding meaning in experience: A broad perspective on embodied language. Neurosci. Biobehav. Rev. *69*, 69–78. https://doi.org/10.1016/j.neubiorev.2016.07.033.

Caspers, S., Zilles, K., Laird, A.R., Eickhoff, S.B., 2010. ALE meta-analysis of action observation and imitation in the human brain. NeuroImage *50* (3), 1148–1167. https://doi.org/10.1016/j.neuroimage.2009.12.112.

Chen, W., Ye, Q., Ji, X., Zhang, S., Yang, X., Zhou, Q., Cong, F., Chen, W., Zhang, X., Zhang, B., Xia, Y., Yuan, T.-F., Shan, C., 2015. Mirror neuron system based therapy for aphasia rehabilitation. Front. Psychol. *6*, 1665. https://doi.org/10.3389/fpsyg.2015.01665.

Chen, W.-L., Ye, Q., Zhang, S.-C., Xia, Y., Yang, X., Yuan, T.-F., Shan, C.-L., Li, J.-A., 2019. Aphasia rehabilitation based on mirror neuron theory: A randomized-block-design study of neuropsychology and functional magnetic resonance imaging. Neural Regen. Res. *14* (6), 1004–1012. https://doi.org/10.4103/1673-5374.250580.

Courson, M., Tremblay, P., 2020. Neural correlates of manual action language: Comparative review, ALE meta-analysis and ROI meta-analysis. Neurosci. Biobehav. Rev. *116*, 221–238. https://doi.org/10.1016/j.neubiorev.2020.06.025.

Craik, L.L.J., Fergus, I.M., 1979. Effects of Elaboration of Processing at Encoding and Retrieval: Trace Distinctiveness and Recovery of Initial Context. In *Levels of Processing in Human Memory (PLE: Memory)*. Psychology Press.

D'Innocenzo, G., Gonzalez, C.C., Nowicky, A.V., Williams, A.M., Bishop, D.T., 2017. Motor resonance during action observation is gaze-contingent: A TMS study. Neuropsychologia *103*, 77–86. https://doi.org/10.1016/j.neuropsychologia.2017.07.017.

DerSimonian, R., Laird, N., 1986. Meta-analysis in clinical trials. Control. Clin. Trials *7* (3), 177–188. https://doi.org/10.1016/0197-2456(86)90046-2.

Dewi, I.S., & Ardaniah, V. (2016, février 1). *Representation of Gender Stereotype in Lexical Verbs*. ⟨https://www.semanticscholar.org/paper/Representation-of-Gender-Stereotype-in-Lexical-Dewi-Ardaniah/44f073aec94b7a9113984d8e72ed36e949182907⟩.

di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., Rizzolatti, G., 1992. Understanding motor events: A neurophysiological study. Article 1. Exp. Brain Res. *91* (1) https://doi.org/10.1007/BF00230027.

Durand, E., Berroir, P., Ansaldo, A.I., 2018. The Neural and Behavioral Correlates of Anomia Recovery following Personalized Observation, Execution, and Mental Imagery Therapy: A Proof of Concept. Neural Plast. *2018*, 5943759 https://doi.org/10.1155/2018/5943759.

Durand, E., Masson-Trottier, M., Sontheimer, A., Ansaldo, A.I., 2021. Increased links between language and motor areas: A proof-of-concept study on resting-state functional connectivity following Personalized Observation, Execution and Mental imagery therapy in chronic aphasia. Brain Cogn. *148*, 105659 https://doi.org/10.1016/j.bandc.2020.105659.

Ertelt, D., Small, S., Solodkin, A., Dettmers, C., McNamara, A., Binkofski, F., Buccino, G., 2007. Action observation has a positive impact on rehabilitation of motor deficits after stroke. NeuroImage *36*, T164–T173. https://doi.org/10.1016/j.neuroimage.2007.03.043.

Fadiga, L., Fogassi, L., Pavesi, G., Rizzolatti, G., 1995. Motor facilitation during action observation: A magnetic stimulation study. J. Neurophysiol. *73* (6), 2608–2611. https://doi.org/10.1152/jn.1995.73.6.2608.

Faelli, E., Strassera, L., Pelosin, E., Perasso, L., Ferrando, V., Bisio, A., Ruggeri, P., 2019. Action Observation Combined With Conventional Training Improves the Rugby Lineout Throwing Performance: A Pilot Study. Front. Psychol. *10* https://doi.org/10.3389/fpsyg.2019.00889.

Francisco, V., Decatoire, A., Bidet-Ildei, C., 2022. Action observation and motor learning: The role of action observation in learning judo techniques. Eur. J. Sport Sci. 1–23. https://doi.org/10.1080/17461391.2022.2036816.

Francisco, V., Louis, F., David, R., Billot, M., Rouquette, A.-L., Broc, L., Bidet-Ildei, C., 2023. Point-light display: A new tool to improve verb recovery in patients with aphasia? A pilot study. Exp. Brain Res. https://doi.org/10.1007/s00221-023-06607-8.

Gainotti, G., Lemmo, M.A., 1976. Comprehension of symbolic gestures in aphasia. Brain Lang. *3* (3), 451–460. https://doi.org/10.1016/0093-934X(76)90039-0.

Gili, T., Fiori, V., De Pasquale, G., Sabatini, U., Caltagirone, C., Marangolo, P., 2017. Right sensory-motor functional networks subserve action observation therapy in aphasia. Brain Imaging Behav. *11* (5), 1397–1411. https://doi.org/10.1007/s11682-016-9635-1.

Grèzes, J., Decety, J., 2001. Functional anatomy of execution, mental simulation, observation, and verb generation of actions: A meta-analysis. Article 1 Hum. Brain Mapp. 12 (1). https://doi.org/10.1002/1097-0193(200101)12:1<1::AID-HBM10>3.0.CO;2-V.

Hardwick, R.M., Caspers, S., Eickhoff, S.B., Swinnen, S.P., 2018. Neural correlates of action: Comparing meta-analyses of imagery, observation, and execution. Neurosci. Biobehav. Rev. *94*, 31–44. https://doi.org/10.1016/j.neubiorev.2018.08.003.

Hauk, O., Johnsrude, I., Pulvermüller, F., 2004. Somatotopic Representation of Action Words in Human Motor and Premotor Cortex. Neuron *41* (2), 301–307. https://doi.org/10.1016/S0896-6273(03)00838-9.

Heilman, K.M., Rothi, L.J., Valenstein, E., 1982. Two forms of ideomotor apraxia. -342 Neurology *32* (4), 342. https://doi.org/10.1212/WNL.32.4.342.

Iacoboni, M., Dapretto, M., 2006. The mirror neuron system and the consequences of its dysfunction. Article 12. Nat. Rev. Neurosci. *7* (12) https://doi.org/10.1038/nrn2024.

James, K.H., Maouene, J., 2009. Auditory verb perception recruits motor systems in the developing brain: An fMRI investigation. Dev. Sci. *12* (6), F26–F34. https://doi.org/10.1111/j.1467-7687.2009.00919.x.

Jeannerod, M., 2001. Neural Simulation of Action: A Unifying Mechanism for Motor Cognition. Article 1. NeuroImage *14* (1) https://doi.org/10.1006/nimg.2001.0832.

Kiran, S., Thompson, C.K., 2019. Neuroplasticity of Language Networks in Aphasia: Advances, Updates, and Future Challenges. Front. Neurol. *10*. ⟨https://www.frontiersin.org/articles/10.3389/fneur.2019.00295⟩.

Kuriakose, D., Xiao, Z., 2020. Pathophysiology and Treatment of Stroke: Present Status and Future Perspectives. Int. J. Mol. Sci. *21* (20) https://doi.org/10.3390/ijms21207609.

Li, T., Higgins, J., Deeks, J., & (editor). (2019). *Chapter 5 : Collecting data* (Cochrane Handbook for Systematic Reviews of Interventions version 6.0 (updated July 2019)). Cochrane. ⟨https://training.cochrane.org/handbook/archive/v6/chapter-05⟩.

Mahon, B.Z., Caramazza, A., 2005. The orchestration of the sensory-motor systems: Clues from neuropsychology. Cogn. Neuropsychol. *22* (3-4), 480–494. https://doi.org/10.1080/02643290442000446.

Mahon, B.Z., Caramazza, A., 2008. A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. J. Physiol., Paris *102* (1-3), 59–70. https://doi.org/10.1016/j.jphysparis.2008.03.004.

Marangolo, P., Bonifazi, S., Tomaiuolo, F., Craighero, L., Coccia, M., Altoè, G., Provinciali, L., Cantagallo, A., 2010. Improving language without words: First evidence from aphasia. Neuropsychologia *48* (13), 3824–3833. https://doi.org/10.1016/j.neuropsychologia.2010.09.025.

Marangolo, P., Cipollari, S., Fiori, V., Razzano, C., Caltagirone, C., 2012. Walking but Not Barking Improves Verb Recovery: Implications for Action Observation Treatment in Aphasia Rehabilitation. PLOS ONE *7* (6), e38610. https://doi.org/10.1371/journal.pone.0038610.

Martineau, J., Cochin, S., Magne, R., Barthelemy, C., 2008. Impaired cortical activation in autistic children: Is the mirror neuron system involved? *Int J. Psychophysiol.*, *68* (1), 35- (40.).

Mohd Faeiz Ikram bin Mohd Jasmani, Mohamad Subakir Mohd Yasin, Bahiyah Abd Hamid, Yuen, C.K., Zarina Othman, & Azhar Jaludin (2011). Verbs and gender: The hidden agenda of a multicultural society. *3L; Language,Linguistics and Literature,The Southeast Asian Journal of English Language Studies.*, *17*(specia), Article specia.

Molenberghs, P., Cunnington, R., Mattingley, J.B., 2012. Brain regions with mirror properties: A meta-analysis of 125 human fMRI studies. Neurosci. Biobehav. Rev. *36* (1), 341–349. https://doi.org/10.1016/j.neubiorev.2011.07.004.

Negri, G.A.L., Rumiati, R.I., Zadini, A., Ukmar, M., Mahon, B.Z., Caramazza, A., 2007. What is the role of motor simulation in action and object recognition? Evidence from apraxia. Cogn. Neuropsychol. https://doi.org/10.1080/02643290701707412.

de Partz, M.-P., & Pillon, A. (2014). Sémiologie, syndromes aphasiques et examen clinique des aphasies. In *Traité de neuropsychologie clinique de l'adulte.: Vol. Tome 1* (2ème édition, p. 249-265). De Boeck-Solal. ⟨https://dial.uclouvain.be/pr/boreal/object/boreal:143160/datastream/PDF_02/view⟩.

Plaza, M., Boiché, J., Brunel, L., Ruchaud, F., 2017. Sport = Male… But not all sports: Investigating the gender stereotypes of sport activities at the explicit and implicit levels. Sex. Roles: A J. Res. *76* (3-4), 202–217. https://doi.org/10.1007/s11199-016-0650-x.

Pulvermuller, F., Fadiga, L., 2010. Active perception: Sensorimotor circuits as a cortical basis for language. *Nat. Rev. Neurosci.*, *11*(5), 351- (360.).

Pulvermüller, F., 2005. Brain mechanisms linking language and action. Article 7. Nat. Rev. Neurosci. *6* (7) https://doi.org/10.1038/nrn1706.

Pulvermüller, F., Fadiga, L., 2010. Active perception: Sensorimotor circuits as a cortical basis for language. Article 5. Nat. Rev. Neurosci. *11* (5) https://doi.org/10.1038/nrn2811.

Rizzolatti, G., Arbib, M.A., 1998. Language within our grasp. Trends Neurosci. *21* (5), 188–194. https://doi.org/10.1016/S0166-2236(98)01260-0.

Rizzolatti, G., Fadiga, L., Matelli, M., Bettinardi, V., Paulesu, E., Perani, D., Fazio, F.D., 1996. Localization of grasp representations in humans by PET: 1. Observation versus execution. Exp. brain Res. Exp. Hirnforsch. Exp. érimentation C. éR. ébrale *111*, 246–252. https://doi.org/10.1007/BF00227301.

Rizzolatti, G., Fabbri-Destro, M., Nuara, A., Gatti, R., Avanzini, P., 2021. The role of mirror mechanism in the recovery, maintenance, and acquisition of motor abilities. Neurosci. Biobehav. Rev. *127*, 404–423. https://doi.org/10.1016/j.neubiorev.2021.04.024.

Rothi, L.J.G., Ochipa, C., Heilman, K.M., 1991. A Cognitive Neuropsychological Model of Limb Praxis. Cogn. Neuropsychol. *8* (6), 443–458. https://doi.org/10.1080/02643299108253382.

Ryan, D., Fullen, B., Rio, E., Segurado, R., Stokes, D., O'Sullivan, C., 2021. Effect of Action Observation Therapy in the Rehabilitation of Neurologic and Musculoskeletal Conditions: A Systematic Review. Arch. Rehabil. Res. Clin. Transl. *3* (1), 100106 https://doi.org/10.1016/j.arrct.2021.100106.

Sarasso, E., Gemma, M., Agosta, F., Filippi, M., Gatti, R., 2015. Action observation training to improve motor function recovery: A systematic review. Arch. Physiother. *5* (1), 14. https://doi.org/10.1186/s40945-015-0013-x.

Schünemann, H., Higgins, J., Vist, G., Glasziou, P., Akl, E., Skoetz, N., & Guyatt, G. (2023). *Chapter 14 : Completing 'Summary of findings' tables and grading the certainty of the evidence* (Cochrane Handbook for Systematic Reviews of Interventions version 6.4 (updated August 2023)). Cochrane. ⟨https://training.cochrane.org/handbook/current/chapter-14⟩.

Sgandurra, G., Ferrari, A., Cossu, G., Guzzetta, A., Fogassi, L., Cioni, G., 2013. Randomized Trial of Observation and Execution of Upper Extremity Actions Versus Action Alone in Children With Unilateral Cerebral Palsy. Neurorehabilitation Neural Repair *27* (9), 808–815. https://doi.org/10.1177/1545968313497101.

Shebani, Z., Carota, F., Hauk, O., Rowe, J.B., Barsalou, L.W., Tomasello, R., Pulvermüller, F., 2022. Brain correlates of action word memory revealed by fMRI. Article 1. Sci. Rep. *12* (1) https://doi.org/10.1038/s41598-022-19416-w.

Slamecka, N.J., Graf, P., 1978. The generation effect: Delineation of a phenomenon. J. Exp. Psychol.: Hum. Learn. Mem. *4* (6), 592–604. https://doi.org/10.1037/0278-7393.4.6.592.

Sterne, J.A.C., Savović, J., Page, M.J., Elbers, R.G., Blencowe, N.S., Boutron, I., Cates, C. J., Cheng, H.-Y., Corbett, M.S., Eldridge, S.M., Emberson, J.R., Hernán, M.A., Hopewell, S., Hróbjartsson, A., Junqueira, D.R., Jüni, P., Kirkham, J.J., Lasserson, T., Li, T., Higgins, J.P.T., 2019. RoB 2: A revised tool for assessing risk of bias in randomised trials. BMJ *366*, l4898. https://doi.org/10.1136/bmj.l4898.

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 Activates Fronto-parietal Motor Circuits. J. Cogn. Neurosci. *17* (2), 273–281. https://doi.org/10.1162/0898929053124965.

Thompson, C.K., Riley, E.A., den Ouden, D.-B., Meltzer-Asscher, A., Lukic, S., 2013. Training verb argument structure production in agrammatic aphasia: Behavioral and neural recovery patterns. Cortex *49* (9), 2358–2376. https://doi.org/10.1016/j.cortex.2013.02.003.

Villatte, J., Taconnat, L., Bidet-Ildei, C., Toussaint, L., 2022. The role of implicit motor simulation on action verb memory. Psychol. Res. https://doi.org/10.1007/s00426-022-01671-1.

Vogt, S., Thomaschke, R., 2007. From visuo-motor interactions to imitation learning: Behavioural and brain imaging studies. J. Sports Sci. *25* (5), 497–517. https://doi.org/10.1080/02640410600946779.

Weeks, Douglas, L., Anderson, L.P., 2000. The interaction of observational learning with overt practice: Effects on motor skill learning. Acta Psychol. *104* (2), 259–271. https://doi.org/10.1016/S0001-6918(00)00039-1.

Whitaker, H.A., 2007. Language Disorders: Aphasia. In J. E. Birren (Éd.). Encyclopedia of Gerontology (Second Edition). Elsevier, pp. 9–16. https://doi.org/10.1016/B0-12-370870-2/00104-9.

You, L., Wang, Y., Chen, W., Zhang, S., Rao, J., Liu, L., Shan, C., 2019. The Effectiveness of Action Observation Therapy Based on Mirror Neuron Theory in Chinese Patients with Apraxia of Speech after Stroke. Eur. Neurol. *81* (5-6), 278–286. https://doi.org/10.1159/000503960.