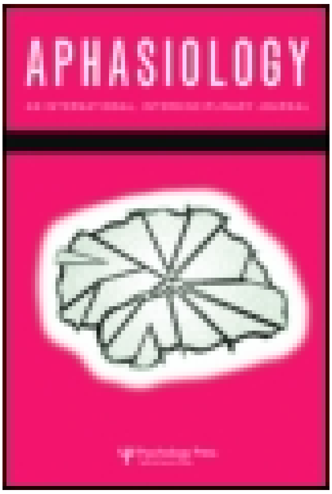

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Comprehension of reversible constructions in semantic aphasia

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Background: Impairments in spatial processing show themselves not only in gnosis and praxis, but also in the language domain. Such deficit is a characteristic feature of so-called semantic aphasia. The impaired comprehension of semantically reversible constructions in those patients can be explained by a disorder of the common spatial neuropsychological factor grounded in the temporal-parietal-occipital (TPO) regions of the brain.
Aims: The aim of the present study was to experimentally test the possibility that individuals with semantic aphasia experience specific difficulties in extracting spatial relations from a linguistic form and rely instead on basic sensorimotor stereotypes to interpret reversible linguistic constructions.
Methods & Procedures: Six individuals with semantic aphasia, 12 people with motor aphasia, 12 people with sensory aphasia, and 12 non-brain-damaged individuals performed a sentence–picture matching task; all participants were native speakers of Russian. Two types of reversible sentences were tested, each representing a direct and an inverted word order: prepositional (*The boy is putting the bag in the box* vs. *The boy is putting in the box the bag*) and instrumental (*The grandmother is covering the scarf with the hat* vs. *The grandmother is covering with the hat the scarf*). Irreversible sentences (*The boy is putting the apple in the bag*) served as control stimuli.
Outcomes & Results: Each group of participants performed better on irreversible than on reversible sentences. Within reversible sentences, an interaction between word order and construction type was found in individuals with semantic aphasia only. They performed more accurately in prepositional constructions with direct word order and in instrumental constructions with inverted word order—both are related to sensorimotor stereotypes reflecting interaction with objects in the real world. Although no such clear dissociation was found in other aphasia types, correlation analysis revealed the same effect in some participants with motor and sensory aphasia.
Conclusions: The findings confirm the importance of situational context for linguistic processing. First, if knowledge of the real world supports the unique interpretation of grammatical markers, it enhances processing in all tested cohorts of participants. Second, people with semantic aphasia consistently use sensorimotor stereotypes to compensate for their linguistic deficits. Since this was also found in some participants with other aphasia types, such a sensorimotor strategy might depend not on the damage to TPO areas as such, but on the intactness and overuse of left premotor regions suggested to be critical for motor and symbolic sequential processing.

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Keywords: semantic aphasia; reversible sentences; spatial relations; sensorimotor stereotype; Russian language

Introduction

Semantic aphasia was first introduced in the taxonomy of aphasia syndromes by Head (1920) who described it as an inability to consolidate meanings of words and to grasp the overall idea of a sentence. Interestingly, sentence length was noticed to be irrelevant for language comprehension in such patients. Rather, although they were able to understand the meanings of single components of a sentence, they could not relate them to one another and synthesise an overall meaning, even if the sentence consisted of two or three words.

Luria further elaborated the notion of semantic aphasia and included it in his aphasia classification (Luria, 1947, 1962, 1973). He characterised the syndrome as having fluent speech, good auditory comprehension, good reading, and repetition of single words and simple phrases. However, complex sentences represented the major source of difficulties in those patients. Luria proposed that the inability to analyse logical relationships between persons, objects, or events as expressed through grammatical relations underlies a central symptom of semantic aphasia. That is, there is impaired comprehension of particular types of sentences, referred to as logical-grammatical constructions: prepositional (*Draw a triangle above a circle*), instrumental (*Point to the key with the pencil*), comparative (*Sonja is taller than Katja*), genitive (*Father's brother*), passive (*Kolja is hit by Petja*), inverted (*Kolja$_{ACC}$ hit Petja$_{NOM}$*), temporal (*I had breakfast after I read a newspaper*), double negation (*I am not accustomed to not obeying rules*), embedded clauses (*The worker came from the factory to the school, where Dunya studied, to give a talk*). A characteristic feature of all those sentence types is that they are semantically reversible, meaning that the direction of the relation between the mentioned persons, objects, or events can be potentially changed, which makes such sentences particularly difficult for individuals with semantic aphasia to process.

Luria was an advocate of syndrome analysis and qualitative identification of a disrupted common neuropsychological factor underlying a patient's deficit and manifested in different cognitive domains. He suggested a single cause of semantic aphasia and the other spatial disorders that typically accompany it (also characteristic of Gerstmann syndrome; Ardila, 2014). According to Luria, impairment of spatial synthesis and analysis results in semantic aphasia, as well as spatial agnosia, apraxia, dysgraphia, dyslexia, and dyscalculia. The outlined spatial neuropsychological factor should be understood broadly; it covers both gnostic and praxic operations in the physical space and abstract operations in the mental quasi-space, which mediates the decoding of complex logical-grammatical constructions and number calculations. Luria considered logical-grammatical constructions to be linguistic expressions of such quasi-spatial representations and claimed that their comprehension is based on simultaneous synthesis of spatial relations among the involved referents or events. For example, to correctly understand the phrase *a triangle above a circle* one has to arrange the objects in the mental quasi-space. The same spatial component is proposed to be involved, although less explicitly, in the comprehension of other logical-grammatical constructions. In this conceptualisation, semantic aphasia represents "the same defect of perception of simultaneous spatial structures but transferred to a higher symbolic level" (Luria, 1973).

The suggested relation between pure spatial disorders and semantic aphasia has been supported by lesion data. Luria's patients with semantic aphasia had lesions in the area of the left temporal-parietal-occipital (TPO) junction, which represents associative cortex that provides syntheses of multimodal stimuli (auditory, visual, kinesthetic, vestibular) in a single simultaneous representation (Luria, 1962). Luria, therefore, related the TPO and adjacent areas (BA 39, 40, 37, 21) with the neuropsychological factor of spatial synthesis and analysis underlying both pure spatial disorders (apraxia and agnosia) and difficulties in performing quasi-spatial processing in the language domain, as well as other disorders such as dyscalculia, spatial dysgraphia, and dyslexia related to an inability to build a word consolidated representation—all representing a single TPO syndrome (Luria, 1973). Contemporary evidence converges with Luria's suggestion and reinforces the role of inferior parietal cortex (BA 39, 40) in semantic processing both at the word and sentence levels (Price, 2000). In addition, taking its function of integrating multisensory input, on the one hand, and its multiple connections to areas classically associated with language, on the other hand, the inferior parietal lobe has been recognised as critical for developing semantic content (Catani, Jones, & Ffytche, 2005).

Within Luria's aphasia classification based on the opposition of syntagmatic (sequencing) and paradigmatic (selection) language disorders (Jakobson, 1956; Luria, 1973), semantic aphasia along with sensory, acoustic-mnestic, and amnestic aphasias represent the paradigmatic axis. In these four aphasia types, according to Luria's framework, a selection deficit underlies aphasic symptoms, but it can be expressed at different levels: phoneme selection (in sensory aphasia, analogous to Wernicke's aphasia in the Boston classification; Benson & Geschwind, 1971), word selection (in acoustic-mnestic and amnestic aphasias, which both share symptoms with anomic aphasia, but in terms of effective mechanism the former is close to the repetition type of conduction aphasia (Shallice & Warrington, 1970), while the latter is related to the disruption of a link between the visual image of an object and its nomination), or meaning selection at the sentence level (in semantic aphasia). Sharing with the other three aphasia types such characteristics as fluent speech, semantic aphasia is differentiated from them by the absence of phoneme discrimination problems, a primary sign of sensory aphasia; preserved auditory verbal short-term memory, specific to acoustic-mnestic aphasia; and spared naming ability, in contrast to amnestic aphasia. The comprehension difficulties observed in semantic aphasia have in fact more in common with those reported for a representative of syntagmatic impairments in Luria's classification—efferent motor aphasia (a disorder of sequencing phonemes, syllables, and words within a sentence) and its equivalent in the Boston classification, Broca's aphasia. Although fluent in their expressive speech, individuals with semantic aphasia experience difficulties in processing reversible constructions, prepositional and embedded structures, similar to non-fluent efferent motor aphasia patients (Akhutina, 1989; Luria, 1975; Tsvetkova & Glozman, 1977) or Broca's patients (Caramazza & Berndt, 1978). How those sentence comprehension problems in taxonomically distinct aphasia types relate to each other in terms of their underlying mechanisms is still open to research.

Notably, semantic aphasia is distinct from semantic dementia, in terms of both symptoms and neurological causes, although the latter is sometimes referred to as semantic aphasia. Semantic dementia involves a fluent type of primary progressive aphasia that results from fronto-temporal lobar degeneration and is characterised by word-finding difficulties (anomia and verbal paraphasias) and impaired comprehension at the word level (Hodges, Patterson, Oxbury, & Funnell, 1992; Snowden, Goulding, & Neary, 1989). By contrast, the critical features of Luria's semantic aphasia, with its typical aetiology being a stroke or trauma, is the lack of obvious lexical-semantic difficulties and rather subtle sentence comprehension impairment revealed only by specific tests.

Although Luria's clinical assessment approach has become recognised outside of Russia—particularly in Nordic countries (Christensen, 1975; Christensen & Caetano, 1999; Golden, Hammeke, & Purisch, 1980) and Spanish-speaking countries in Europe and South America (Ardila, 1999; Ardila, Ostrosky, & Canseco, 1981; Galindo & Ibarra, 1984; Peña-Casanova, 1991)—semantic aphasia has not been sufficiently addressed compared to other aphasia types in the literature. Semantic aphasia has received little attention in experimental studies targeting either the underlying deficits of specific aphasia types or the neural substrate related to those deficits, possibly because the syndrome has not been acknowledged in the most influential western aphasia classification proposed by the Boston Group (Benson & Geschwind, 1971); it is primarily mentioned in the context of Luria's neuropsychological approach and its contemporary elaborations (see, e.g., Ardila, 1981, 1984, 2010; Ardila, Lopez, & Solano, 1989; Benson & Ardila, 1996). A rare exception is the work by Hier, Mogil, Rubin, and Komros (1980) who reported three English-speaking patients with impaired comprehension of characteristic syntactic constructions (comparative, temporal, passive, spatial) and concomitant complex spatial impairments (constructional apraxia, spatial agnosia, dyscalculia, and dysgraphia) due to lesions to the TPO junction of the left hemisphere. Showing no notable difficulties in articulation, fluency, expressive grammar, auditory discrimination, single word or casual conversation comprehension, these cases were taken as exemplifying classic semantic aphasia as described by Luria (1947). Other studies of semantic aphasia were naturally grounded within the Russian aphasiological tradition established by Luria. For example, Akhutina (1992) examined nine individuals with semantic aphasia and revealed a specific impairment of verbal semantics processing in them: they classified words (but not visually perceived correspondent images) on the basis of situational associations and were not able to sort them into categories, thus demonstrating an impairment of the linguistically mediated semantic system. Later, addressing the demands of clinical rehabilitation, Khrakovskaya (2003) suggested building a speech therapy programme for individuals with semantic aphasia on their more preserved syntagmatic processes (as opposed to disturbed paradigmatic ones), using, for example, sentence completion techniques.

During routine neuropsychological investigations according to Luria's protocol (Luria, 1962), as well as in experimental testing as referenced earlier, the difficulties of semantic aphasia patients during comprehension of specific linguistic constructions, referred as logical-grammatical by Luria (1947), are typically reported in terms of global success or failure, as Valdois, Ryalls, and Lecours (1989) fairly noted. However, the quality of misinterpretation errors could potentially shed light on the underlying deficit in semantic aphasia and its distinction from other aphasia types. Specifically, when they are not able to process or produce complex linguistic expression, individuals with aphasia might adopt particular heuristics reflecting their adaptation to the defect, which affects both the psychological structure and cerebral organisation of the language system (Luria, 1973). For semantic aphasia, a few observations have been previously reported. Luria (1962) described the standard reaction of individuals with semantic aphasia to the instruction *Draw a circle beneath a triangle*: they simply drew the geometric figures as they were mentioned. Similarly, when prompted with the command *Point to the key with the pencil*, patients tended to interact with the objects in the mentioned order. In the same vein, Akhutina (1989) reported individuals with semantic aphasia, in contrast to those with efferent motor or acoustic-mnestic aphasia, trying to stress different constituents of a sentence and change the word order to grasp its meaning. The present study was largely inspired by those insightful observations.

Aims of the study

We aimed at testing two major predictions derived from Luria's theory about semantic aphasia and its underlying deficits. The first prediction was related to the effect of a linguistic construction's semantic reversibility. Luria suggested that an inability to decode grammatical relations expressed in a semantically reversible sentence is characteristic of semantic aphasia (Luria, 1975). Akhutina also observed multiple cases of individuals with semantic aphasia, and summarised their speech comprehension difficulties as a stable impairment of understanding reversible logical-grammatical constructions, in contrast to their spared ability to process irreversible ones (Akhutina, 1989). However, comprehension of reversible logical-grammatical constructions was also shown to be compromised in various other types of aphasia (Johnsen, 1985). Syntactically simple but semantically reversible sentences (e.g., *The leopard races the young lion*) are more prone to misinterpretation and delayed processing even in healthy adults and normally developing children (Herriot, 1969; Kemper & Catlin, 1979; Slobin, 1966). When syntactic derivations add to sentence complexity (e.g., passive constructions), semantically reversible sentences are consistently misinterpreted across populations: healthy adults (Ferreira, 2003), patients with Alzheimer's disease (Bickel, Pantel, Eysenbach, & Schröder, 2000), and children with specific language impairment (SLI) (Leonard, 1998). Such sentences are a known source of comprehension difficulties in various types of aphasia: both Broca's and Wernicke's aphasias in western aphasia classification terms (Caramazza & Zurif, 1976; Kolk & Friederici, 1985; Luzzatti et al., 2001), and both motor and sensory aphasias in Luria's terms (Akhutina, 1979; 1989; Tsvetkova & Glozman, 1977). Such universally poorer performance on reversible constructions in comparison to irreversible ones strongly suggests that pragmatic heuristics, based on the assessment of the semantic likelihood of an event (that cats chase mice, grandmothers cut bread, and not vice versa), universally drive sentence interpretation. We anticipated therefore that difficulties in the interpretation of reversible sentences as compared to their irreversible counterparts are not characteristic to semantic aphasia and can be observed in all aphasia types and even in non-brain-damaged individuals.

The second prediction was related to Luria's original claim about a specific deficit in the comprehension of logical-grammatical constructions in semantic aphasia. We hypothesised that if such patients experience characteristic difficulties with decoding quasi-spatial relations from grammatical markers, they would tend to resort to pragmatic heuristics and rely on real-world knowledge when interpreting reversible sentences. In particular, individuals with semantic aphasia would overuse sensorimotor stereotypes reflecting the temporal order of interactions with objects during action implementation, and then map them on the surface word order of a sentence. To test that, Russian prepositional and instrumental constructions with direct and inverted word orders were employed in the present study. Prepositional constructions with direct word order (*Put the bag in the box*) naturally map on the corresponding sensorimotor stereotype (*Take the bag, put it in the box*), while those with inverted word order (*Put in the box the bag*) do not. Instrumental constructions represent a clear dissociation: only when they are inverted (*Cover with the hat the scarf*) do they follow a sensorimotor stereotype (*Take the hat, cover the scarf with it*), while their direct word order counterparts (*Cover the scarf with the hat*) do not. Due to the flexible word order of the Russian language, all four types of sentences are plausible. We predicted therefore that individuals with semantic aphasia would show better performance on prepositional constructions with direct word order and instrumental constructions with indirect word order, since both map onto the sensorimotor stereotypes. The two other sentence types would be more often misinterpreted, since patients would assign thematic roles to the nouns not based on their grammatical markers, but driven by the stereotype. That is, in a prepositional construction, the first postverbal noun would be taken as the theme and the second as the location; in an instrumental construction, the first noun would be taken as the instrument and the second as the theme). Since this heuristic was suggested to explain the specific linguistic deficit of individuals with semantic aphasia (Luria, 1947, 1962), one should not expect to find the effect of sensorimotor stereotypes in other aphasia syndromes, which do not involve impairment of quasi-spatial analysis. Thus, people with motor or sensory aphasias were tested as clinical control groups in this respect.

Method

Participants

Thirty individuals with aphasia and 12 neurologically healthy individuals participated in the study. Aphasia types were identified in terms of A.R. Luria's classification (Luria, 1962) by certified clinical neuropsychologists and speech-language pathologists at the Center for Speech Pathology and Neurorehabilitation (Moscow, Russia) based on the results of extensive neuropsychological examinations of all major cognitive domains (praxis, gnosis, memory, arithmetic, intellect, language). Consistent with the goals of the current study, characteristic functional deficits underlied the selection for the three clinical groups, which were distinguished based on aphasia syndromes and not lesion locations. Six patients were diagnosed with semantic aphasia and assigned to the semantic aphasia group (3 female; mean age 48 years (range 19–72 years); mean post onset time 19 months (range 3–69 months)). Due to the fact that it rarely occurs in isolation, semantic aphasia was accompanied by acoustic-mnestic aphasia in all six participants, and in two cases also by elements of sensory aphasia.[1] The motor aphasia group ($N = 12$; 6 female; mean age 47.4 years (range 33–71 years); mean post onset time 27.6 months (range 2–65 months)) included individuals with efferent motor aphasia, which in eight cases was accompanied by afferent motor aphasia and in two cases by dynamic aphasia as well, exemplifying syntagmatic deficits. The inclusion criterion for the sensory group ($N = 12$; 6 female; mean age 48.5 years (range 21–74 years); mean post onset time 17 months (range 3–52 months)) was primary sensory aphasia, which in seven cases coincided with acoustic-mnestic aphasia, both aphasia types representing deficits on the paradigmatic scale (Jakobson, 1956). Critically, none of the patients in the motor and sensory aphasia groups was ascribed any degree of semantic aphasia. Aphasia severity in the three clinical groups was measured by the Quantitative Assessment of Speech in Aphasia (Tsvetkova, Akhutina, & Pylaeva, 1981) and ranged from 1 to 4 on the scale, with 1 representing mild impairment and 5 representing severe disability. The motor and sensory groups had higher severity scores than the semantic group ($M = 3.3$, 2.8, and 2.2 correspondingly), which is in line with the relatively mild language impairment detected by standard aphasia tests in individuals with semantic aphasia.

An age-matched control group ($N = 12$; 9 female; mean age 47 years (range 30–71 years)) with no reported neurological or psychiatric disorders was also tested. All participants were native speakers of Russian, and had normal or corrected to normal vision and hearing. Participants' individual data are presented in Table 1.

Table 1. Information about participants.

Group	Subject	Age	Gender	Aphasia type	Severity (1–5)	Months post onset	Aetiology
Semantic	Sem1	19	f	semantic, acoustic-mnestic	3	3	TBI
	Sem2	27	f	semantic, acoustic-mnestic	1	69	TBI
	Sem3	72	m	semantic, acoustic-mnestic, sensory	2	15	stroke
	Sem4	55	f	semantic, acoustic-mnestic	3	20	stroke
	Sem5	44	m	semantic, acoustic-mnestic, sensory	2	4	stroke
	Sem6	72	m	semantic, acoustic-mnestic	2	3	stroke
Motor	M1	50	m	efferent and afferent motor	2	28	stroke
	M2	33	f	efferent and afferent motor	3	37	stroke
	M3	59	m	efferent and afferent motor	4	65	stroke
	M4	71	m	efferent and afferent motor	1	7	stroke
	M5	67	m	efferent motor	1	2	stroke
	M6	49	f	efferent and afferent motor	4	3	stroke
	M7	36	m	efferent motor	3	29	stroke
	M8	38	f	efferent motor	2	53	stroke
	M9	49	m	efferent motor	2	19	stroke
	M10	33	f	efferent and afferent motor, dynamic	4	13	TBI and stroke
	M11	38	f	efferent and afferent motor, dynamic	4	42	stroke
	M12	46	f	efferent and afferent motor	4	33	stroke
Sensory	Sens1	21	m	sensory	3	4	TBI
	Sens2	65	f	sensory, acoustic-mnestic	3	52	stroke
	Sens3	48	m	sensory, acoustic-mnestic	3	15	TBI
	Sens4	28	f	sensory, acoustic-mnestic	2	5	TBI
	Sens5	62	m	sensory, acoustic-mnestic	4	28	stroke
	Sens6	48	f	sensory	4	44	stroke
	Sens7	59	f	sensory, acoustic-mnestic	3	11	stroke
	Sens8	31	m	sensory	4	8	TBI
	Sens9	24	m	sensory	4	3	stroke
	Sens10	56	m	sensory, acoustic-mnestic	3	15	TBI
	Sens11	66	f	sensory	3	8	stroke
	Sens12	74	f	sensory, acoustic-mnestic	3	14	stroke
Control	C1	30	f				
	C2	52	m				
	C3	67	m				
	C4	57	f				
	C5	32	m				
	C6	30	f				
	C7	63	f				
	C8	45	f				
	C9	30	f				
	C10	71	f				
	C11	35	f				
	C12	33	f				

Materials

Two types of Russian reversible sentences, 12 prepositional and 12 instrumental constructions, were tested in two different conditions: direct word order and inverted word order. In addition, 12 irreversible prepositional constructions and 12 irreversible

Table 2. Examples of experimental constructions: Russian sentences, glosses, and literal English translations.

		Direct word order	Inverted word order
Prepositional	reversible	*(1) Malchik kladet* *boy-NOM to put-PRES* *sumku* v *korobku* *bag-ACC in box-ACC* "The boy is putting the bag in the box"	*(2) Malchik kladet* *boy-NOM to put-PRES* v *korobku sumku* *in box-ACC bag-ACC* "The boy is putting in the box the bag"
	Irreversible	*(3) Malchik kladet* *boy-NOM to put-PRES* *jabloko* v *sumku* *apple-ACC in bag-ACC* "The boy is putting the apple in the bag"	*(4) Malchik kladet* *boy-NOM to put-PRES* *v sumku jabloko* *in bag-ACC apple-ACC* "The boy is putting in the bag the apple"
Instrumental	reversible	*(5) Babushka nakryvaet* *grandmother-NOM to cover-PRES* *sharf shapkoj* *scarf-ACC hat-INSTR* "The grandmother is covering the scarf with the hat"	*(6) Babushka nakryvaet* *grandmother-NOM to cover-PRES* *shapkoj sharf* *hat-INSTR scarf-ACC* "The grandmother is covering with the hat the scarf"
	Irreversible	*(7) Babushka nakryvaet* *grandmother-NOM to cover-PRES* *telefon shlapoj* *telephone-ACC hat-INSTR* "The grandmother is covering the telephone with the hat"	*(8) Babushka nakryvaet* *grandmother-NOM to cover-PRES* *shlapoj telefon* *hat-INSTR telephone-ACC* "The grandmother is covering with the hat the telephone"

Note: NOM, nominative case; ACC, accusative case; INSTR, instrumental case; PRES, present tense.

instrumental constructions, each again with direct and inverted word order options, were used to identify baseline performance in the clinical groups. In sum, 48 experimental sentences were tested. Examples of the experimental stimuli are presented in Table 2; all experimental sentences in the direct word order condition are available in Appendix 1. In addition, test materials included 39 filler items of other grammatical construction types. There were 12 comparative-reversible constructions (e.g., *The girl is taller than the boy*) and 12 comparative-irreversible constructions (e.g., *The giraffe is taller than the gazelle*); 9 sentences were attributive-reversible (e.g., *The pilot's airplane is burning*) and 6 were attributive-irreversible (e.g., *The grandmother's dog is eating*).

To correctly decode the thematic roles of the nouns mentioned in the reversible sentences, it is necessary to extract the corresponding information from its linguistic carriers—prepositions and inflections. That is, only grammatical markers are a reliable source for interpreting a reversible prepositional or instrumental construction. However, to interpret irreversible sentences, situational pragmatics could help. Critically, the reversible prepositional and instrumental constructions dissociated in terms of their word order mapping on the sensorimotor stereotypes. Prepositional constructions with direct word order (1) and instrumental constructions with inverted word order (6) mapped on their corresponding stereotypes, while their word order counterparts (2) and (5) did not (see Table 2).

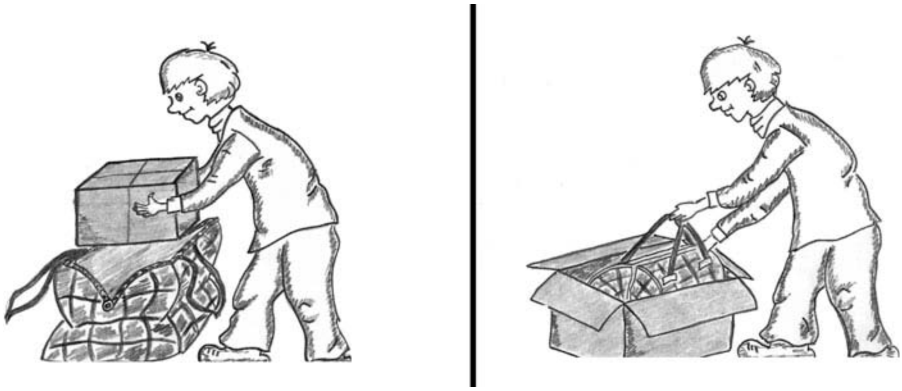

Figure 1. Pictorial stimuli used for sentences *The boy is putting the bag in the box* and *The boy is putting in the box the bag*.

In addition to linguistic materials, visual stimuli were developed: for each of the sentences two pictures were drawn. For reversible sentences like (1) *The boy is putting the bag in the box*, one picture represented the situation described in the sentence, featuring a boy putting a bag in a box, and the other showed the reversed situation of the boy putting a box in a bag (see Figure 1). For irreversible sentences like (3) *The boy is putting the apple in the bag*, the second picture illustrated a situation irrelevant to the sentence, such as a boy putting an apple near a box. The same procedure applied for instrumental constructions (see Figure 2). The experimental linguistic and pictorial materials are freely available at http://philology.hse.ru/en/neuroling/experimental_materials.

To reduce repetition effects and the overall test length for individuals with aphasia, sentences were assigned to four lists: two lists contained prepositional constructions and the other two lists contained instrumental constructions. Each list contained only one word order version of an experimental item. Thus, 24 experimental sentences were included in a list: 6 reversible sentences with direct word order, 6 different reversible sentences with inverted word order, 6 irreversible sentences with direct word order,

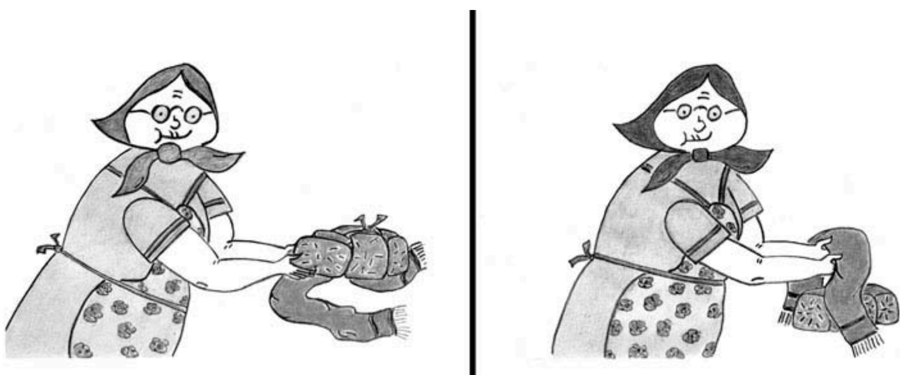

Figure 2. Pictorial stimuli used for sentences *The grandmother is covering the scarf with the hat* and *The grandmother is covering with the hat the scarf*.

and 6 different irreversible sentences with inverted word order. The lists with prepositional constructions were complemented by 24 comparative filler sentences, and the lists with instrumental constructions included 15 attributive fillers, which resulted in 39 or 48 trials per list. The order of trial presentation was pseudo-randomised so that the conditions were evenly spread across lists to avoid effects of learning or attention loss.

Procedure

Participants were tested individually sitting approximately 60 cm from a computer screen. Programming and presentation were done using E-prime (Psychology Software Tools Inc., 2001). Each trial involved the presentation of two pictures organised horizontally on the screen, and simultaneous auditory and visual presentation of a sentence, to allow participants to use another receptive modality if one was impaired. Participants were instructed to listen to (and read if necessary) each sentence carefully and to identify the picture which matched the sentence by pressing the left or the right button assigned on the keyboard, depending on the location of the corresponding picture on the screen. In patients' protocol, a pause between trials was controlled by the experimenter who pressed a mouse button to proceed to the next trial. Thus, short breaks were given to participants with aphasia when necessary. For non-brain-damaged individuals, a participant's response automatically initiated the next trial. The total testing time of each list was approximately 5 minutes for healthy individuals and 15 minutes for participants with aphasia. All four lists of materials were tested by each participant in at least two separate sessions, separated by several days so that the two word order conditions of a single item were never tested in the same session.

Analysis

The accuracy of participants' responses was evaluated in relation to three experimental factors: reversibility of the construction (reversible/irreversible), type of the construction (prepositional/instrumental), and word order (direct/inverted). Statistical analysis was carried out in R (R Development Core Team, 2014). For all comparisons reported below, we employed the binomial test and false discovery rate multiple comparison correction. p-Values after correction are reported.

Results

As for the effect of reversibility, in all groups of participants there were more correct responses to irreversible sentences than to reversible ones: 95% and 73%, accordingly, in the group of individuals with semantic aphasia; 95% and 76% in participants with motor aphasia; 90% and 67.5% in individuals with sensory aphasia; and 99.8% versus 97% in the control group ($p < 0.001$ for all comparisons).

The mean accuracy scores obtained by the semantic, motor, and sensory aphasia groups and the control group in reversible experimental sentences are presented in Figure 3. Individual scores of participants are provided in Table 3.

Regarding the effects of construction type and word order in the group of individuals with semantic aphasia, in the reversible prepositional constructions, no significant difference was found between the accuracy scores when given direct (65%) and inverted (61%) word orders. However, at the group level, only when the word order was direct did

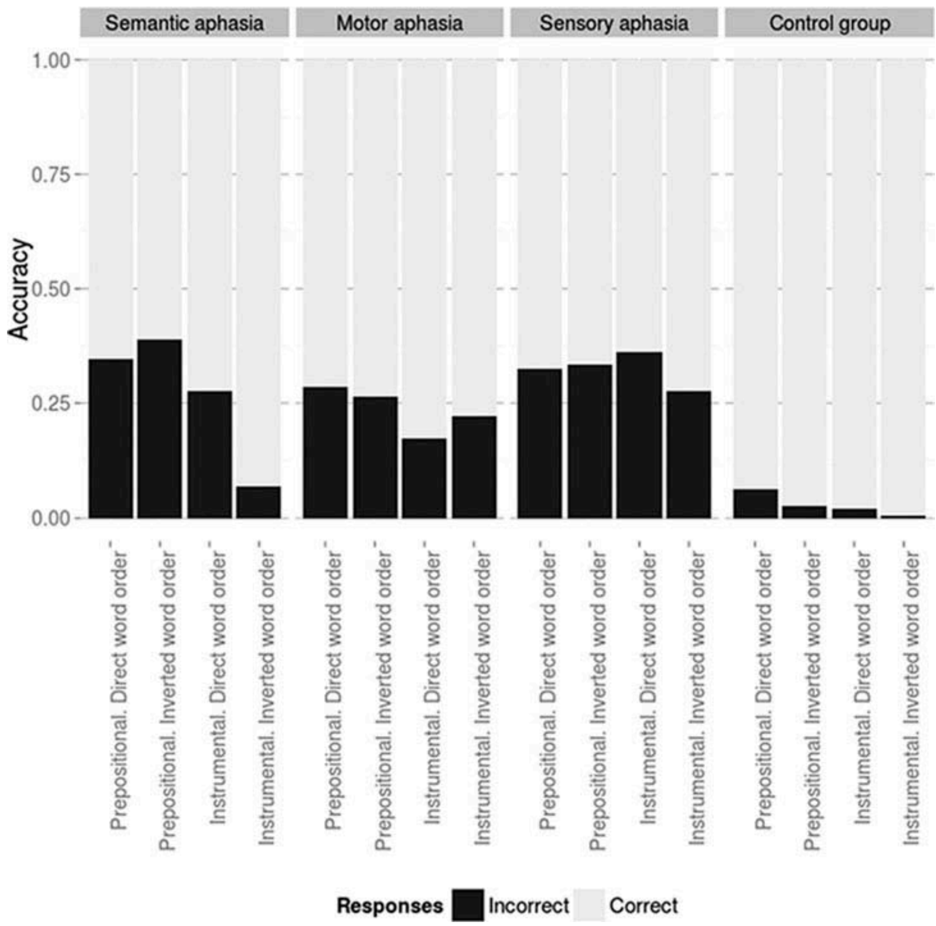

Figure 3. Mean accuracy scores across experimental conditions in four groups of participants.

accuracy significantly differ from chance ($p < 0.01$); when the word order was inverted, it did not ($p > 0.05$). Reversible instrumental constructions elicited significantly fewer correct responses in this group when the word order was direct (72%) compared to the inverted word order (93%), with $p < 0.001$. In the group of participants with motor aphasia, no significant difference in accuracy was found for prepositional constructions with direct (72%) and inverted (74%) word orders, nor for instrumental constructions with direct (83%) and inverted (78%) word orders ($p > 0.1$). Similarly, in the group of individuals with sensory aphasia, no difference was found for direct (67%) and inverted (67%) word orders in prepositional constructions, nor for processing instrumental constructions with direct (64%) and inverted (72%) word orders ($p > 0.1$). Finally, in the control group, the same lack of difference between direct (94%) and inverted (97%) word orders was revealed in prepositional constructions as well as between the direct (98%) and indirect (99%) word orders in the instrumental constructions ($p > 0.1$). All accuracy scores were significantly different from chance in the motor, sensory, and control groups ($p < 0.001$).

Table 3. Proportions of correct responses per participant in reversible experimental sentences.

		Prepositional constructions		Instrumental constructions	
Group	Subject	Direct WO	Inverted WO	Direct WO	Inverted WO
Semantic	Sem1	0.92	0.92	0.92	1.00
	Sem2	0.83	0.92	0.92	1.00
	Sem3	0.67	0.33	0.75	1.00
	Sem4	0.50	0.42	0.42	0.67
	Sem5	0.58	0.67	0.58	0.92
	Sem6	0.42	0.42	0.75	1.00
Motor	M1	0.92	0.92	0.92	0.92
	M2	0.00	0.50	0.83	0.67
	M3	0.83	0.67	0.67	0.83
	M4	1.00	0.83	0.83	0.92
	M5	1.00	1.00	1.00	0.92
	M6	0.75	0.50	0.67	0.75
	M7	0.75	0.75	0.75	0.83
	M8	0.92	1.00	0.92	0.75
	M9	1.00	0.92	1.00	0.92
	M10	0.42	0.67	0.58	0.58
	M11	0.58	0.67	0.75	0.58
	M12	0.42	0.42	1.00	0.67
Sensory	Sens1	0.42	0.42	0.42	0.50
	Sens2	0.50	0.67	0.83	0.58
	Sens3	0.58	0.67	0.75	0.75
	Sens4	1.00	1.00	1.00	0.83
	Sens5	0.92	1.00	0.83	0.92
	Sens6	0.92	0.50	0.42	0.92
	Sens7	0.67	0.75	0.92	0.83
	Sens8	0.92	0.92	0.42	0.92
	Sens9	0.58	0.83	0.50	0.50
	Sens10	0.75	0.33	0.50	0.83
	Sens11	0.42	0.67	0.50	0.67
	Sens12	0.42	0.25	0.58	0.42
Control	C1	1.00	1.00	1.00	1.00
	C2	1.00	0.92	1.00	1.00
	C3	0.58	1.00	1.00	0.92
	C4	1.00	1.00	1.00	1.00
	C5	1.00	0.92	0.92	1.00
	C6	1.00	0.92	1.00	1.00
	C7	1.00	1.00	1.00	1.00
	C8	1.00	1.00	0.92	1.00
	C9	1.00	1.00	0.92	1.00
	C10	0.75	0.92	1.00	1.00
	C11	0.92	1.00	1.00	1.00
	C12	1.00	1.00	1.00	1.00

Note: WO, word order.

The within-group results thus confirmed that performance on reversible prepositional and instrumental constructions with direct versus inverted word order is similar for all tested groups, except for the group of participants with semantic aphasia. The latter, as a group, processed prepositional constructions better when the word order was direct, and processed the instrumental constructions better when the word order was indirect. At the individual level, all participants with semantic aphasia showed this pattern for instrumental constructions; for prepositional constructions, more heterogeneity was found (see Table 3). Additional inspection of individual participants' data led to the assumption that there might be a trade-off between performance on prepositional and instrumental constructions with different word orders. To test this, we ran a post hoc correlation analysis. For each participant, two measures were computed: the difference between the number of correct responses to the direct and inverted reversible prepositional constructions, and the difference between the number of correct responses to the direct and inverted reversible instrumental constructions. Note that although these scores do not represent the overall performance of the participant, they reflect difference in accuracy across constructions.

The Spearman's rank correlation test proved that there is a negative correlation between the two calculated scores (S = 17,688, ρ = −0.43, p < 0.01). Individual data points for each participant are presented in Figure 4.

We would like to emphasise that the correlation remains significant when healthy control participants and individuals with semantic aphasia are excluded from the analysis (S = 3232, ρ = −0.40, p = 0.05). Thus, participants with motor and sensory aphasia, irrespective of their aphasia type, tended to adhere either to the "semantic" strategy (i.e., prepositional constructions are processed better when word order is direct, and instrumental constructions are easier to process with indirect word order) or to the reverse strategy (i.e., prepositional constructions are processed better when word order is indirect,

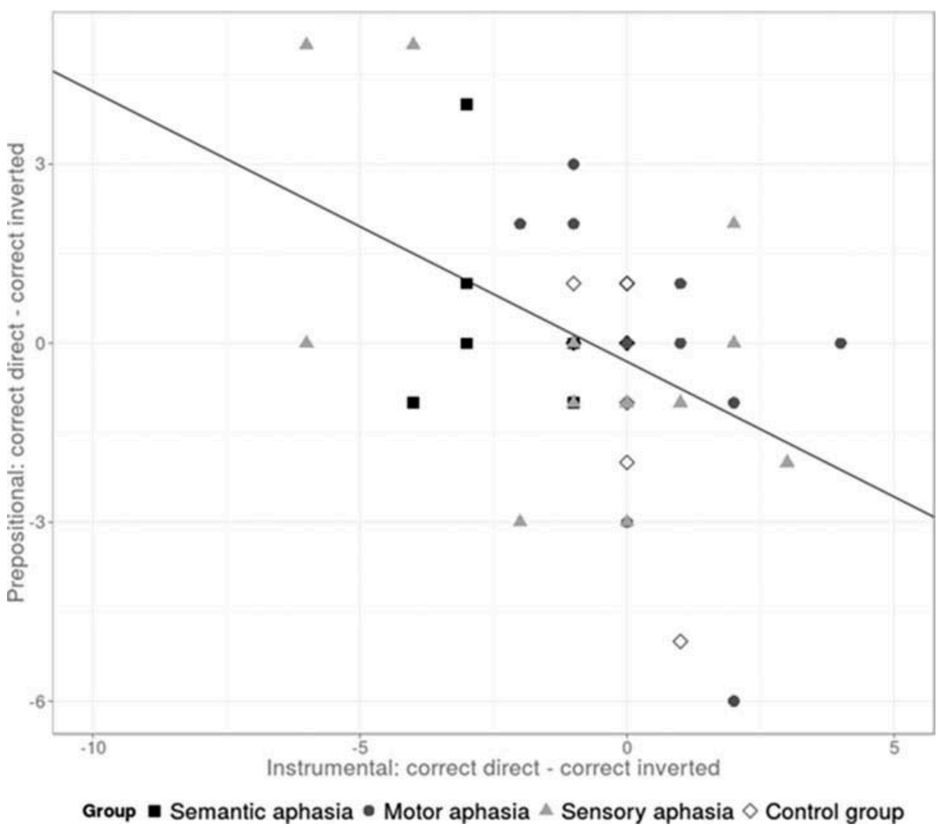

Figure 4. Results of the correlation analysis.

and instrumental constructions are facilitated by direct word order). However, the control group taken alone did not exhibit this trade-off between performance on prepositional and instrumental constructions with different word orders (S = 298, ρ = −0.04, p > 0.1).

Discussion

This study tested two predictions derived from Luria's theory on the specific deficits underlying semantic aphasia. The first experimental aim involved Luria's suggestion that difficulties in the processing of semantically reversible sentences (i.e., an inability to decode grammatical relations without relying on real-world knowledge) is characteristic to semantic aphasia (Luria, 1975). We tested four groups of participants—people with semantic, motor, or sensory aphasia and healthy non-brain-damaged individuals—and found a negative effect of reversibility in all groups. Semantically irreversible sentences such as *The boy is putting the apple in the bag* were matched to their corresponding picture more accurately than their reversible counterparts such as *The boy is putting the box in the bag*, by all participants. The accuracy rate for irreversible sentences did not drop below 90% in any of the groups, including individuals with semantic and sensory aphasia, in which the core linguistic deficit belongs to the comprehension domain. This finding supports the importance of situational pragmatics at all levels of linguistic processing: if real-world knowledge supports the correct interpretation of a grammatical construction, the sentence has a processing advantage. On the other hand, the lack of such knowledge increases processing difficulties independently of the systemic language deficit—aphasia—and its type. The result is in line with other evidence from both clinical and healthy populations: people with aphasia (Johnsen, 1985) and Alzheimer's disease (Bickel et al., 2000), children with SLI (Leonard, 1998), as well as healthy adults and normally developing children (Ferreira, 2003; Herriot, 1969; Kemper & Catlin, 1979; Slobin, 1966) experience difficulties when processing semantically reversible sentences. Given the universality of the effect, it should be stressed nevertheless that, in the present study, the effect size was found to be much larger in individuals with aphasia than in the control group (3% difference between accuracy scores for irreversible and reversible sentences in the control group vs. 22% difference in the semantic and sensory aphasia groups and 19% difference in the motor aphasia group). This suggests that although pragmatically oriented strategies taking into account knowledge of the real world are implemented during language processing by any person, such strategies become critical when an individual is otherwise linguistically impaired, as in aphasia. While healthy individuals can successfully decode relations between the mentioned referents from grammar as well, people with aphasia cannot do so due to their characteristic linguistic deficits. This explains the unequal influence of reversibility on healthy and aphasic comprehension.

The universally poorer comprehension of reversible constructions in comparison to irreversible ones and the decrease of performance observed in clinical populations are compatible with the approach suggesting that a working memory deficit might contribute to sentence comprehension difficulties (Friedmann & Gvion, 2003; Wright, Downey, Gravier, Love, & Shapiro, 2007). Specifically, Richardson, Thomas, and Price (2010) showed that semantically reversible sentences placed additional demands on the phonological working memory related to the activation on left temporal-parietal boundary. On the other hand, Makuuchi, Grodzinsky, Amunts, Santi, and Friederici (2013) demonstrated that increased verbal short-term memory load caused additional activation in the left inferior frontal gyrus. Thus, working memory resources required for sentence comprehension represent a distributed system of involved brain areas. Specific pathologies or individual weaknesses may disrupt its particular components and disintegrate the system. This might explain why difficulties in the interpretation of reversible sentences as compared to their irreversible counterparts can be observed in all aphasia types and even in non-brain-damaged individuals.

The second prediction tested in the present study was based on Luria's theory and observations on the nature of errors made by people with semantic aphasia, and was related to the specific role of sensorimotor stereotypes in the comprehension of semantically reversible sentences. We anticipated that individuals with semantic aphasia would show better performance on the constructions with direct mapping of the word order onto the sensorimotor stereotype; that is, the order of interaction with the objects in the real world. Indeed, in the semantic aphasia group a clear dissociation was found for prepositional and instrumental constructions with direct and inverted word orders. Prepositional constructions with direct word order (e.g., *The boy is putting the bag in the box*) corresponding to the sensorimotor stereotype (*Take the bag, put it in the box*) were understood correctly above chance level, while those with inverted word order (*The boy is putting in the box the bag*) and not corresponding to the sensorimotor stereotype were performed at chance level. This pattern was not consistent at the individual level, but holds for the group. In contrast, instrumental constructions with inverted word order (e.g., *The grandmother is covering with the hat the scarf*) mapped onto the sensorimotor stereotype (*Take the hat, cover the scarf with it*), and individuals with semantic aphasia were significantly more accurate in this condition than for instrumental constructions with direct word order (e.g., *The grandmother is covering the scarf with the hat*). Thus, an advantage was revealed for people with semantic aphasia in the processing of semantically reversible sentences in line with sensorimotor stereotypes, similarly to Luria's observations. At the group level, no such effect was found for people with sensory or motor aphasia, nor for healthy participants. This appears to confirm that an impairment of quasi-spatial analysis and an inability to decode spatial relations from grammar, a characteristic feature of semantic aphasia, elicit a specific strategy to rely on real-world knowledge about the interaction with objects during action implementation, in order to understand semantically reversible prepositional and instrumental sentences. This finding, however, requires further verification, given the small number of participants with semantic aphasia in the present study and the lack of consistency in responses to prepositional constructions at the individual level.

However, the post hoc correlation analysis showed that all participants with aphasia adhered either to the "semantic" or the reverse strategy. In the former case, they performed better on prepositional constructions with direct word order and instrumental constructions with inverted word order, both corresponding to sensorimotor stereotypes. In the latter case, by contrast, they were more accurate on prepositional constructions with inverted word order and instrumental constructions with direct word order, which both violate the sequence of real-world interactions with objects. The collected data are sufficient for claiming that the heuristics to assign the thematic roles to the nouns, not based on their grammatical markers but driven by the sensorimotor stereotype, is predominant in semantic aphasia and may occur in selected individuals with other aphasia types.

From a practical point of view, these findings have important implications for the methodology of aphasia assessment. In Luria's approach, reversible logical-grammatical constructions, such as the prepositional and instrumental ones tested in the present study, are the major linguistic tool used to diagnose semantic aphasia (Luria, 1962). People with semantic aphasia are expected to perform poorly on reversible logical-grammatical constructions in general, and to make specific errors following sensorimotor stereotypes in some of them (Luria, 1975). However, as our data show, the diagnostic value of both criteria should be toned down. First, the drop in accuracy rates on semantically reversible sentences in people with semantic, motor, and sensory aphasia is very comparable. Thus, the constructions do not help to distinguish between different aphasia types. Nevertheless, when there is a need to exclude the input of pragmatics in language processing, semantically reversible sentences are of great interest for clinical assessment and experimental research.

Second, the effect of sensorimotor mapping in the comprehension of prepositional and instrumental constructions resulting in a specific error pattern was again found in all tested populations. This means that at the individual level, the qualitative analysis of errors made by a person with aphasia in reversible prepositional and instrumental constructions seemingly does not allow us to draw a clear distinction between semantic aphasia and other aphasic syndromes. However, Luria's approach to aphasia is based on systematic investigation of both linguistic and non-linguistic domains. This is why, together with more complete data about the spatial gnosis, praxis, and calculation abilities of a patient, consistent difficulties in processing reversible linguistic constructions and the strategy to map sensorimotor stereotypes on word order still might be a useful signature of semantic aphasia. The philosophy of Luria's approach implies that semantic aphasia does not show up as an isolated linguistic deficit, but rather is a representative part of the general TPO syndrome. Because of that, the four conditions used in the present study (reversible prepositional and instrumental constructions with direct and inverted word orders) must be included in the testing battery. Those sentences in which word order does not correspond to sensorimotor stereotypes are expected to be consistently misinterpreted by individuals with semantic aphasia.

From a theoretical point of view, it remains an open question why some people with motor or sensory aphasia overuse sensorimotor stereotypes and map them onto the surface word order in a sentence, similar to the behaviour of people with semantic aphasia. Besides individual sensorimotor experience and the depth of its interaction with linguistic processing, the effect may be caused by specific patterns of brain pathology. On the one hand, partial dysfunction of the left TPO junction (cortical areas or pathways) might not result in a regular complex of spatial and quasi-spatial disorders which can be labelled semantic aphasia on the basis of a neuropsychological examination. However, signatures of such damage can be revealed by focused testing, as happened in our study. According to Luria, it is the damage to the TPO region which causes impaired decoding of logical relations between objects from grammar and adherence to compensatory heuristics (Luria, 1947, 1962). If this is the case, TPO lesions, even if they are partial and not responsible for the major deficit of a patient labelled with a non-semantic aphasia, must correlate in a regular way with difficulties in understanding semantically reversible sentences, which might cause the compensatory strategy of mapping sensorimotor stereotypes on the word order. This hypothesis also suggests a potential explanation for other problems with reversible sentences in different aphasia types (Akhutina, 1979; 1989; Caramazza & Zurif, 1976; Kolk & Friederici, 1985; Luzzatti et al., 2001; Tsvetkova & Glozman, 1977).

On the other hand, the sensorimotor heuristics of language processing itself might require a specific brain substrate. It can be hypothesised that left frontal areas might serve as the substrate necessary for sensorimotor action representations, which must be active in order to be reliable. Presumably, these can be primary motor or premotor regions, both found to be activated in a somatotopic manner during the processing of action words (Hauk, Johnsrude, & Pulvermüller, 2004; Tettamanti et al., 2005) and suggested to be critical for motor and symbolic sequential processing (Luria, 1947; Sahin, Pinker, Cash, Schomer, & Halgren, 2009). If so, the degree of structural integrity of these frontal brain areas defines whether a patient can adhere to the sensorimotor strategy or not. Although the correspondence between lesion site and aphasia type is not straightforward, a recent study using a voxel-based lesion-symptom approach (Bates et al., 2003) by Henseler, Regenbrecht, and Obrig (2014) convincingly proved that at least Broca's and Wernicke's aphasia syndromes correspond to non-overlapping anterior and posterior lesion sites. Considering the higher probability of frontal lesions in individuals with Broca's (or efferent motor) aphasia and the relatively lower probability in people with Wernicke's (sensory) aphasia, the data of Akhutina (1989) can be taken as support for our hypothesis: she showed that people with efferent motor aphasia do not prefer any particular word order when processing instrumental constructions, while individuals with sensory aphasia better understand the order "instrument-object." Since the current study used syndrome distinctions among tested participants, brain lesion analysis was out of its scope, and MRI images were not consistently collected for all participants. Thus, the relation between adherence to sensorimotor strategy during language comprehension and the structural integrity of the left TPO and frontal areas should be addressed in another study.

In conclusion, the present research showed that semantically reversible sentences are more difficult to process not only for people with semantic aphasia, but also for other cohorts: people with efferent motor and sensory aphasia, as well as non-brain-damaged individuals. In addition, despite the prevalence of a sensorimotor strategy in individuals with semantic aphasia, an advantage of processing semantically reversible sentences in line with sensorimotor stereotypes (i.e., the order of interaction with objects in the real world) was found in all tested groups of participants with aphasia. Without undermining Luria's neuropsychological approach to semantic aphasia (Luria, 1947, 1962), these findings have important implications for the clinical assessment of people with aphasia and the diagnostic value of reversible logical-grammatical constructions. They also raise interesting questions about the biological foundations of the specific error pattern regularly shown by people with semantic aphasia, which may or may not contrast with that of other individuals with or without aphasia. This question should be addressed in further research, together with testing the effects obtained in the present study in a larger sample of participants with aphasia.

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Note

1. Luria's aphasia classification allows to diagnose a combination of several aphasia syndromes.

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Appendix 1. Experimental sentences in the direct order condition

		Russian sentence	English translation
Prepositional	Reversible	Мальчик кладет сумку в коробку	The boy is putting the bag into the box
		Мальчик кладет ведро в мешок	The boy is putting the bucket into the sack
		Дедушка ставит блюдце на стакан	The grandfather is putting the saucer on the glass
		Дедушка ставит бочку на ящик	The grandfather is putting the barrel on the box
		Хозяйка вешает картину над часами	The lady is hanging the painting above the clock
		Хозяйка вешает зеркало над полкой	The lady is hanging the mirror above the shelf
		Бабушка ставит кружку под тарелку	The grandmother is putting the mug under the plate
		Бабушка ставит кастрюлю под миску	The grandmother is putting the pot under the bowl
		Хозяин ставит кровать перед столом	The landlord is placing the bed in front of the table
		Хозяин ставит рюмку перед бутылкой	The landlord is placing the glass in front of the bottle
		Водитель ставит машину за мотоциклом	The driver is parking the car behind the motorcycle
		Садовник ставит цветок за лейкой	The gardener is putting the flower behind the watering-pot
	Irreversible	Мальчик ставит ведро в кладовку	The boy is putting the bucket into the store room
		Садовник кладет доску на сарай	The gardener is putting the plank on the shed
		Хозяйка вешает картину над стулом	The lady is hanging the painting above the chair
		Водитель ставит мотоцикл под навес	The driver is parking the motorcycle under the shed
		Мальчик ставит корзину перед норой	The boy is putting the basket in front of the hole
		Хозяин кладет грабли за дом	The landlord is putting the rake behind the house
		Мальчик кладет яблоко в сумку	The boy is putting the apple inside the bag
		Дедушка ставит тарелку на диван	The grandfather is putting the plate on the sofa
		Хозяин делает навес над будкой	The landlord is making a shed above the dog house
		Бабушка ставит стакан под кровать	The grandmother is putting the glass under the bed
		Дирижер ставит солистов перед хором	The conductor is placing the soloists in front of the choir
		Дедушка прячет рюмку за ящик	The grandfather is hiding the glass behind the box

(*continued*)

(*Continued*).

		Russian sentence	English translation
Instrumental	Reversible	Бабушка накрывает шляпу платком	The grandmother is covering the hat with the shawl
		Бабушка накрывает шарф шапкой	The grandmother is covering the scarf with the hat
		Мальчик двигает ручку карандашом	The boy is moving the pen with the pencil
		Мальчик двигает гвоздь расческой	The boy is moving the nail with the comb
		Хозяин разбивает камень кирпичом	The landlord is breaking the stone with the brick
		Хозяин разбивает вазу тарелкой	The landlord is breaking the vase with the plate
		Дедушка ломает палку лопатой	The grandfather is breaking the stick with the shovel
		Дедушка ломает доску граблями	The grandfather is breaking the plank with the rake
		Хозяйка трогает нож вилкой	The lady is touching the knife with the fork
		Хозяйка трогает молоток отверткой	The lady is touching the hammer with the screwdriver
		Девочка чистит перо кисточкой	The girl is cleaning the feather with the brush
		Девочка поднимает клещи магнитом	The girl is lifting the pincers with the magnet
	Irreversible	Бабушка накрывает телефон шляпой	The grandmother is covering the phone with the hat
		Бабушка накрывает щетку шапкой	The grandmother is covering the toothbrush with the hat
		Девочка пишет письмо карандашом	The girl is writing the letter with the pencil
		Мальчик собирает листья граблями	The boy is gathering the leaves with the rake
		Хозяин разбивает стакан кирпичом	The landlord is breaking the glass with the brick
		Хозяин разбивает тарелку утюгом	The landlord is breaking the plate with the iron
		Дедушка рубит палку топором	The grandfather is chopping the stick with the axe
		Дедушка чистит ковер щеткой	The grandfather is cleaning the carpet with the brush
		Хозяйка вытирает стол тряпкой	The lady is wiping the table with the rag
		Хозяйка царапает шкаф отверткой	The lady is scratching the cupboard with the screwdriver
		Мальчик царапает дверь гвоздем	The boy is scratching the door with the nail
		Девочка царапает холодильник ножом	The girl is scratching the fridge with the knife